

elementenergy

Electric vehicles in
Scotland:
Emission reductions and
Infrastructure needs
for
WWF Scotland

Final Report
November 2009

Element Energy Limited
20 Station Road

Cambridge CB1 2JD

Tel: 01223 227764

Fax: 01223 356215

Authors:**Element Energy**

Mike Dolman mike.dolman@element-energy.co.uk 01223 227531

Craig Douglas craig.douglas@element-energy.co.uk 0207 462 5883

Disclaimer

While Element Energy Limited considers that the information and opinions provided in this document are sound, all parties must rely upon their own skill and judgement when interpreting or making use of it. While Element Energy believes forecasting assumptions to be reasonable for purposes of preparing this analysis, actual future outcomes may differ from those forecasted. Element Energy Limited does not accept liability for losses incurred, whether direct or consequential, arising out of any reliance on this analysis.

Copyright © 2009 Element Energy Ltd.

No part of this document may be reproduced without the prior written permission of Element Energy Limited.

Glossary of terms

BAU	Business as usual
BEV	Battery electric vehicle
BWEA	British Wind Energy Association
CCC	The Committee on Climate Change
GHG	Greenhouse gas
GWh	Gigawatt hour (unit of energy) 1GWh = 10 ⁶ kWh
EV	Electric vehicle (used as a generic term to refer to BEVs and PHEVs)
ICEV	Internal combustion engine vehicle (used to refer to traditional cars)
kt	Kilo tonne (one thousand tonnes)
kWh	Kilowatt hour (unit of energy)
LATIS	Land Use and Transport Integration in Scotland
Mt	Mega tonne (one million tonnes)
MW	Megawatt (unit of power)
NAEI	National Atmospheric Emissions Inventory
NTS	National Travel Survey
PHEV	Plug-in hybrid electric vehicle
SHCS	Scottish House Condition Survey
VED	Vehicle excise duty

Contents

1	Summary	1
1.1	Electric vehicle uptake.....	1
1.2	Infrastructure requirements	2
1.3	Potential greenhouse gas emission reductions.....	3
1.4	Impacts on urban air quality	3
1.5	Implications for electricity demand and renewable energy generation	4
2	Introduction.....	5
2.1	Background	5
2.2	Objectives of study	6
2.3	Introduction to low carbon vehicles	6
3	Methodology.....	9
3.1	Overall approach and scope of work.....	9
3.2	Approach to finding CO ₂ emissions and key assumptions.....	10
4	Scenarios for EV uptake: vehicle numbers and CO ₂ emissions	15
4.1	Definition of scenarios	15
4.2	Representative EV sales over time	20
4.3	Greenhouse gas emission reductions	23
5	Recharging infrastructure requirements	27
5.1	Recharging infrastructure: general considerations	27
5.2	Key results from National Travel Survey statistics analysis.....	27
5.3	Impact of workplace charge points.....	30
5.4	Recharging infrastructure: scenario-specific results	30
6	Impacts on urban air quality	36
6.1	Overall approach	36
6.2	Results.....	36
7	Electricity demand and renewable electricity generation implications	41
7.1	Introduction.....	41
7.2	Future electricity production in Scotland	41
7.3	Impacts of electric vehicles	41

8	Market incentivisation and support policies.....	44
8.1	Overview of policy options.....	44
8.2	Scenario-specific support policies.....	45
9	Appendix A: overview of data sources.....	46
9.1	National Travel Survey.....	46
9.2	Scottish Household Survey.....	46
9.3	National Atmospheric Emissions Inventory.....	46
9.4	UK Air Quality Archive.....	46
9.5	The Climate Change Delivery Plan.....	47
9.6	Committee on Climate Change.....	47
9.7	Land Use and Transport Integration in Scotland.....	47
9.8	Arup / Cenex report for DfT and BERR: Investigation into the scope for the transport sector to switch to EV and PHEVs.....	47
10	Appendix B: CO ₂ saving in non-road transport sectors.....	48
10.1	Common improvement approaches.....	48
10.2	Vehicle-specific considerations.....	49
11	Appendix C: key assumptions.....	50
11.1	CO ₂ savings.....	50
11.2	Forecast carbon intensity of grid electricity.....	54
11.3	Technical characteristics of vehicles.....	55
12	Appendix D: methodologies.....	59
12.1	Sales and stock model.....	59
12.2	Calculation of annual mileage of BEVs and PHEVs.....	59
12.3	Impacts of EVs on urban air quality.....	64
13	Appendix E: types of recharging infrastructure.....	66

1 Summary

1.1 Electric vehicle uptake

This study considers four distinct electric vehicle uptake scenarios in Scotland in the period to 2030: two are based on published data and two are target-driven. In the target-driven scenarios the number of EVs in the stock is determined by specific CO₂ emission reduction targets. The scenarios are:

- **Business as usual (BAU)**
The BAU scenario is based on published data from a UK study applied to Scotland and represents the levels of EV uptake resulting from existing and announced policies.¹
- **Upper**
The Upper scenario corresponds to a reasonable upper bound on EV uptake and is also based on published data.
- **Stretch: traffic stabilisation**
The Stretch scenarios represent the levels of EV uptake required to achieve ambitious CO₂ emission reduction targets in 2020 and 2030. These targets are derived from the Scottish government's Climate Change Delivery Plan and equate to a 43% and a 70% reduction in road transport emissions in 2020 and 2030 relative to 1990 levels. The Stretch: traffic stabilisation scenario corresponds to EV uptake levels required when future demand for car travel is curbed (total car-km in Scotland are stabilised at 2001 levels from 2020).
- **Stretch: traffic growth**
The Stretch: traffic growth scenario is also target-driven. In this case however demand for car travel increases such that total car-km in Scotland grows by c.7% from current levels to 2020. EV uptake is highest in this scenario.

It should be noted that these indicative scenarios are based either on published data or specific CO₂ reduction targets. No vehicle uptake model has been used in the course of this study, i.e. the number of EVs in the stock is an exogenous input rather than the result of a consumer choice model for example. A simple stock model was developed to give an indication of the levels of sales required to achieve the market penetration levels of each scenario. This revealed the following points:

- The level of EV uptake in the BAU scenario could be achieved with steady annual growth in EV sales such that BEVs and PHEVs together represent around 1.5% and 15% of total new car sales in 2020 and 2030 respectively.
- In the Upper scenario a more rapid increase in EV sales penetration is required, with EVs accounting for around 9% of new car sales in 2020 and 54% in 2030.

¹ *Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles*, Arup / Cenex for BERR, (October 2008).

- The Stretch: traffic stabilisation scenario would require an increase in EV sales to achieve 20% of the new car sales market by 2020. Under this scenario EV sales begin to dominate new car sales through the 2020s and nearly all new cars sold are EVs by 2030.
- Under the Stretch: traffic growth scenario ICE car sales cease by 2020. This would require an extremely rapid increase in EV sales over the next decade.

The figure for total CO₂ emissions from cars is highly sensitive to demand for car travel, i.e. total car-km driven. A key output of this study is the effect of each scenario on CO₂ emissions from cars in Scotland in 2020 and 2030. Given the uncertainty around future demand for car travel, the effect of the BAU, Upper and Stretch scenarios on CO₂ emissions has been found in two future circumstances: one in which the traffic stabilisation goal is achieved and one in which demand for car travel grows in line with historical trends. This leads to a total of six distinct scenarios in terms of the effect on CO₂ emissions (BAU, Upper and Stretch each for traffic stabilisation and traffic growth futures).

1.2 Infrastructure requirements

An analysis of the infrastructure requirements to support EV uptake has been completed. This includes a description of general principles to be considered and a more specific analysis of basic infrastructure needs for each scenario. The key conclusions are as follows:

- Provided EVs are adopted predominately by households with access to off-street parking, there are anticipated to be sufficient off-street domestic parking places for all EVs in 2020 and 2030 under the BAU and Upper scenarios at the national level.
- The proportion of households with access to off-street parking is lower in cities than in Scotland as a whole. This is a potential obstacle to EV uptake that warrants further investigation, for example, through research to identify the extent to which a lack of off-street parking restricts EV uptake and to identify the most cost-effective solutions to providing adequate domestic charging facilities.
- Dedicated on-street domestic charge points may be required in the target-driven scenarios as the number of plug-in vehicles exceeds the number of households with access to off-street parking in 2020 or 2030 (depending on traffic growth).
- Publicly available recharging infrastructure is likely to play a strategic role in increasing awareness and encouraging EV uptake, especially if accompanied by additional incentives (preferential parking, free recharging etc).
- The key locations in which charge points should be located are homes and workplaces. Other possible locations for charge points (based on frequency of car journeys by purpose) are supermarkets and car parks that serve shopping centres. However, given the relatively low average time spent parked at these locations, the utility of slow charge points may be low.
- The alternative to slow charge is fast charge points. These can give a significant boost in charge in a period of tens of minutes rather than many hours required with slow

charge. However, the cost of fast charge infrastructure is significantly higher than slow charge, especially if network reinforcement is required.

- Public recharging infrastructure represents a high capital investment and therefore should be seen as a supportive rather than a central delivery mechanism. The bulk of EV recharging should be done by private charge points, principally at drivers' homes and workplaces. These offer the most economic solution as they are less expensive than public charge points and are likely to benefit from higher utilisation rates.

1.3 Potential greenhouse gas emission reductions

The impacts of EV uptake on total CO₂ emissions from cars in Scotland have been assessed, with the following results:

- Business as usual (little EV uptake) leads to a CO₂ saving of around 40% in the passenger car sector under the traffic stabilisation scenario. This relies on achievement of the 2021 traffic stabilisation target for Scotland, and the realisation of improvements in ICE efficiency in line with EU directives for new car CO₂ emissions.
- Improvements in ICE emissions characteristics also lead to CO₂ savings relative to 1990 levels under the traffic growth scenario. However, in this case the savings under BAU are around 20% relative to 1990 emissions.
- A 43% reduction in emissions from passenger cars by 2020 (the 2020 target) is beyond the anticipated savings from EV uptake in the Upper scenario in both the traffic stabilisation and the traffic growth cases. This suggests that further measures are required if this target is to be met.
- The contribution that EVs will have to make towards meeting ambitious CO₂ reduction targets depends strongly on future traffic growth. Other methods for reducing emissions such as technological advances in internal combustion engine cars, modal shift towards greater public transport use and changing driver behaviour will have an important part to play in reducing the environmental impact of cars.
- If demand for car travel continues on a growth path in line with historical trends, these results suggest that a maximum CO₂ saving of around 21.5% relative to 1990 levels may be achieved under the Upper scenario by 2020. This means that for deep CO₂ cuts efforts to curb demand for car travel in Scotland must be effective.

1.4 Impacts on urban air quality

A high-level analysis of the potential impact of EVs on urban air quality in a selection of Scottish cities has been completed. The key conclusions are:

- Cars are responsible for a relatively low proportion of total pollutant emissions in Aberdeen, Edinburgh and Glasgow for most pollutant species. The analysis suggests that cars account for c.10% or less of SO₂ and VOC emissions, 10–20% of PM10 and NOx emissions and 30–45% of CO emissions.
- Substitution of ICEVs for EVs is therefore expected to have a relatively limited effect in terms of reducing emissions in cities. However, the benefit of EVs in terms of

improved urban air quality may be important in areas that are at the margins of air quality management designation.

- EVs could have a greater benefit on local air quality in terms of pollutant concentrations but analysis to this level of detail was outside the scope of this study.

1.5 Implications for electricity demand and renewable energy generation

Results from a recent WWF Scotland study show predicted electricity generation in Scotland by plant type.² A comparison of these data to anticipated additional electricity demands from EVs under each scenario has shown that the additional demands are no greater than the expected renewable electricity generation.

- Additional electricity demand from EVs has been estimated at c.1,100GWh/yr by 2030 under the Upper scenario. This corresponds to around 1.7% of the total anticipated annual electricity demand in Scotland.
- The maximum increase in electricity demand occurs under the Stretch: traffic growth scenario and equates to around 6% of total annual electricity demand in Scotland by 2030.
- The technical electricity storage potential of all EVs in the stock in 2030 under the Upper scenario is around 10GWh. This figure is comparable to the total storage offered by Scotland's largest pumped hydro-electric power station.

² *The Power of Scotland Renewed* (July 2009).
www.wwf.org.uk/research_centre/?3172/The-Power-of-Scotland-Renewed.

2 Introduction

2.1 Background

The Scottish Government is committed to reducing greenhouse gas (GHG) emissions and enabling Scotland to transition to a low carbon economy; a fact reflected by the unanimous decision by members of the Scottish Parliament to pass The Climate Change (Scotland) Act 2009 in June this year. The Act sets an interim target of a 42% reduction in GHG emissions for 2020 on the way to the ultimate goal of achieving at least an 80% reduction by 2050.

Along with energy supply, the transport sector is one of Scotland’s biggest sources of GHG emissions. Over the past couple of decades efficiency improvements have led to significant reductions in specific emissions from internal combustion engine vehicles (g/km), but these savings have been more than offset by traffic growth, as shown in Figure 1.

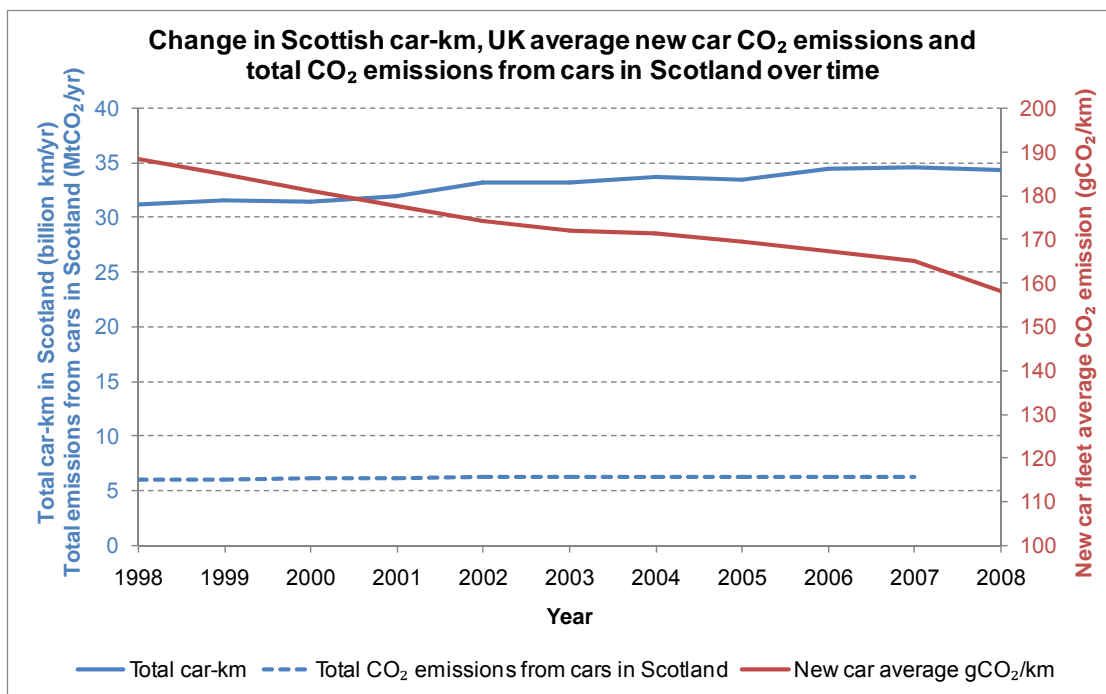


Figure 1: Effect of changing total car-km and specific CO₂ emissions of cars on overall emissions over time³

Note: total car-km and total CO₂ emissions are displayed on the left vertical axis, new car fleet average emissions are on the right vertical axis

³ Estimates of total car-km per year taken from DfT: <http://www.dft.gov.uk/pgr/statistics/datatablespublications/roadtraffic/traffic/rtstatisticsla/roadtrafficstatisticsforloca5434>.
Total CO₂ emissions from cars in Scotland from NAEI data: <http://www.naei.org.uk/>.
New car average CO₂ emissions from SMMT: <http://www.smmt.co.uk/downloads/SMMT-Annual-CO2-report.pdf> p.11.

Significant CO₂ emission cuts are required for the transport sector to play its part in meeting the GHG emission reduction targets. Electric vehicles offer the potential to contribute to emission reduction targets, along with other measures such as modal shift (curbing private car traffic growth and encouraging greater use of public transport) and non-powertrain changes (e.g. eco driving, active traffic management).

2.2 Objectives of study

This research focuses on the role of electric vehicles in reducing CO₂ emissions in Scotland and specifically addresses infrastructure requirements and the potential for emissions reductions associated with a number of scenarios of low carbon vehicle use. In particular, the aims of this research are as follows:

1. Calculate the greenhouse gas emissions reductions associated with each scenario in 2020 and 2030.
2. Present a quantitative and qualitative description of the infrastructure needs to support the scenarios of EV use by 2020 and 2030.
3. Find the predicted change in air quality as a result of each scenario in 2020 and 2030 in Edinburgh, Glasgow and Aberdeen.
4. Provide an analysis of the implications for renewable electricity generation and the potential electricity storage capacity associated with each scenario of EV use.

2.3 Introduction to low carbon vehicles

There are numerous ways to reduce CO₂ emissions from vehicles. Broadly speaking, these methods fall into one of three categories: improvements in vehicle design, changes in fuels and driver behaviour, and powertrain improvements, as summarised in the following table.

Table 1: Summary of methods for reducing vehicle emissions

Category	Measure	Description
Vehicle design	Aerodynamics improvement	Improved aerodynamics lead to lower drag and enhanced fuel efficiency, particularly at higher speeds.
	Weight reduction	Vehicle lightweighting is an effective method of reducing fuel consumption and therefore emissions.
	Improved tyres	Low rolling resistance tyres can be used to reduce fuel consumption and hence emissions.
Fuels and driver behaviour	Biofuels	Introduction of biofuels into standard fuels. This is a simple method of achieving carbon savings but the savings are limited unless high blends are used. The Scottish government has a target for 8% of transport fuels (by energy) to be from renewable sources by 2020. ⁴
	Modal shift	Modal shift refers to encouraging people to use other forms of transport (e.g. walk, cycle, public transport) to complete journeys. Furthermore, people can be encouraged to consider whether their journey is absolutely necessary. Reducing vehicle-km is a simple and direct way to reduce emissions.
	Speed limits	Speed limit reductions, primarily on trunk roads where the limit is 70mph, could be used to cut emissions since fuel efficiency reduces at higher speeds.
	Active traffic management	Active traffic management aims to keep traffic flowing during busy periods. Reducing traffic jams and stop-start traffic leads to improved fuel efficiency and therefore lower emissions.
	Smarter choices and eco driving	<i>Smarter choices</i> refers to encouraging better journey planning and greater use of public transport. In its December 2008 report the CCC identified Smarter Choices as a low cost means of achieving CO ₂ savings from transport. Eco driving includes decisions to purchase less polluting cars, and driving techniques which maximise fuel economy (smooth driving to avoid unnecessary stop/starts, early gear change etc).
Powertrain	Evolutionary improvements	Powertrain improvements involve the improvement in the energy transfer in the vehicle either through improved ICE technology, evolution , or a change in the vehicle's propulsion technology, revolution (see below).
	Revolutionary improvements	

2.3.1 Evolutionary technologies

Internal combustion engines in vehicles are only 20–35% efficient in that only around a fifth to a third of the energy in the fuel goes in to vehicle propulsion (most of the remainder is lost as

⁴ See CCDP, Table 6, p.34. <http://www.scotland.gov.uk/Publications/2009/06/18103720/0>.

heat). There is significant scope for improvements in this technology, as demonstrated by Weiss et al. in a paper exploring emissions of passenger cars to 2020.⁵

To date the implementation of evolutionary improvements in engine technology has been relatively modest. The main reason for this has been a lack of incentive for manufacturers to reduce emissions. The key vehicle attributes that consumers consider when making purchasing decisions include price, performance, design (aesthetics) etc. Even recent surveys of the public have shown that consumers do not value low CO₂ emissions.⁶

2.3.2 Revolutionary technologies

Revolutionary technologies are new powertrain technologies that do not rely solely on internal combustion engines. They include battery electric vehicles (BEVs), plug in hybrid electric vehicles (PHEVs), and hydrogen fuel cells. The focus of this report is on BEVs and PHEVs.

Battery electric vehicles (BEVs)

BEVs use an electric motor, or a number of electric motors to propel the vehicle. The energy supplied is from batteries within the vehicle. A BEV's range is limited by the storage capacity of the battery. Instead of filling up at a petrol station, the battery must be recharged from an external source.

Plug-in hybrid electric vehicles (PHEVs)

PHEVs use a combination of an electric motor and batteries along with an internal combustion engine. PHEVs come in two main types: parallel and series. In series hybrids the sole source of motive power to the wheels comes from the electric motor(s). The motor is supplied with electricity from a battery or directly from a generator (driven by an internal combustion engine). When the engine is running any excess charge is used to recharge the battery.

Parallel hybrids differ from series in that they can transmit power to drive the wheels from two separate sources, such as an ICE and battery-powered electric motors. Some manufacturers are developing series-parallel hybrids, which are able to operate in either series or parallel mode.

⁵ *On the road in 2020: a lifecycle analysis of new automobile technologies*, Weiss et al., MIT (October 2000). Table 3.4, p.3-24.

As an example, one method for improving engines' emissions characteristics is to make use of super-chargers and turbo-chargers, which lead to higher cylinder pressures, more efficient fuel burn and higher specific power outputs. Such measures improve vehicle efficiency without compromising performance.

⁶ See for example *Revolution: The road to a low carbon future*, Energy Saving Trust, Table 3, p.31, (September 2009).

<http://www.energysavingtrust.org.uk/corporate/Global-Data/Publications/Corporate-publications-folder/Revolution-the-road-to-a-low-carbon-future>.

3 Methodology

3.1 Overall approach and scope of work

To meet the objectives stated in section 2.2 a scenario-based approach has been adopted. In each scenario the total number of BEVs and PHEVs in Scotland is defined in the years of interest (2020 and 2030). The scenarios are either target-driven (i.e. number of EVs required to meet a specific carbon saving target) or are based on published data from other studies. It should be noted that these are **indicative scenarios** (representing a range of EV uptake levels and low carbon futures). The intention of this project is not to attempt to forecast future EV uptake levels and **no vehicle uptake model has been used**.

The focus of this study is the passenger car market, which is the largest market for electric vehicles, and accounted for 62% of CO₂ emissions in the road transport sector in Scotland in 2007. The following table shows the contribution by vehicle type to overall road transport emissions for 1990 (the base year from which emission reduction targets are set) and 2007 (latest available data).

Table 2: Road transport emission by vehicle type in Scotland⁷

Vehicle	Emissions in 1990		Emissions in 2007	
	(ktCO ₂)	Fraction of total	(ktCO ₂)	Fraction of total
Passenger cars	5,704	63%	6,229	62%
Buses and Coaches	378	4%	326	3%
HGVs	2,007	22%	2,274	23%
LGVs	875	10%	1,223	12%
Motorbikes	50	0.6%	31	0.3%
Other	21	0.2%	13	0.1%
Total	9,035	100%	10,096	100%

Note: percentage figures may not sum to 100% due to rounding.

Whilst a detailed investigation into the potential for electric vehicles to reduce emissions in the non-passenger car sectors was outside the scope of this work, a discussion of the relevant carbon saving measures in other sectors within road transport is included in section 10.

For clarity purposes this study considers three types of passenger car only:

- Battery electric (BEV) – pure battery electric vehicle, with range limited to on-board battery capacity.
- Plug-in hybrid electric (PHEV) – series PHEVs (which travel on battery power only until the electric range limit is reached), with an internal combustion engine to provide range comparable to a standard car.

⁷ NAEI data: <http://www.naei.org.uk/reports.php>.

- Internal combustion engine car (ICEV) – zero electric range.

Details of the technical characteristics of the vehicle types considered are given in the technical appendix, section 11.3.

Key Points

- A scenario based approach has been taken to assess the potential impacts of EVs on GHG emissions, urban air quality and electricity demand in Scotland.
- This study draws upon published data where possible. Extensive efforts have been made to source and use data specific to Scotland, with UK data used only where Scotland-specific data were unavailable.
- The focus of this study is on the passenger car market, which for the purposes of this work is divided into three segments: pure battery electric vehicles, plug-in hybrid electric vehicles, and internal combustion engine vehicles.

3.2 Approach to finding CO₂ emissions and key assumptions

In this study carbon emissions from the passenger car market are calculated according to the following formula:

$$\text{CO}_2 \text{ emissions from car type A (MtCO}_2\text{/yr)} = \text{Fleet average CO}_2 \text{ emissions for car type A (kg/km)} \times \text{Total annual distance done by all cars of type A (billion km/yr)}$$

Performing this calculation for each car type (BEVs, PHEVs, and ICEVs) and summing the results leads to a figure for total annual emissions from cars.

Calculating the carbon-saving potential of EVs involves finding the emissions associated with their use, which requires an assessment of how far they are likely to be driven and of the specific CO₂ emissions in use (g/km). Furthermore, future carbon savings from passenger cars are not expected to come solely from EVs (see section 2.3). An assessment of the savings from other measures is therefore also required.

The total distance driven by each car type (BEVs, PHEVs, ICEVs) is calculated based on the total number of each car type, total car-km for all cars in the stock, and the usable range of BEVs. Details of the methodology used are given in section 12.2. The main point to note is that BEVs are not direct replacements for ICEVs (the average annual mileage figure for BEVs is typically below that of ICEVs due to range constraints).

The following table summarises the key assumptions in this study. Full details of all assumptions made are included in the appendix (section 11).

Table 3: Summary of key assumptions⁸

Parameter	Value in year of interest			Notes
	2006	2020	2030	
Total car-km in Scotland: traffic stabilisation (billion km)	34.5	31.9	31.9	Value for 2006 from DfT statistics. ⁹ Values in 2020 and 2030 set to 2001 total car-km levels (based on Scottish government target, see below).
Total car-km in Scotland: traffic growth (billion km)	34.5	42.5	42.5	Value for 2020 derived from results from the LATIS model, which gives predictions to 2021. ¹⁰ Stabilisation assumed from 2020 to 2030.
Total number of cars in Scottish car parc (millions of cars)	2.2	2.5	2.8	2006 data from vehicle licensing statistics for Scotland (DfT). ¹¹ Values in 2020 and 2030 based on constant annual growth rate (see below).
Fleet average CO ₂ emissions from ICEVs (gCO ₂ /km)	180	120	95	2006 value calculated from total car-km (DfT data) and emissions from cars (NAEI data). 2020 value provided by the CCC. 2030 value based on EU directives for new cars and academic research (for full justification see section 11.3.2).
Adjusted fleet average ICEV emissions (gCO ₂ /km)	180	107	85	Fleet average CO ₂ emissions adjusted to reflect savings possible from non-drivetrain measures (see section 11.1.2 for details).
Fleet average CO ₂ emissions from BEVs and PHEVs in electric mode (gCO ₂ /km)	81	28	18	Calculated based on EV energy demands (kWh/km), charging efficiency and grid carbon intensity (gCO ₂ /kWh). See section 11.3 for full details.
Fleet average CO ₂ emissions from PHEVs in non-electric mode (gCO ₂ /km)	130	100	95	Based on EU targets for new car emissions.
Overall fleet average CO ₂ emissions from PHEVs (gCO ₂ /km)	97	51	43	Based on emissions in electric and non-electric mode and proportion of distance covered in electric mode (see section 12.2).

⁸ For the full derivation of these values see the appendix, section 11.

⁹

<http://www.dft.gov.uk/pgr/statistics/datatablespublications/roadtraffic/traffic/rtstatisticsla/roadtrafficstatisticsforloca5434>.

¹⁰ The LATIS model predicts traffic growth of 25% between 2007 and 2021. Assuming a linear change, this corresponds to a 23.2% increase on 2007 levels by 2020, which equates to 42.5 billion car-km in 2020. Results from the LATIS model provided by Transport Scotland.

¹¹

<http://www.dft.gov.uk/pgr/statistics/datatablespublications/vehicles/licensing/vehiclelicensingstatistics2008>.

3.2.1 Total number of cars in Scotland in 2020 and 2030

Car ownership levels in Scotland have increased consistently over the past few decades. With continued economic growth and development in Scotland this trend is likely to continue for some time. In this work the number of cars in Scotland is assumed to increase annually at a rate of 1%. This figure is slightly lower than the growth rate over the past decade, but gives future car ownership levels which are consistent with population and housing growth forecasts. For example, there were 2.3 million households in Scotland in 2006, which gives an average car ownership per household figure of 0.93. The number of households in Scotland is projected to increase to 2.7 million by 2030, which leads to a figure of 1.03 for the average car ownership per household in 2030.¹² The implications of the car ownership and total car-km assumptions in terms of average annual mileage per car are shown graphically in Figure 3, in section 3.2.2.

In the scenarios based on published data EV uptake is set by penetration levels (percentage of stock), which means that the total number of cars in Scotland (together with the relevant penetration level) sets the numbers of BEVs and PHEVs in the Scottish car parc. The calculation methodology adopted means that the total car-km driven in Scotland is independent of the number of cars in the parc.

3.2.2 Total car-km in 2020 and 2030

One future scenario (in terms of demand for car travel in Scotland) shows the total car-km figure from 2020 set at 31.9 billion, with an assumption of no further change to 2030 ('traffic stabilisation'). This is consistent with the Scottish Government's aspiration to stabilise car-km at 2001 levels from 2021.¹³ It also fits with the 'Smarter Choices (low)' scenario set out by the CCC, which shows a slight reduction in total vehicle-km in the UK from now to 2020.¹⁴

It is widely acknowledged that stimulating a market for electric vehicles will require significant funding. For example, the recent CCC report suggests that support levels will initially be in the range £6,000–£20,000 per vehicle.¹⁵ A relatively cheap method of reducing road transport emissions is to simply curb the increase in (or reduce) total vehicle-km.¹⁶ It seems an appropriate assumption that in a future with electric vehicles, other measures will have been taken to limit the demand for car use.

However, the results of the carbon impact assessment work are highly sensitive to total car-km driven. In recognition of this an alternative scenario is also considered in which car-km

¹² Household growth projections from <http://www.gro-scotland.gov.uk/files1/stats/high-level-summary-of-statistics-population-and-migration/j1068518.htm>.

For comparison, average car ownership per household figures in 2006 were 1.09 and 1.14 for England and Wales respectively (and 1.08 for Great Britain as a whole).

¹³ <http://www.scotland.gov.uk/Publications/2002/04/14640/4040> (paragraph 41). Note also that overall vehicle-km is one of the key *Indicators of Sustainable Development* for Scotland (see section 2.4.4 of *Strategic Transport Projects Review: Environmental Report*).

¹⁴ *Meeting Carbon Budgets – the need for a step change*, p.229, Committee on Climate Change (October 2009).

¹⁵ *Meeting Carbon Budgets – the need for a step change*, p.207, Committee on Climate Change (October 2009).

¹⁶ Details of 'Smarter Choices' are given in Chapter 6 of the CCC October 2009 report.

grow to 2020 in line with predictions from the Land Use and Transport Integration in Scotland (LATIS) model, and then stabilise to 2030.¹⁷

For clarity purposes the scenario in which demand for car travel is curbed is termed ‘traffic stabilisation’, while the scenario with increased car-km in the future is referred to as the ‘traffic growth’ scenario. The total car-km figures in each case are summarised in the figure below.

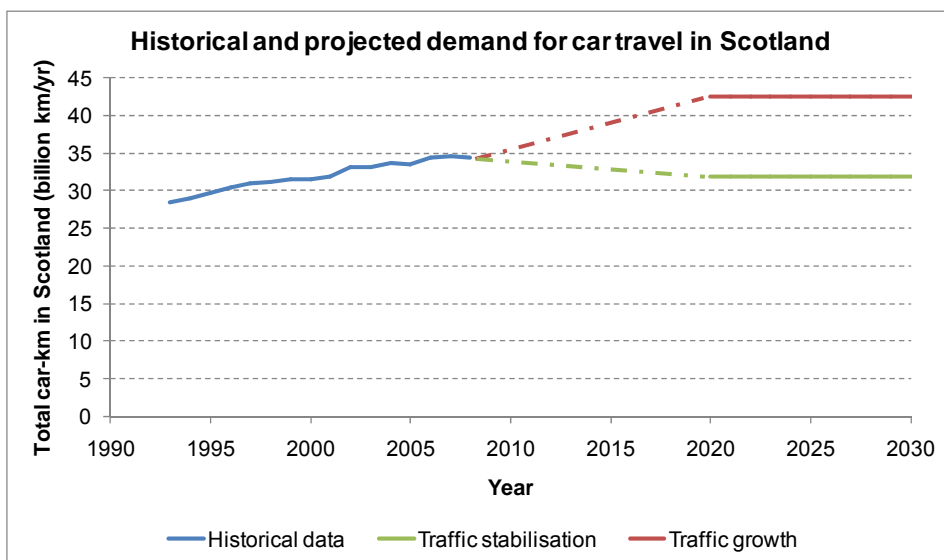


Figure 2: Total car-km in Scotland – historical data and reference projections

The following figure shows the change in annual mileage per licensed car in Scotland over the past decade (blue line). The dotted lines show the effect of the assumptions relating to car ownership and total car-km on average annual mileage per car.

¹⁷ The LATIS model takes Local Authority planning policy data, demographic and economic forecasts, and predicted changes in transport infrastructure as inputs. From these inputs it forecasts changes in traffic and travel patterns over time. The car-km figure in the traffic growth scenario in this work is based on the growth predicted by the LATIS model, which in turn is a result of the input assumptions. These include growth in population and employment levels in Scotland over the medium to long term.

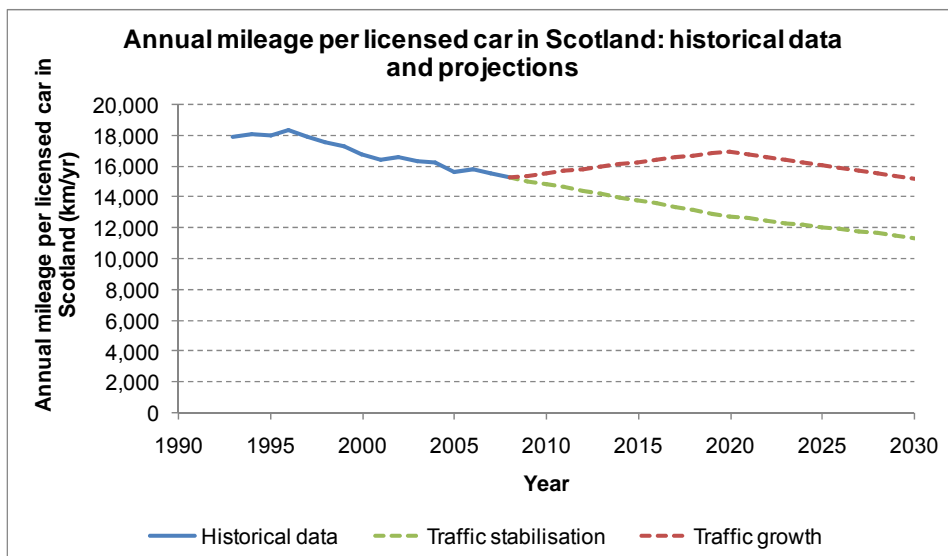


Figure 3: Historical and projected average annual mileage per car¹⁸

These data suggest that average annual mileage per car in Scotland has been steadily decreasing over the past decade. Under the assumption that total car-km stabilise at 2001 levels from 2020, this trend continues. In the traffic growth scenario the trend of decreasing average annual mileage per car reverses through the 2010s before resuming in the 2020s (since traffic levels do not grow from 2020 in this scenario).

Key Points

- Total CO₂ emissions are calculated based on the total distance driven by each car type (km/yr) and specific emissions (gCO₂/km).
- In terms of total car-km driven in Scotland, two alternative futures are considered: one in which demand for car travel falls back to 2001 levels (traffic stabilisation) and one where demand increases to 2020 (traffic growth).
- The data used to calculate the impact of EV uptake on GHG emissions have been taken from published sources where possible. Full details of the methodology and assumptions are given in the technical appendix, section 11.

¹⁸ Historical data from estimations of total car-km in Scotland (DfT data) and vehicle licensing statistics (DfT data).

4 Scenarios for EV uptake: vehicle numbers and CO₂ emissions

A total of four scenarios for EV uptake have been considered:

- Business as Usual (BAU)
- Upper
- Stretch: traffic stabilisation
- Stretch: traffic growth

The first two (BAU and Upper) were defined based on scenarios derived in a study by Arup and Cenex for BERR.¹⁹ Both Stretch scenarios on the other hand are target-driven, with the level of EV uptake set by required carbon savings in 2020 and 2030. It should be noted that the Stretch scenarios are in no way intended to be taken as an expected representation of EV uptake levels, they are purely illustrative. They have been derived to satisfy specific carbon saving targets which are described below.

4.1 Definition of scenarios

4.1.1 Business as Usual

The Business as Usual scenario represents the level of EV uptake with existing and announced policies in place, with no further support for EVs. The number of BEVs and PHEVs in Scotland in 2020 and 2030 are based on the penetration levels (percentage of stock) from the Arup / Cenex study. This work shows battery costs remaining relatively high, with whole-life cost parity between BEVs and conventional cars not achieved until 2020. In this scenario ICEVs remain the preferred purchasing choice through the 2020s and EV uptake levels remain relatively low, for example limited to congestion zones (such as London, where specific incentives exist) and early adopters ('green' consumers).

Table 4: Number of cars in Scotland by type: Business as Usual scenario

Parameter		Value in year of interest		
		2006	2020	2030
No. of cars by type in Scottish car parc	BEVs	0	5,550	40,000
	PHEVs	0	15,850	199,900
	ICEVs	2,173,050	2,512,150	2,558,750
Percentage of Scottish car stock	BEVs	0%	0.2%	1.4%
	PHEVs	0%	0.6%	7.1%
	ICEVs	100%	99.2%	91.4%

¹⁹ Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles, Arup / Cenex for BERR, (October 2008).

Without specific EV support policies the BAU scenario shows very low uptake in 2020. The ratio of PHEVs to BEVs reflects the fact that without appropriate support BEVs will remain niche (whereas PHEVs could find a wider market due to their higher utility).

4.1.2 Upper

This scenario represents a realistic upper bound of EV uptake, assuming proactive support measures for EVs are implemented. As for the BAU scenario, the levels of BEV and PHEV penetration in the Upper scenario are based on uptake figures from the Arup / Cenex work (in this case based on the ‘High-Range’ scenario from the study).

Under this scenario support for EVs is sufficient for whole-life costs of EVs to be comparable to ICEVs by 2015. Realisation of this level of EV uptake would require significant intervention to encourage EV sales, widely available battery leasing opportunities, and widespread charging infrastructure in urban and sub-urban areas.²⁰

Table 5: Number of cars in Scotland by type: Upper scenario

Parameter		Value in year of interest		
		2006	2020	2030
No. of cars by type in Scottish car parc	BEVs	0	95,000	263,900
	PHEVs	0	27,700	631,700
	ICEVs	2,173,050	2,410,850	1,903,050
Percentage of Scottish car stock	BEVs	0%	3.7%	9.4%
	PHEVs	0%	1.1%	22.6%
	ICEVs	100%	95.2%	68.0%

In this scenario support policies through the 2010s drive demand for EVs, particularly BEVs in urban areas, for example where policies such as congestion charge derogation can be applied. Given sufficient support, and the fact that BEV development is slightly more advanced than PHEV development (i.e. there are currently no PHEVs available to the UK market whereas BEVs have been available for some time); a higher number of BEVs relative to PHEVs may be expected in 2020. However, in the longer term PHEVs are likely to find a larger market since they can be used as a direct replacement for ICEVs (since they do not have the same range constraints as BEVs).

The Scottish government is considering setting a target for 100% of public sector vehicles to be ‘alternatively powered’ by 2020, with a national target of 30% of vehicles to make use of ‘alternative power’.²¹ The precise definition of ‘alternative power’ is not currently clear, however, the uptake levels in the Upper scenario can be compared to this target assuming ‘alternative power’ refers to electric vehicles.

²⁰ Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles, Arup / Cenex for BERR, p.5, (October 2008).

²¹ This is based on the Scottish government’s 2007 manifesto commitment. Consultation on low carbon vehicles: <http://www.scotland.gov.uk/Resource/Doc/277292/0083254.pdf> p.8.

There are approximately 1,000 cars and 6,900 LGVs in the Scottish public sector fleet (based on 2008 data).²² In the Upper scenario defined above there is a total of over 122,000 BEVs and PHEVs in Scotland in 2020. This scenario is therefore consistent with the target to switch public sector cars to alternative power by 2020.

4.1.3 Stretch: traffic stabilisation

Unlike the BAU and Upper scenarios described above, the Stretch scenarios are target-driven, i.e. the number of EVs is set by a specific CO₂ reduction target. Thus the Stretch scenarios are intended to demonstrate what EV uptake levels would be required to meet given targets.

The target CO₂ reduction from cars for 2020 was derived based on emission reduction targets set out in Scotland’s Climate Change Delivery Plan (CCDP).²³ The CCDP sets a target CO₂ saving of 27% by 2020 for transport relative to 1990 emission levels, but with no specific targets for each component of the transport sector (road, rail, shipping etc). However, road transport is expected to contribute the bulk of the savings and in this study it has been assumed that the savings from the road transport sector alone must be sufficient for the transport sector as a whole to meet the 27% reduction target. This equates to reductions from road transport of 43% by 2020 relative to 1990 emission levels. Further detail behind the derivation of this figure is given in the appendix, section 11.1.

In the absence of any clear carbon saving target for 2030, a target of 70% relative to 1990 emission levels has been taken for the passenger car sector. This figure has been selected for the purposes of demonstration and is based on consideration of CO₂ saving projections from 2020 to 2030.

Table 6: Number of cars in Scotland by type: Stretch: traffic stabilisation scenario

Parameter		Value in year of interest		
		2006	2020	2030
No. of cars by type in Scottish car parc	BEVs	0	221,900	500,000
	PHEVs	0	64,350	1,200,000
	ICEVs	2,173,050	2,247,350	1,098,650
Percentage of Scottish car stock	BEVs	0%	8.8%	17.9%
	PHEVs	0%	2.5%	42.9%
	ICEVs	100%	88.7%	39.3%

Under this scenario the proportion of EVs in the stock is comparable to the ‘Extreme Range’ in the Arup/ Cenex study (which shows 8.1% BEVs and 1.6% PHEVs in 2020 and 16.5% BEVs and 42.3% PHEVs in 2030). The CCC Stretch ambition shows BEVs and PHEVs representing 12.1% and 8.7% of the stock in 2020, which is even more ambitious than the Stretch: traffic stabilisation scenario defined above.²⁴ The Stretch ambition as defined by the CCC includes

²² <http://www.scotland.gov.uk/Resource/Doc/277292/0083254.pdf> Figure 2, p.14.

²³ The CCDP sets out high level measures required in each sector to meet Scotland’s statutory emissions targets (which in turn are set out in the Climate Change (Scotland) Bill. See: <http://www.scotland.gov.uk/Publications/2009/06/18103720/0>.

²⁴ <http://www.scotland.gov.uk/Resource/Doc/277292/0083254.pdf> p.24.

ambitious assumptions regarding the penetration of EVs, for which there are currently no policy commitments in place. This ambition includes relatively radical new technology deployment and significant lifestyle adjustments.

4.1.4 Stretch: traffic growth

Given that total emissions from passenger cars in Scotland are sensitive to total car-km driven, a second target-based scenario is considered. This scenario investigates the contribution that EVs would have to make to meeting the 2020 and 2030 CO₂ reduction targets given traffic growth to 2020 (with stabilisation thereafter).²⁵

In this scenario very high uptake levels of EVs are required by 2020. For the purpose of demonstration this dominance of EVs in new car sales has been continued through the 2020s, leading to total replacement of ICEVs in the stock by 2030.

Again, this scenario is not to be taken as indicative of potential levels of EV uptake, but is included to demonstrate the scale of the challenge of meeting ambitious targets against growing demand for car travel.

Table 7: Number of cars in Scotland by type: Stretch: traffic growth scenario

Parameter		Value in year of interest		
		2006	2020	2030
No. of cars by type in Scottish car parc	BEVs	0	700,000	823,150
	PHEVs	0	809,200	1,975,500
	ICEVs	2,173,050	1,024,350	0
Percentage of Scottish car stock	BEVs	0.0%	27.6%	29.4%
	PHEVs	0.0%	31.9%	70.6%
	ICEVs	100%	40.4%	0.0%

Considering 2020 figures, EVs comprise 5%, 11% and 60% of the Scottish car stock in the Upper, Stretch: traffic stabilisation and Stretch: traffic growth scenarios respectively. Given that the Upper scenario represents a reasonable estimation of the upper levels of EV uptake, the increase in the number of EVs in the stock required in the Stretch: traffic stabilisation scenario is considerable. However, the challenge in a scenario with traffic growth is even more extreme, with a requirement for around 60% of all cars in Scotland to be EVs by 2020 to meet the same CO₂ reduction target. This is purely a result of the increase in total car-km under the traffic growth scenario. Further details of the implications of the total car-km assumption are given in section 11.1.2.

The total numbers of vehicles in each of the scenarios are presented graphically in the following figure.

²⁵ Increase in total car-km taken from LATIS model results (see section 3.2.2).

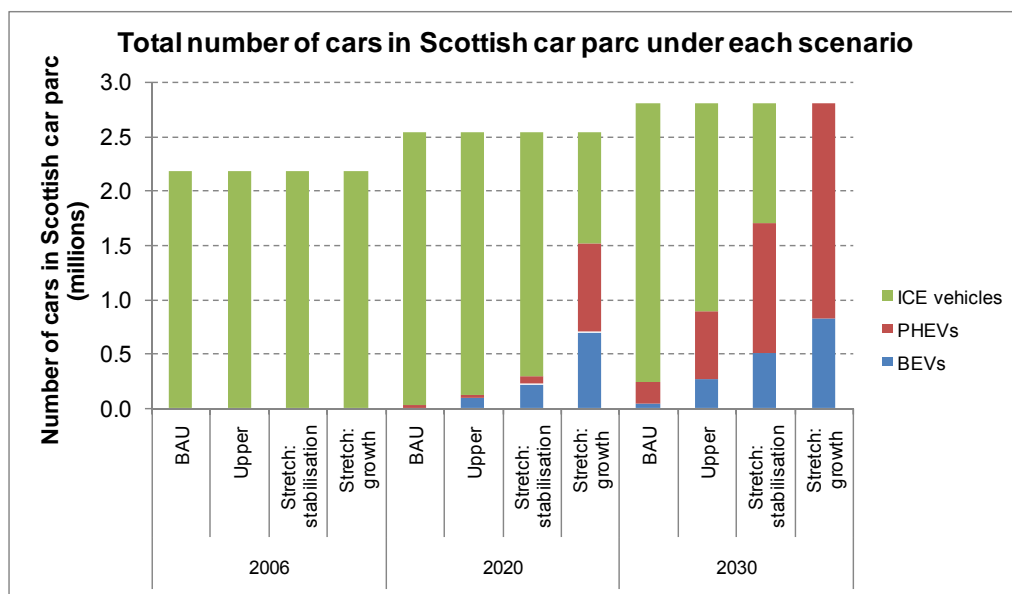


Figure 4: Number of cars in Scotland by type under each scenario

This graph reveals the gap between the number of EVs in the stock in 2020 under a predicted upper bound of EV uptake (Upper scenario) and the number in the stock required to meet the 2020 CO₂ reduction target (Stretch: stabilisation scenario). Even with a decline in overall car-km from today’s levels to 2001 levels in 2020 (traffic stabilisation), these results show that the total number of EVs required to meet the 2020 target is over double the value in the stock under the Upper scenario.

If demand for car travel is not curbed and the total car-km figure grows in line with predictions from the LATIS model (see section 3.2.2), the level of EV uptake required to meet the 2020 target becomes even more extreme. In the Stretch: traffic growth scenario, BEVs and PHEVs comprise 60% of the total passenger car stock in 2020. A change of this magnitude would require imminent fundamental changes to car purchasing behaviour, with a significant shift to the purchase and use of EVs from around 2010 onwards. The scale of such a challenge is further contextualised in the following section.

Key Points

- Four scenarios of EV uptake are defined. Two are based on published data (BAU and Upper) and two are purely target-driven (Stretch scenarios).
- The BAU scenario draws on data from previous studies in this area and is intended to represent EV uptake levels resulting from existing and announced policies.
- The Upper scenario is also based on published data and represents a realistic upper bound on EV uptake with the implementation of further supportive measures for EVs.
- The Stretch scenarios are target-driven. This means that the number of EVs in the stock is set such that a particular CO₂ saving is achieved in a given year. The Stretch scenarios are not intended to represent realistic levels of EV uptake.

4.2 Representative EV sales over time

The following graphs indicate the level of increase in EV sales required to realise the scenarios defined above. The methodology for estimating new car sales required is given in the technical appendix, section 12.1.

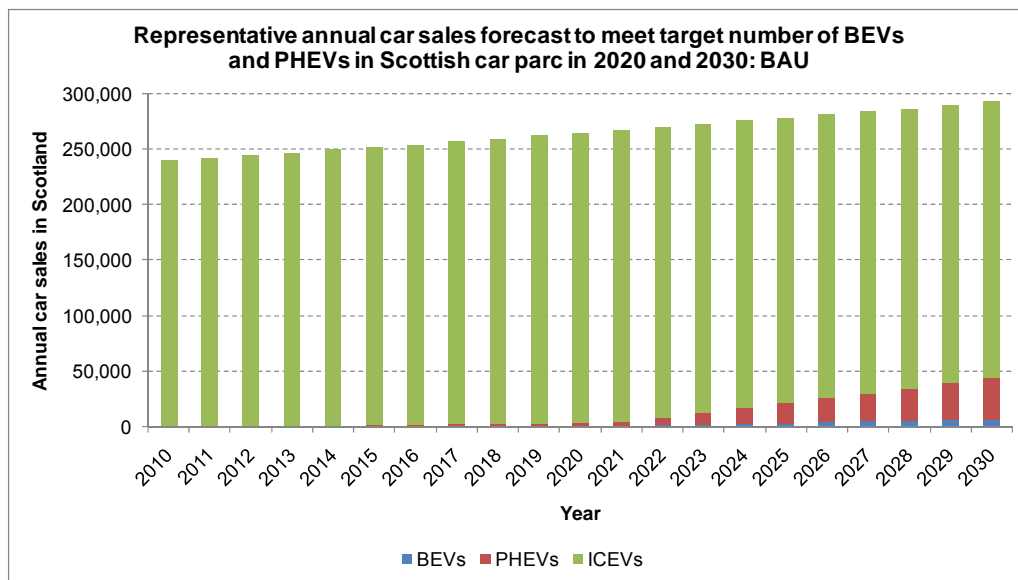


Figure 5: Annual car sales required under the Business as Usual scenario

The sales required to achieve the uptake level in the BAU scenario are relatively low, with around 1.5% of new car sales being EVs in 2020, rising to around 15% by 2030.

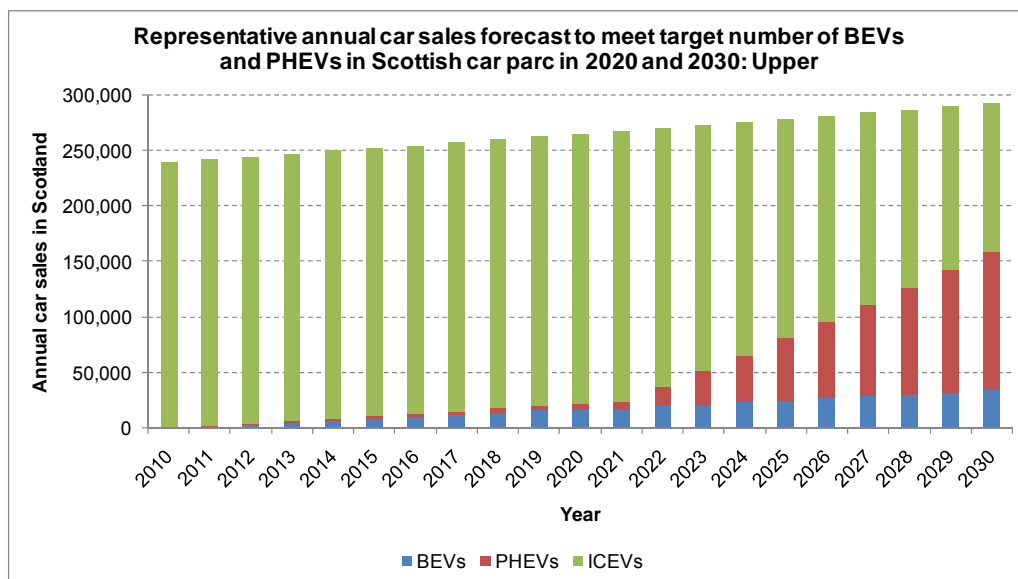


Figure 6: Annual car sales required under the Upper scenario

To reach the levels of EV uptake considered in the Upper scenario, higher sales would be required, with EVs representing around 9% and 54% of new car sales in 2020 and 2030 respectively.

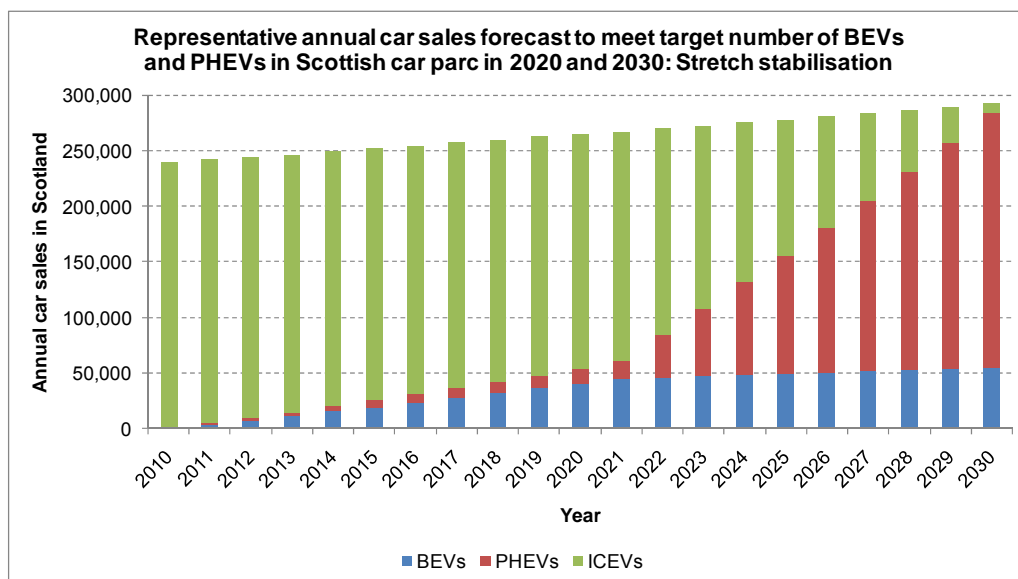


Figure 7: Annual car sales required under the Stretch: traffic stabilisation scenario

In the Stretch: traffic stabilisation scenario BEV and PHEV sales together represent 20% of new car sales in 2020, with significant growth through the 2020s such that by 2030 nearly all new car sales are EVs.

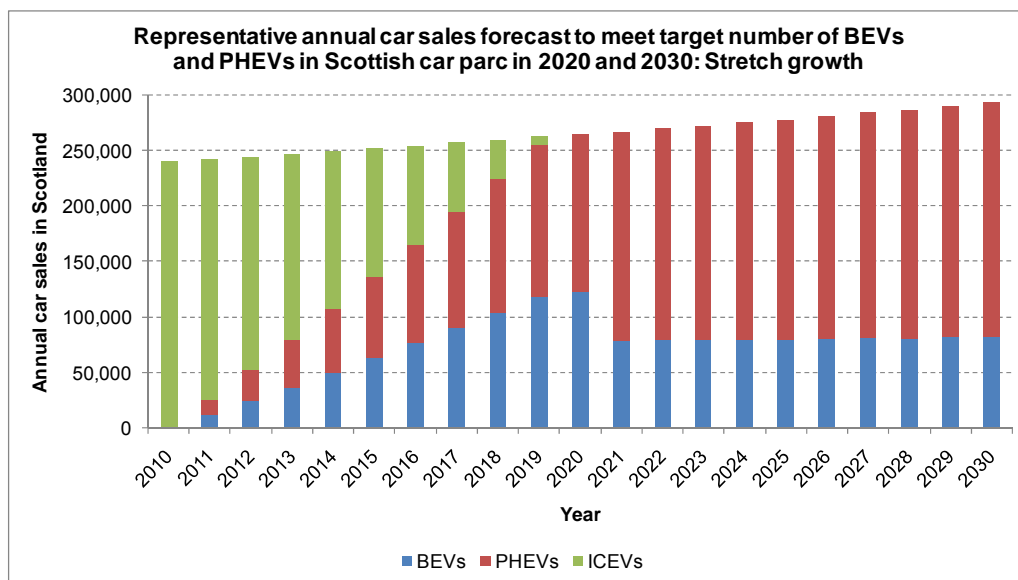


Figure 8: Annual car sales required under the Stretch: traffic growth scenario

Figure 8 gives a representation of how the sales profile of new cars in Scotland would have to shift for the targets in the Stretch: traffic growth scenario to be reached. EVs become increasingly dominant in new car sales through the 2010s and completely replace ICE cars from around 2020 in order to achieve total substitution of the stock with EVs by 2030.

Key Points

- The level of EV uptake in the BAU scenario could be achieved with steady annual growth in EV sales such that BEVs and PHEVs together represent around 1.5% and 15% of total new car sales in 2020 and 2030 respectively.
- In the Upper scenario a more rapid increase in EV sales penetration is required, with EVs accounting for around 9% of sales in 2020 and 54% in 2030.
- The Stretch: traffic stabilisation scenario would require an increase in EV sales to achieve 20% of the new car sales market by 2020. Under this scenario EV sales begin to dominate new car sales through the 2020s and nearly all new cars sold are EVs by 2030.
- Under the Stretch: traffic growth scenario ICE car sales cease by 2020. This would require an unprecedented rise in EV sales over the next decade, well above any realistic expectations.

4.3 Greenhouse gas emission reductions

This section explores the potential CO₂ emission reductions associated with each scenario of low carbon vehicle uptake. Two sets of results are presented:

- Traffic stabilisation: CO₂ emissions resulting from the levels of EV uptake in each scenario under the traffic stabilisation assumption.
- Traffic growth: CO₂ emissions resulting from EV uptake under the traffic growth scenario.

4.3.1 Traffic stabilisation

The following graph shows the predicted CO₂ emissions in Scotland resulting from the methodology described in section 3.

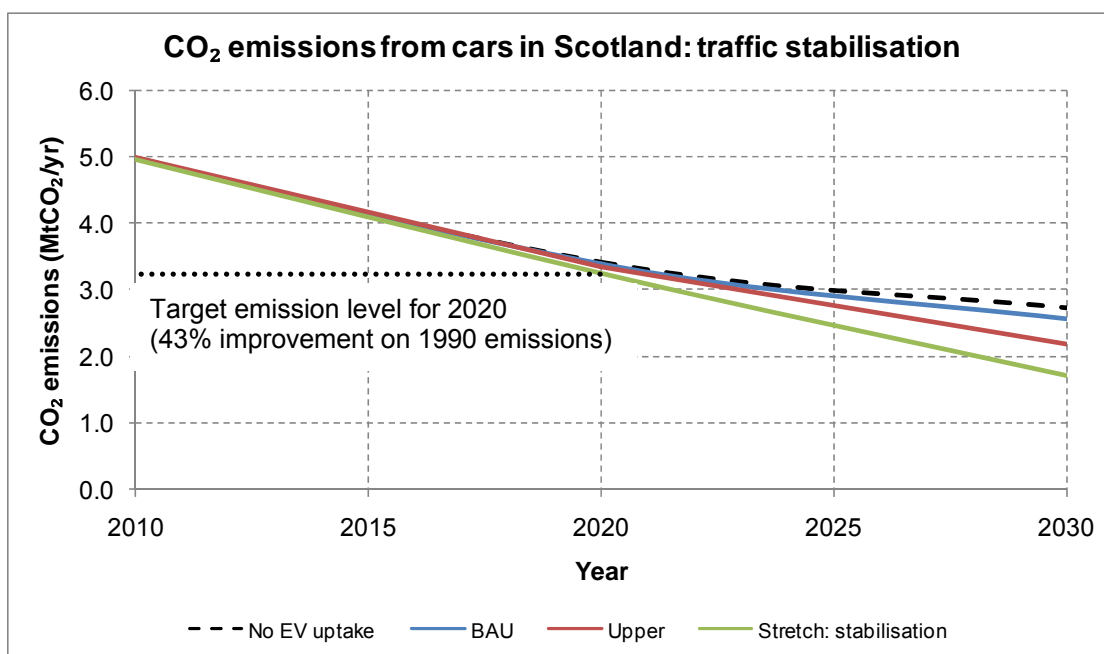


Figure 9: Forecast CO₂ emissions from cars in Scotland: traffic stabilisation

In this graph the emissions resulting with no BEV or PHEV uptake are also plotted (the 'No EV uptake' series). With no EV uptake all reductions are due to reduced distance driven (overall car-km), improvements in ICE efficiency, and non-powertrain measures (see section 11.1.2).

The key observations from these results are:

- The Business as Usual scenario leads to CO₂ savings in 2020 of around 40% relative to 1990 levels. This suggests that if the goal of stabilising total car-km at 2001 levels from 2021 is attained, and ICE efficiencies improve to the extent that the CCC forecasts, then the additional savings required from EVs are relatively modest.
- The CO₂ savings in 2030 equate to 55%, 62% and 70% reductions relative to 1990 levels in the BAU, Upper and Stretch: stabilisation scenarios respectively. Note that these savings depend on total car-km reducing by around 7% from 2008 levels by

2020, with zero growth thereafter. Furthermore, the assumptions behind these results lead to fleet average specific CO₂ emissions for ICE cars of 107gCO₂/km and 85gCO₂/km in 2020 and 2030.²⁶

Figure 9 shows that if the ambitious target of stabilising total car-km at 2001 levels in the 2020s and beyond is achieved, then provided that the specific CO₂ emissions of ICE cars continue to decrease as expected, significant savings can be realised even without significant levels of EV uptake. However, achieving the target of a 43% reduction in car emissions (from 1990 levels) by 2020 will require a contribution from EVs beyond the savings anticipated in what is considered to be a realistic upper bound on EV uptake. This is a result of a combination of factors, principally that the 2020 target is extremely challenging and that not all EVs are a direct replacement for ICEVs (see section 12.2).²⁷

4.3.2 Traffic growth

Given the sensitivity of total car emissions to total car-km driven, it is important to consider the impact of failing to meet the traffic stabilisation goal. This section presents the results from a scenario in which total car-km increase by 24% from 2008 levels by 2020, which represents a more accurate reflection of past trends in traffic growth.

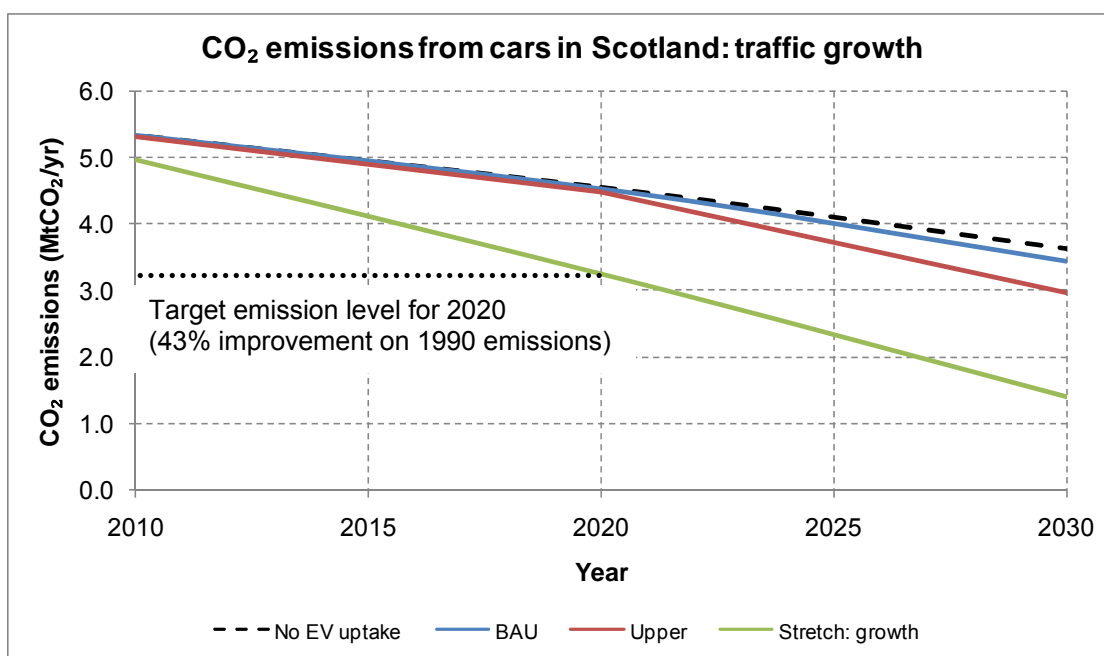


Figure 10: Forecast CO₂ emissions from cars in Scotland: traffic growth

The only change compared to the results presented in Figure 9 is that the total car-km in 2020 and 2030 are increased in this scenario. This therefore impacts the numbers of BEVs and

²⁶ The ICE car fleet is considered to be all cars excluding plug-in vehicles (BEVs and PHEVs) and therefore includes technology such as stop-start, mild hybrids etc. The figures of 107gCO₂/km and 85gCO₂/km include adjustment for non-drivetrain measures. For the full derivation and justification of these figures, see section 11.3.2.

²⁷ For example the average annual mileage of BEVs is lower than the average annual mileage of ICE cars (due to their limited range). This has a limiting effect on the overall emissions reductions possible from introducing BEVs into the stock.

PHEVs in 2020 and 2030 in the Stretch scenario since it is target-driven. Compared to the traffic stabilisation results, the data plotted in Figure 10 show significantly higher CO₂ emissions under the BAU and Upper scenarios. For example, while emissions from cars in 2020 are 3.40MtCO₂/yr under BAU in the traffic stabilisation scenario, the equivalent figure under the traffic growth scenario is 4.55MtCO₂/yr. Specific points of interest from these results include:

- The CO₂ savings in 2020 under BAU correspond to a 20% reduction relative to 1990 levels (compared to 40% in the traffic stabilisation scenario).
- The Upper scenario leads to savings in 2020 of around 21.5% relative to 1990 levels, around half the saving required to meet the 43% 2020 target.
- Being target-driven, the Stretch: traffic growth scenario meets the 2020 emission reduction ambition. However, the levels of EV uptake required to accomplish this under the traffic growth scenario are beyond what could be realistically envisaged, as discussed in section 4.2.
- These results highlight the importance of curbing demand for car travel. In a scenario where total car-km continue to rise broadly in line with historical trends, meeting an ambitious CO₂ emission reduction target in 2020 is well beyond realistic expectations of EV market growth (even with significant support and relatively ambitious uptake levels).

4.3.3 Impact of traffic growth assumptions on number of EVs required to meet the 2020 target

The results presented above relate to two alternative futures: one in which an ambitious target for reducing demand for car travel is met and one in which the total car-km figure grows by 24% from current levels to 2020. In reality, demand for car travel in 2020 is likely to lie between these two values. The following graph shows the total number of EVs required to meet the 2020 CO₂ reduction target against total annual car-km in 2020. The two data points plotted relate to the two stretch scenarios discussed above (traffic stabilisation and traffic growth). The linear relationship shown is a reasonable approximation of how the number of EVs in the stock must change to meet the 2020 target as demand for car travel increases.

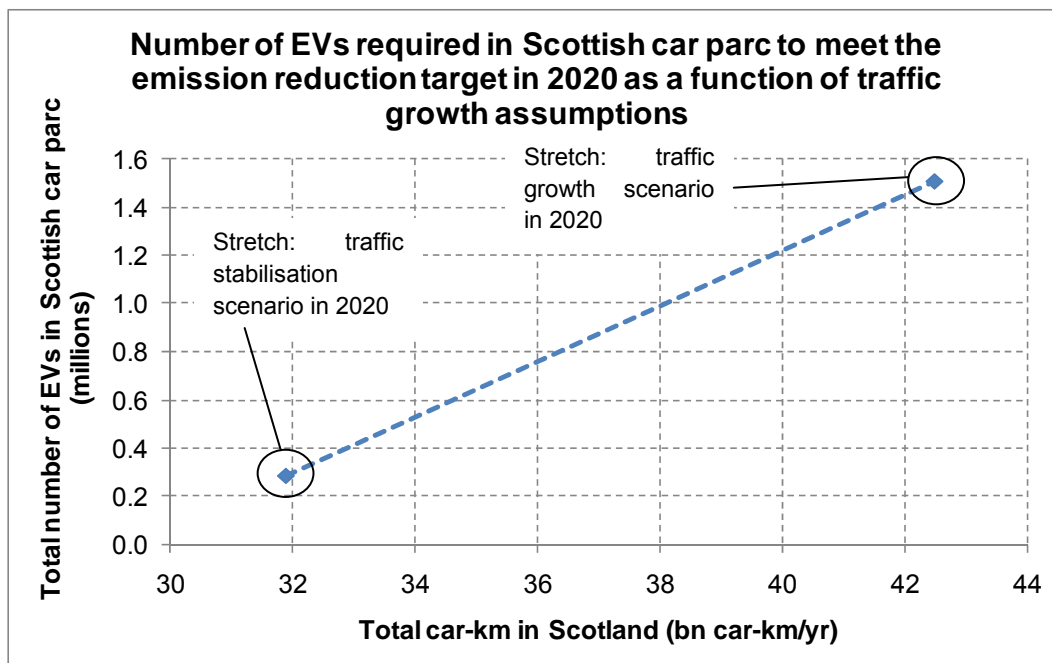


Figure 11: Number of EVs required to meet 2020 CO₂ emission reduction target as a function of demand for car travel

Key Points

- The BAU scenario (little EV uptake) leads to a CO₂ saving of around 40% in the passenger car sector under the traffic stabilisation scenario. This relies on achievement of the 2021 traffic stabilisation target for Scotland, and the realisation of improvements in ICE efficiency in line with EU directives for new car CO₂ emissions.
- Improvements in ICE emissions characteristics also lead to CO₂ savings relative to 1990 levels under the traffic growth scenario. However, in this case the savings under BAU are around 20% relative to 1990 emissions, half the value for the traffic stabilisation scenario.
- A 43% reduction in emissions from passenger cars by 2020 is beyond the anticipated savings from EV uptake in the Upper scenario in both the traffic stabilisation and the traffic growth cases. This suggests that further measures would be required if this target is to be met.

5 Recharging infrastructure requirements

This section presents a discussion of the infrastructure requirements to support the levels of EV uptake defined in each scenario. A summary of key results from analysis of National Travel Survey driving statistics for Scotland is given in section 5.2, followed by scenario-specific consideration in section 5.3.

5.1 Recharging infrastructure: general considerations

Electric vehicle recharging infrastructure includes charge points located in a variety of locations, including at people's homes, workplaces, in public and private car parks (e.g. supermarket car parks) and on-street. Furthermore, there are two main types of recharging points: slow and fast chargers. For further details of different types of charge points, see section 13.

Contrary to the view that widespread dense, publicly available recharging infrastructure must be in place to encourage EV adoption, a recent report for the CCC demonstrated that domestic charging alone could go a long way towards electrification of car-km in the UK.²⁸ This work highlighted the fact that publicly available charge points represent an expensive solution (on the basis of £/kWh of electricity delivered), and that while visible public charge points have a role to play in sending signals to potential end users, infrastructure solutions offer better value when targeted at specific locations. Key conclusions from this work include:

- Slow charge may have relatively low utility in public recharge points.
- Fast charge points can be effective in increasing the proportion of an EV's technical range that drivers are willing to use.
- Compared to domestic and workplace charging, recharging vehicles via publicly available charge points is an expensive option.

5.2 Key results from National Travel Survey statistics analysis

5.2.1 Trips and mileage by purpose and distance band

An analysis of the driving patterns of Scottish drivers was completed based on NTS Scotland-specific data from 2004–2006. The NTS defines twenty-three distinct trip purposes. Figure 12 shows the proportion of trips in given distance bands by trip purpose for the eight most common trip purposes.²⁹ These eight most frequent trip purposes accounted for 78% of all trips in the sample analysed.

This graph demonstrates that a high proportion of trips are in the lower distance bands. For example, 64% of all commuting journeys were less than 16km, which suggests that around 64% of commuters who drive to work complete round trip commutes of less than 32km. Commutes of this length would be within the usable range of today's BEVs, and well within the predicted range of future vehicles, see Table 19, section 11.3.1.

²⁸ *Strategies for the uptake of electric vehicles and associated infrastructure implications*, Element Energy for the Committee on Climate Change (October 2009).

²⁹ These results are based on an analysis of a total of around 39,000 journeys in Scotland.

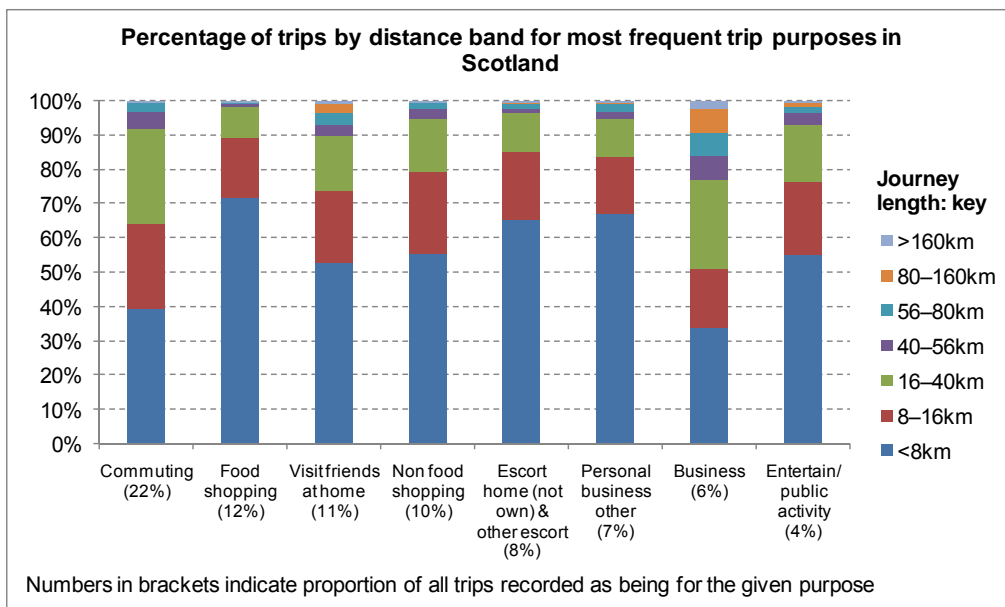


Figure 12: Trips by distance band and trip purpose for eight most frequent trip types

In terms of contribution to overall distance driven, the frequency and distribution of trips by distance band are both contributing factors, as illustrated by the graph below.

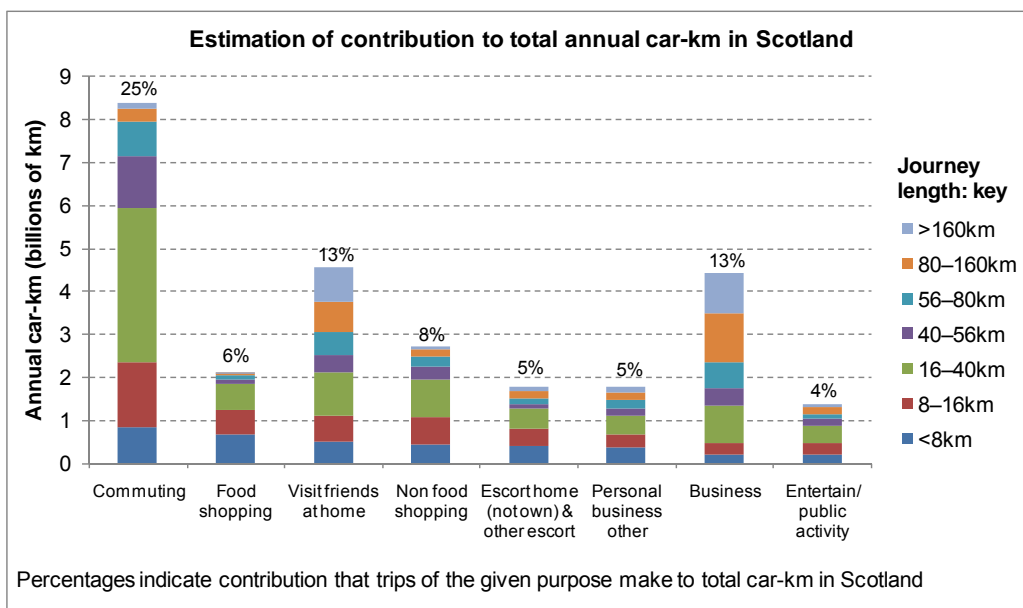


Figure 13: Contribution of most frequent trip purposes to total car-km in Scotland

These results show that trip purposes with a high proportion of longer distance journeys account for a higher proportion of total car-km, even if they are not the most common. For example, while 12% of all trips were for 'Food shopping' and 6% for 'Business', business trips overall account for 13% of total car-km and food shopping trips only 6%. This is a consequence of the high frequency of shorter trips in the food shopping category.

5.2.2 Length of stay by trip purpose

Time to recharge is often cited as an issue that could negatively impact EV uptake. Any infrastructure deployment should take full account of the habits of drivers, for example how long people typically spend parked at potential electric charge point sites.

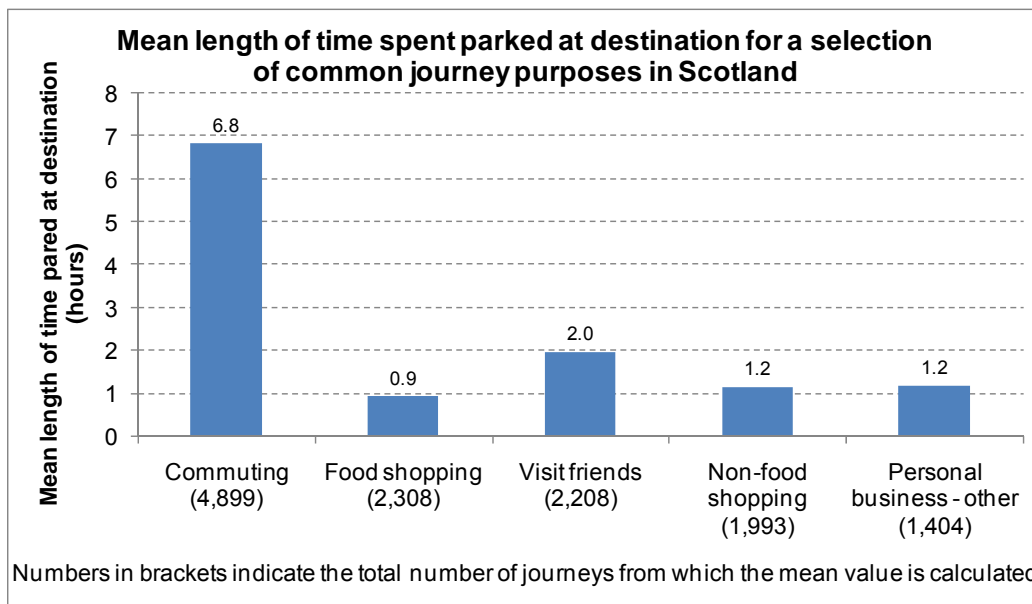


Figure 14: Time parked at destination for a selection of common journey purposes³⁰

These results suggest that slow charge points could be of use to EV drivers if located at workplaces (or in car parks used by commuters). However, it is important to note that the utility of slow charge points in other locations may be relatively limited given the relatively low mean residence times. Indeed, there is evidence that publicly available slow charge points do little to increase the proportion of a BEV's technical range that is actually utilised, whereas the addition of fast charge points can have a significant impact.³¹

Key Points

- Commuting is the most frequent trip purpose of car drivers in Scotland, with 22% of trips as a driver of a private car made for the purpose of travelling to or from work. Commuting trips account for around 25% of all car-km driven in Scotland.
- Other major contributors to total car-km in Scotland include business trips (13%), visiting friends at home (13%), and shopping (14%).
- The mean length of time parked at work is around seven hours. For other common trip purposes such as shopping the mean time spent parked is around one hour. This must be considered when specifying infrastructure solutions.

³⁰ Based on Scotland-specific NTS data (2004–2006).

³¹ Based on data from a Tepco trial in Japan, as reported in: *Strategies for the uptake of electric vehicles and associated infrastructure implications*, Element Energy for the Committee on Climate Change, p.19–20, (October 2009).

5.3 Impact of workplace charge points

Commuting is the most frequent journey purpose for drivers in Scotland, and trips to and from work account for a quarter of all car-km driven. An analysis of the potential impact of adding workplace EV charge points on CO₂ savings was completed (see section 12.2.4). This showed that giving BEV users the facility to recharge at work could increase the annual distance done by BEVs. Although the associated carbon savings are fairly marginal, that is not to say workplace charge points have no part to play in supporting EV uptake. In fact, the contrary is true.

The carbon savings associated with EV uptake in a situation with home charging only will only be realised if EVs are purchased and used by drivers in place of incumbent cars. Given the importance of commuting, a BEV purchaser will need to be confident that their vehicle will be able to meet their commuting needs, even if they change job. This suggests that for medium or large scale uptake, BEVs will have to be capable of completing a very high proportion of all commuting journeys. Given their relatively low cost, workplace charge points certainly have a role to play in realising this ambition.

In summary, a lack of workplace charge points could act as a constraint in realising the technical potential of EVs and such infrastructure is important in sending signals to the market which encourage consumers to consider EVs as a viable alternative choice when making purchasing decisions.

5.4 Recharging infrastructure: scenario-specific results

5.4.1 Infrastructure limits

In this section the total numbers of plug-in vehicles (EVs) under each scenario are compared to other relevant data such as number of households in Scotland with access to off-street parking. The aim of this analysis is to identify any urgent infrastructure requirements for each scenario (such as the need to provide on-street home charge facilities for EV owners) and to make recommendations as to appropriate infrastructure solutions.

In terms of infrastructure required, an important consideration is the ratio between the total number of EVs in the stock and the number of households with access to off-street parking. Another relevant figure, particularly in the short to medium term, is the ratio of BEVs in the stock to number of car-owning urban households with access to off-street parking. This ratio is of interest since BEV uptake is expected (at least initially) to be predominately in urban areas (where daily distances tend to be lower and smaller cars (better suited to being electrified) are often preferred). Both ratios are plotted in the figure below for each scenario in 2020 and 2030.

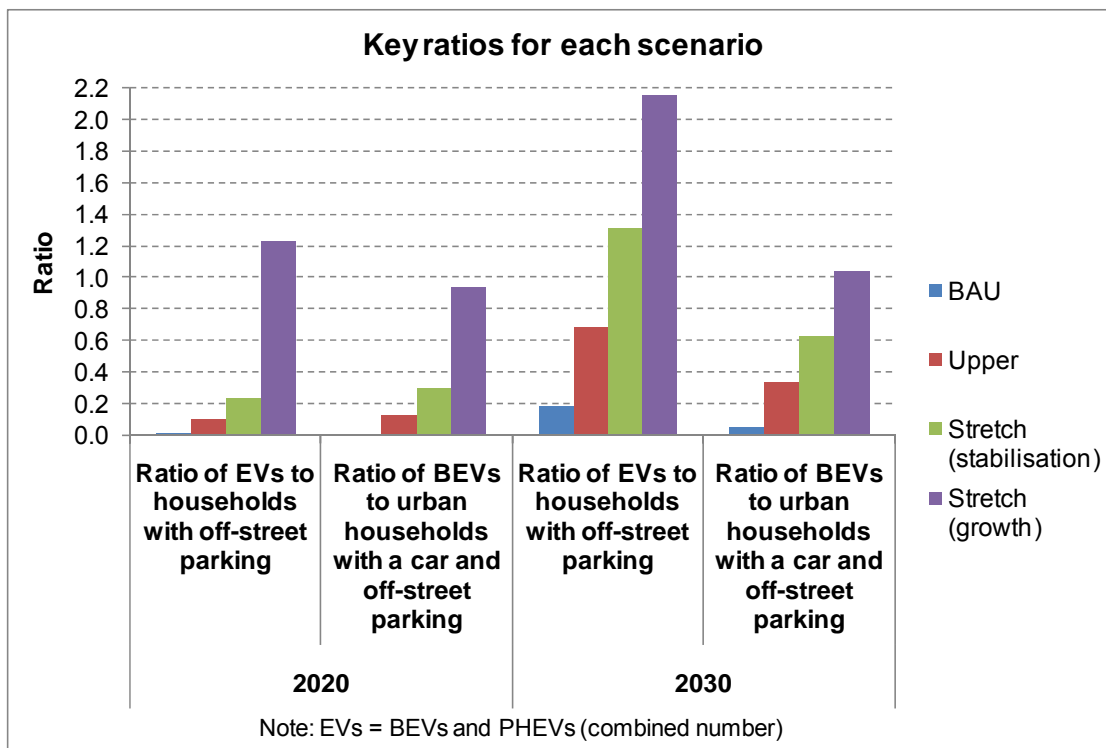


Figure 15: Ratio of number of EVs to households with off-street parking and number of BEVs to urban car-owning households with off-street parking³²

The ratio of plug-in vehicles to households with off-street parking is well below one in all cases except the Stretch: traffic growth scenario. The implications of this ratio exceeding one are that on-street recharging points will be required outside the homes of EV owners unless:

- 1) Some households with access to off-street parking own more than one plug-in car.
- 2) The driving patterns of a proportion of EV users mean that domestic charging is not required for all EVs in the stock (e.g. if the EV is used predominately for commuting and is mainly charged at work).

The second ratio considered in Figure 15 compares the total number of BEVs in the stock with the number of car-owning households in urban areas with access to off-street parking.³³ This is more relevant in 2020, when BEV uptake is expected to be mainly in urban areas. These results suggest that the total number of BEVs in Scotland does not exceed the number of car-owning urban households with access to off-street parking in 2020 under any scenario.

³² Data sources: proportion of households with off-street parking and proportion of all households in urban areas with a car and off-street parking from SHCS (2007) (assumed no change over time), household growth projections from: <http://www.gro-scotland.gov.uk/files1/stats/high-level-summary-of-statistics-population-and-migration/j1068518.htm>.

³³ 'Urban' in this context refers to 'Large Urban Areas' and 'Other Urban Areas' as defined by the SHCS. Large Urban Areas are defined as settlements of over 125,000 people and Other Urban Areas are settlements of 10,000–125,000 people.

5.4.2 Infrastructure requirements: home and workplace

The following tables summarise the base level domestic infrastructure requirements under each scenario in 2020 and 2030. It is assumed that every household that owns an EV will require a domestic charge point (see section 13.1.1 for details of domestic charge points). These tables also include estimated workplace charge point requirements, which are based on the total number of BEVs in the stock.

Table 8: Number of plug in cars and domestic and workplace charge points required in Scotland under each scenario in 2020

		BAU	Upper	Stretch: stabilisation	Stretch: growth
Number of plug-in cars		21,400	122,700	286,250	1,509,200
Domestic charge points required	Total number	21,400	122,700	286,250	1,509,200
	No. as % of households	1%	5%	11%	59%
	No. as % of households with off-street parking	2%	10%	23%	123%
No. of workplace charge points required (upper bound – based on no. of BEVs in stock) ³⁴		5,550	95,000	221,900	700,000

Table 9: Number of plug in cars and domestic and workplace charge points required in Scotland under each scenario in 2030

		BAU	Upper	Stretch: stabilisation	Stretch: growth
Number of plug-in cars		239,900	895,600	1,700,000	2,798,650
Domestic charge points required	Total number	239,900	895,600	1,700,000	2,798,650
	No. as % of households	9%	33%	63%	104%
	No. as % of households with off-street parking	19%	69%	131%	216%
No. of workplace charge points required (upper bound – based on no. of BEVs in stock)		40,000	263,900	500,000	823,150

These results suggest that if EVs are adopted by households with access to off-street parking, domestic charging will pose no problems (in terms of adequate parking to facilitate such charging) in the BAU or Upper scenarios. However, the number of plug-in vehicles in the stock exceeds the projected number of households with off-street parking under the Stretch: traffic growth scenario in 2020 (and 2030) and under the Stretch: traffic stabilisation in 2030.

³⁴ To put these figures in context, approximately 1.1 million people in Scotland commute to work by driving a private car. This figure is based on 2001 Census data, which shows there are around 1.85 million commuters in Scotland, and NTS statistics, which suggest that 60% of commuters drive to work.

This suggests that charge points on the public street outside the homes of EV owners may be required by 2020 or 2030 to support the levels of EV uptake needed to meet the emission reductions targets (timing depends on traffic growth).

While there may be sufficient off-street parking at the national level for domestic charging of all EVs under the BAU and Upper scenarios, a further consideration is the ability of local distribution networks to withstand the additional electricity demands resulting from the connection of EVs. Domestic slow charging places less severe strains on the distribution system than fast charge points, however, connection of a large number of EVs in a localised area may necessitate infrastructure reinforcement. Having said this, increased demand for domestic recharging of EVs is a relatively containable issue which can be managed within the overall programme of electricity grid upgrades for example.

5.4.3 City-specific considerations

In the previous section the number of plug-in cars under each scenario was contextualised by comparing it with the total number of households in Scotland with access to off-street parking. Given that uptake of EVs (particularly BEVs) is expected to be predominately in urban areas (at least initially), consideration of parking availability in cities is pertinent. The following table presents data relating to parking availability by Local Authority from the Scottish House Condition Survey.

Table 10: Number of households and off-street parking availability in Aberdeen, Edinburgh and Glasgow³⁵

	Aberdeen	Edinburgh	Glasgow
Total number of households in city	101,000	211,000	276,000
Percentage of households with adequate off-street parking	46%	32%	22%
Number of households with adequate off-street parking	45,988	67,144	61,597

In this table ‘adequate off-street parking’ refers to properties with one or more of the following: an integral garage, a garage on the plot, or space on the plot. For reference, the same data set suggests that 55% of households in the rest of Scotland (excluding these three cities) have adequate off-street parking. These figures highlight a potential challenge to large scale EV uptake in that whilst BEVs are purportedly best suited to urban environments, households in urban areas are on average less likely to have access to off-street parking facilities. This is a reflection of the relatively high proportion of dwellings such as tenement housing in these cities, which have little or no dedicated off-street parking facilities.

5.4.4 Infrastructure requirements: other locations

Electric vehicle recharging infrastructure represents a high capital cost investment. As with any such capital intensive investment, the financial case is enhanced by increased utilisation. Publicly available recharging stations risk suffering from low utilisation rates. The implications of low utilisation rates are that either the capital costs of the infrastructure will not be paid back (or not in a reasonable timeframe) or the price of electricity from public charge points must be

³⁵ Source: SHCS (2004–2007).

sufficiently high to pay off the capital. In the second case a major benefit of EVs (i.e. their lower running costs relative to ICE cars) may be eroded. This fact is illustrated by the calculations included in the appendix, section 13.1.5.

The relatively restricted role that public charge points may play has been recognised in London, where the Mayor has announced ambitious plans to turn the city into a world-leader in electric vehicles. London's Electric Vehicle Delivery Plan includes an ambition for 1,000 EVs in the GLA fleet by 2015 and a total of 25,000 charge points by this date. Of these, around ten percent are expected to be publicly available, with the remainder to be provided in partnership with business in locations such as workplaces and retail/leisure centres.³⁶

Having said this, publicly available charging points will have a role to play in encouraging EV uptake. The early stages of EV deployment could be supported by a mix of private and public charge points, with the public facilities located in high-profile locations. The risk of low utilisation rates could be mitigated by additional incentives, for example by allocating dedicated EV parking spaces with charge points at supermarkets near the store entrance, possibly combined with 'free' electricity while EV drivers shop.

In addition to slow charge points, fast charge stations could be used to support EV uptake. For example there is evidence to suggest that availability of fast charge points can lead to greater utilisation of the technical range of BEVs (see section 5.2.2). Although they represent a relatively expensive infrastructure solution, with careful planning the installed costs of fast charge points can be kept to a minimum, for example by minimising or avoiding the need for network reinforcement.

³⁶ *An Electric Vehicle Delivery Plan for London* (May 2009).
www.london.gov/mayor/publications/2009/docs/electric-vehicles-plan.pdf.

Key Points

- Provided EVs are adopted predominately by households with access to off-street parking, there are anticipated to be sufficient off-street domestic parking places for all EVs in 2020 and 2030 under the BAU and Upper scenarios at the national level.
- The proportion of households with access to off-street parking is lower in cities than in Scotland as a whole. This is a potential obstacle to EV uptake that warrants further investigation. For example, through research to identify the extent to which a lack of off-street parking restricts EV uptake and to identify the most cost-effective solutions to providing adequate domestic charging facilities.
- On-street domestic charge points may be required in the target-driven scenarios as the number of plug-in vehicles exceeds the number of households with access to off-street parking in 2020 or 2030 (depending on traffic growth).
- Publicly available recharging infrastructure is likely to play a strategic role in increasing awareness and encouraging EV uptake, especially if accompanied by additional incentives (preferential parking, free recharging etc).
- Public recharging infrastructure represents a high capital investment and therefore should be seen as a supportive rather than a central delivery mechanism. The bulk of EV recharging should be done by private charge points, principally at drivers' homes and workplaces. These offer the most economic solution as they are less expensive than public charge points and are likely to benefit from higher utilisation rates.

6 Impacts on urban air quality

6.1 Overall approach

An analysis of the impact electric vehicles could have on urban air quality using detailed emissions/atmospheric dispersion models is outside the scope of this project. The approach taken in this study involves providing an assessment of the potential of EVs to reduce total annual emissions of certain pollutants, which gives a high-level assessment of the potential impact of EVs.

The pollutants considered are: carbon monoxide (CO), nitrogen oxide (NO_x), sulphur dioxide (SO₂), volatile organic compounds (VOC) and particulate matter below 10µm (PM10). These pollutants are of particular interest because of their effect on human health (CO, VOC, and PM10 in particular) and the environment (acid rain from NO_x and SO₂). Details of the methodology followed are given in section 12.3.

6.2 Results

6.2.1 Emissions from road transport

The following graph shows the emissions from road transport as a proportion of total emissions (of each pollutant species) for the cities of interest.

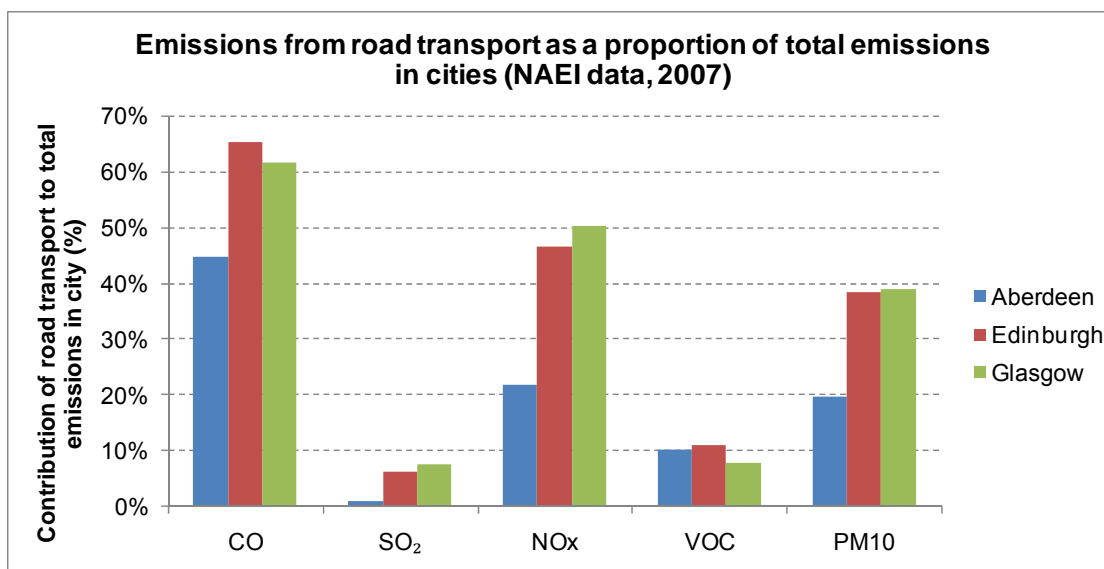


Figure 16: Contribution of road transport to total emissions in selected Scottish cities in 2007

Other major sources of pollution include: energy production, combustion (commercial, residential, industrial), industrial processes, solvent use, waste treatment and disposal, agriculture, nature, and any large point sources.

In order to understand the potential effects of replacing ICE cars with EVs a further breakdown of these figures is required to find the contribution that cars make to total emissions.

6.2.2 Emissions from cars

An estimation of the contribution that cars make to total emissions was made based on specific pollutant emissions and traffic flow data (see section 12.3). The results are shown below.

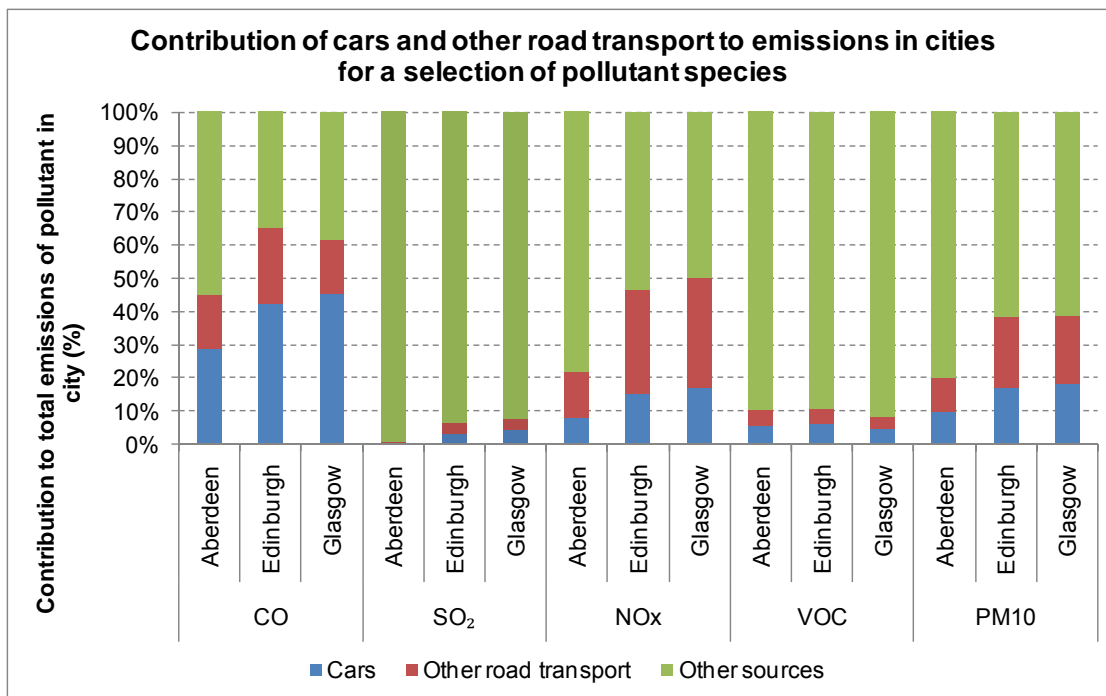


Figure 17: Contribution of cars and road transport to total emissions in selected Scottish cities

These results suggest that cars are responsible for up to around 45% of pollutant emissions in the cities of interest, depending on pollutant species.

6.2.3 Effect of EVs on pollutant emissions

To determine how emissions will change as a result of BEVs and PHEVs the contribution of each car type to the total car km in each city must be calculated. Whilst BEVs always have zero emissions at point of use, emissions from PHEVs depend on the propulsion method in use (i.e. electric or ICE mode). An assessment of the proportion of PHEV mileage in electric mode in the cities in question exceeds the available data. The approach taken therefore considers two cases: one in which all the distance driven by PHEVs is done in electric mode and one in which 68% is done in electric mode (based on the method outlined in section 12.2.3, which shows that 68% of total mileage could be done in electric mode for series PHEVs that are recharged overnight).

The results presented in this section relate to the Stretch: traffic growth scenario and therefore give an indication of the maximum potential impact of EVs on pollutant emissions. The following graph shows the proportion of car-km driven in each city by vehicle type (and propulsion mode) in 2020 and 2030 under the Stretch: traffic growth scenario for both cases described above.

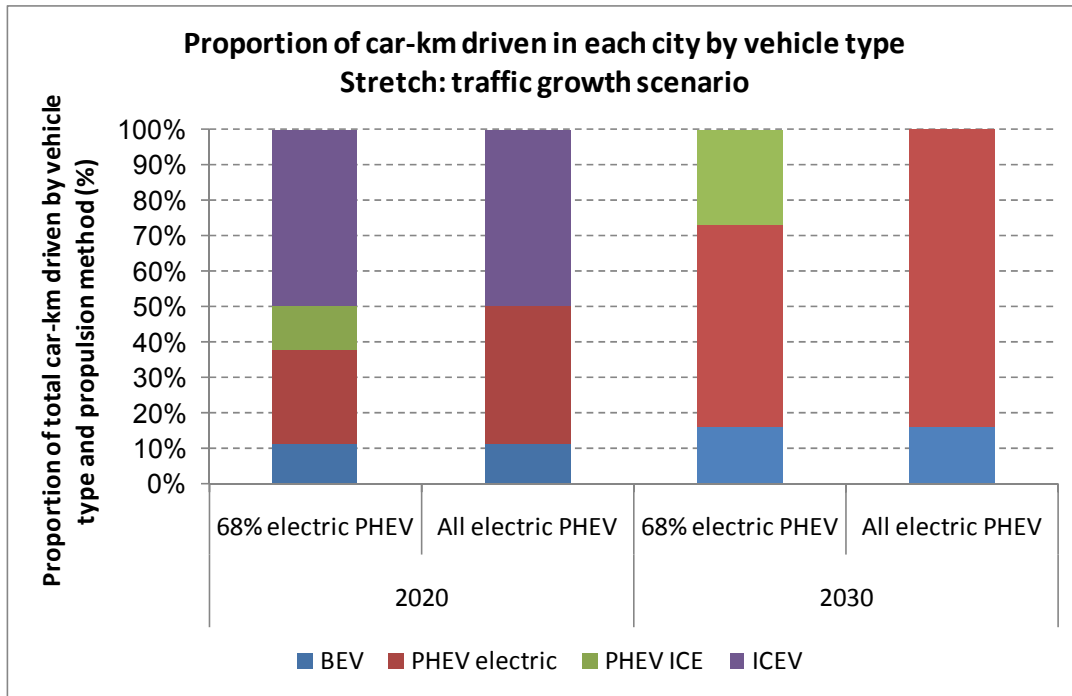


Figure 18: Car-km driven in cities by vehicle type and propulsion method

The impact of the shift towards EVs illustrated above in terms of change in total emissions is shown in the following graphs. In each case, the percentage figure illustrates the emissions as a proportion of total emissions in the cities with no EVs on the road.

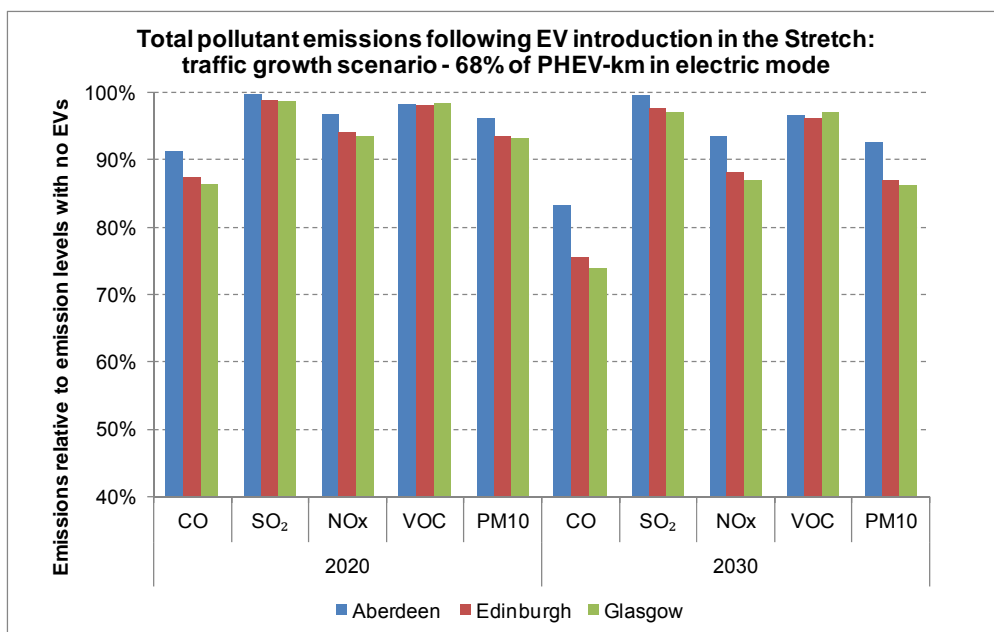


Figure 19: Change in pollutant emissions in cities as a result of EV uptake under the Stretch: traffic growth scenario with 68% of PHEV-km in electric mode

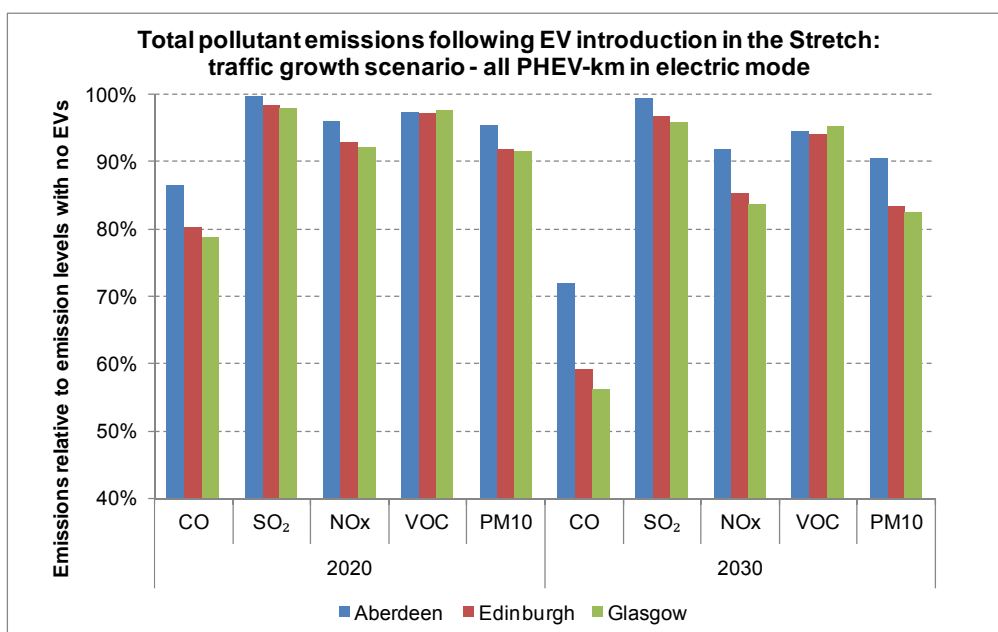


Figure 20: Change in pollutant emissions in cities as a result of EV uptake under the Stretch: traffic growth scenario with 100% of PHEV-km in electric mode

These results are consistent with the data shown in Figure 17, which showed that cars are responsible for a relatively low proportion of total emissions for most pollutant species. The data plotted in the graphs above suggest that switching to electric vehicles would have the greatest impact on carbon monoxide emissions in cities. However, for significant reductions in

emissions of pollutants such as NOx and PM10, efforts should be made to reduce emissions from other (larger) vehicles.³⁷

Although EVs offer relatively limited potential to reduce overall emissions of key pollutants in cities, replacing ICE cars with EVs has a positive effect in terms of noise pollution. Furthermore, it should be noted that this analysis considered pollutant emissions at the city-level. The benefits of switching to EVs on pollutant concentrations at a local level (at street level along busy roads for example) are likely to be considerably greater.

Key Points

- Cars are responsible for a relatively low proportion of total pollutant emissions in Aberdeen, Edinburgh and Glasgow for most pollutant species. This analysis suggests that cars account for c.10% or less of SO₂ and VOC emissions, 10–20% of PM10 and NOx emissions and up to around 30–45% of CO emissions.
- Substitution of ICE cars for EVs is therefore expected to have a relatively limited effect in terms of reducing emissions in cities. However, the benefit of EVs in terms of improved urban air quality may be important in areas that are at the margins of air quality management designation.
- EVs could have a greater benefit on local air quality in terms of pollutant concentrations but analysis to this level of detail was outside the scope of this study.

³⁷ For example, HGVs may be responsible for around half of all PM10 pollution in urban environments: www.eeb.org/activities/air/.../EUROVI_EEB_position_May_08.pdf.

7 Electricity demand and renewable electricity generation implications

7.1 Introduction

When it comes to the electricity grid, EVs offer challenges and opportunities. For example, EVs place additional demands on the grid and significant EV uptake could exacerbate the current spikes in electricity demand (e.g. adding to the evening peak). However, EVs could have a positive impact by providing demand at times where overall electricity demand is low (e.g. through controlled charging). This could be particularly beneficial in the future as more renewables come on to the grid since the outputs from renewables are typically less controllable than traditional thermal plant (e.g. wind turbines give greatest output at times of high wind speed and wind speeds are typically higher at night).

This section considers the additional electricity demands arising from the levels of EV uptake associated with each scenario and the extent to which this additional demand could be met by electricity from renewables. The total energy storage capacity of EVs is also considered.

7.2 Future electricity production in Scotland

The WWF Scotland report *The Power of Scotland Renewed* shows that total electricity demand in Scotland is expected to be around 33,600 GWh³⁸ in 2020 and 31,100 GWh in 2030.³⁹ These figures are used to contextualise the additional demands from EVs in the following section.

7.3 Impacts of electric vehicles

7.3.1 Additional electricity demand

Additional electricity demands due to EVs in 2020 and 2030 are calculated from the total car-km travelled in electric mode and the overall vehicle efficiency (including charging efficiency).⁴⁰ These demands are presented in the table below.

Table 11: Additional electricity demands from EVs under each scenario⁴¹

Scenario	Year	Total electricity demands of EVs in stock (GWh/yr)	Percent of total Scottish electricity demand
----------	------	--	--

³⁸ This figure compares to a total electricity demand figure of 43,935 GWh presented in the Scottish Energy Study Volume 5. See <http://www.scotland.gov.uk/Resource/Doc/245369/0069126.pdf> for this report. This figure does not include an equivalent level of demand reduction to that applied to the Power of Scotland Renewed report.

³⁹ See http://assets.wwf.org.uk/downloads/powerofscotland_renewed.pdf for the full report. These figures are based on achieving a 20% reduction in demand by 2020 and 26% by 2030.

⁴⁰ See section 11.3 for full details of technical assumptions.

⁴¹ Values for the BAU and Upper scenarios correspond to the traffic growth future and therefore represent the upper bound.

BAU	2020	31.5	0.09%
	2030	294	0.94%
Upper	2020	138	0.41%
	2030	1,100	3.53%
Stretch: stabilisation	2020	297	0.88%
	2030	1,706	5.4%
Stretch: growth	2020	2,315	6.8%
	2030	3,798	12.2%

EV uptake levels in the BAU and Upper scenarios lead to small increases in annual electricity demands, with an increase of c.3.53% by 2030 under the Upper scenario. Under the stretch: traffic growth scenario the additional electricity generation required is 12%.

7.3.2 Storage capacity offered

A potential benefit of plug-in vehicles purported by some is the concept of ‘vehicle-to-grid’ (V2G). This involves communication between plug-in vehicles and the electricity grid such that EVs can be used to aid in load balancing (‘valley filling’ and ‘peak shaving’). Vehicle-to-grid has a potential role in stabilising the intermittency of renewables such as wind power by providing a storage medium for times of high generation (if generation exceeds demand) and feeding power back to grid during periods of high demand.

The following table shows the total storage capacity of all plug-in vehicles in the Scottish car parc under each scenario.

Table 12: Total technical storage capacity of all EVs in Scotland under each scenario

Scenario	Year	Total electricity storage capacity of EVs (GWh)
BAU	2020	0.3
	2030	2.2
Upper	2020	2.4
	2030	10.3
Stretch: traffic stabilisation	2020	5.7
	2030	19.5
Stretch: traffic growth	2020	22.7
	2030	32.1

Ben Cruachan is the largest pumped water storage facility in Scotland, giving approximately 9GWh of storage capacity.⁴² The theoretical storage capacity of EVs is over double the storage capacity of Ben Cruachan in 2030 in the Stretch: traffic stabilisation scenario. Table 12 shows the maximum technical storage capacity of all EVs in the stock. However, the useful

⁴² This hydroelectric power station is used to meet peak demands and can provide 440MW for up to 20 hours. See <http://www.spenergywholesale.com/userfiles/file/CruachanSite.pdf>.

storage potential in any V2G application would be significantly lower since at any point in time some EVs will not be grid-connected and those that are will be at various states of charge.

Many other issues must be considered and resolved before V2G becomes viable. For example EV owners (and vehicle manufacturers) could have concerns over the impact of V2G on battery charge cycling and hence battery life. There are also numerous technical and commercial issues to be addressed, however a detailed discussion of the challenges facing V2G is outside the scope of this work.⁴³

Key Points

- Additional electricity demand from EVs has been estimated at c.1,100GWh/yr by 2030 under the Upper scenario. This corresponds to around 3.5% of the total anticipated annual electricity demand in Scotland.
- The maximum increase in electricity demand occurs under the Stretch: traffic growth scenario and equates to around 12% of total annual electricity demand in Scotland by 2030.

⁴³ For further details of V2G technology and on-going research in this area see <http://www.udel.edu/V2G/index.html>.

8 Market incentivisation and support policies

8.1 Overview of policy options

Electric vehicle uptake may be supported by one or a number of a large range of different policies. Some of the principal policy options are summarised in the table below.

Table 13: Summary of policies and approaches to support EV uptake

Incentive	Benefit	Description
Capital grant	Reduced capital cost	Grants offered to EV purchasers to offset the additional capital cost relative to other vehicle choices
Loans	Reduced capital cost	Low interest or interest free loans offer another method of offsetting the high capital costs of EVs
R&D investment	Reduced capital cost	Government investment in R&D programmes can accelerate technology development, which can lead to cost reductions (e.g. advances in battery technology leading to lower specific battery costs (£/kWh))
Tax rebates	Reduced capital cost	Reducing or waiving VAT on new car purchases is another potential means of reducing capital costs for consumers. A similar approach has been taken in Denmark where EVs are tax-exempt until 2012 (avoiding the 180% new car tax)
Fuel duty escalators	Reduced relative running costs	Increasing fuel duty for fossil fuel powered vehicles improves the economic case of EVs when on-going costs are considered Rising fuel prices can have a similar effect
Carbon taxes	Reduced relative running costs	Taxes on carbon emissions may be implemented via a variety of mechanisms, e.g. taxes on new cars can be set according to emission characteristics, or road tax can be charged according to specific CO ₂ emissions (as is the case in the UK for cars registered after 01/03/01, with bands A-M costing £0-£405/yr)
Legislation	Improved consumer choice and technology familiarity	Legislation can be used to force manufacturers to produce low carbon vehicles in general or EVs in particular (e.g. EU directive on fleet average emissions of new cars to 2020 – see section 11.3.2)
Dedicated / free parking	Additional incentive, reduced relative running costs	Dedicated EV parking spaces and ‘free’ parking opportunities are valuable to drivers, especially in areas with limited and/or expensive parking facilities
Derogation of congestion charges	Reduced relative running costs	EV drivers can be given exemption from congestion charges in cities with such a scheme in place
Demonstration projects	Improved consumer confidence	EV trials can be used to demonstrate technology (both vehicles and charging infrastructure), thus increasing the profile of EVs and confidence in the technology

8.2 Scenario-specific support policies

This section presents a qualitative description of the policies that may be required to support EV uptake in each scenario. No uptake model was used in this project and a quantitative assessment of policies required is outside the scope of this work.

8.2.1 Business as usual

The BAU scenario represents estimated EV uptake levels resulting from existing and announced policies. These include:

- A fund of £230m to provide capital grants of up to £5,000 per car for electric vehicles sold in the UK from 2011.
- Electric vehicles exempt from purchase and annual vehicle taxes (VED).
- Subsidised or free parking in certain inner city areas.
- Congestion charge derogation (where such charges exist).

Electric vehicle uptake also relies on gradual reductions in battery costs over time such that whole-life cost parity with conventional cars is achieved by around 2020.⁴⁴

8.2.2 Upper

This scenario is based on the 'High-Range' scenario defined in the Arup / Cenex study. In addition to the support policies described above, more rapid battery cost reductions are required under this scenario to allow the whole-life cost EVs to be competitive with traditional cars by 2015. This scenario requires strong signals to be sent to car manufacturers that will act as incentives for the development and mass production of EVs. As noted in the Arup / Cenex study, manufacturers will need to 'see a clear vision for both the UK and Europe' since no volume manufacturer will produce EVs for the UK market alone.⁴⁵

8.2.3 Stretch scenarios

The Stretch scenarios defined in this study are driven by ambitious CO₂ emission reduction targets for 2020 and 2030. EV uptake levels under these scenarios are likely to occur only with extremely high levels of support for the technology and a seismic shift in consumer attitudes and purchasing behaviour. The Stretch: traffic stabilisation scenario requires EVs to account for around 10% of new car sales by 2015 and 20% by 2020. Whilst challenging, this could potentially be realised given sufficiently high and sustained levels of support for EVs over the coming years (a combination of the support measures outlined in Table 13 would be required).

The Stretch: traffic growth scenario, however, would require EVs to represent 55% of new car sales by 2015 and 100% by 2020. This translates into new EV sales of over 130,000 and 260,000 in 2015 and 2020 respectively, leading to a total of over 1.5m EVs in the stock by 2020. Given the relative immaturity of the industry (at least in terms of mass market production), this scenario is likely to be constrained by supply considerations.

⁴⁴ *Investigation into the Scope for the Transport Sector to Switch to Electric Vehicles and Plug-in Hybrid Vehicles*, Arup / Cenex, p.5 (October 2008).

⁴⁵ Arup / Cenex, p.10 (October 2008).

9 Appendix A: overview of data sources

9.1 National Travel Survey

The National Travel Survey (NTS) has been run continuously in Great Britain since July 1988, following ad hoc surveys conducted since the 1960s. The NTS is designed to monitor long-term trends in travel patterns and provides detailed information on households, vehicles owned by participating households, individuals, and trips undertaken by all participants.

Aspects of this work relied on analysis of Scotland specific data from the survey. Full details of the survey can be found in technical reports published on the Department for Transport website:

<http://www.dft.gov.uk/pgr/statistics/datatablespublications/personal/methodology/ntstechreports/>

9.2 Scottish Household Survey

The Scottish Household Survey (SHS) was commissioned in 1998 by the Scottish Office Development Department as a new survey to give Scotland specific information using a large sample size. The data is collected continuously with 3,900 households being surveyed each quarter. The SHS provides the Scottish government with detailed up-to-date information in a large range of areas including Social Justice, Transport and Housing to help ministers form new policy measures and assess the impact of existing policies.

More information on the SHS can be found at:

<http://www.scotland.gov.uk/Topics/Statistics/16002>

9.3 National Atmospheric Emissions Inventory

The National Atmospheric Emissions Inventory (NAEI) compiles estimates of atmospheric emissions by different sources. The NAEI provides estimates for different pollutant and greenhouse gas species by UK regions. They also provide 1x1km emissions data for different UK regions. The NAEI is funded by Defra, the National Assembly for Wales, the Scottish Government and the Department for the Environment, Northern Ireland. The emissions estimates produced are used to find ways of reducing the impact of human activities on the environment and human health.

<http://www.naei.org.uk/>

9.4 UK Air Quality Archive

The Air Quality Archive collects data on pollutant emissions from monitoring sites around the UK. Local councils must collect information on urban air quality and create development plans to reduce the emissions to within EU limits. To this end the local councils for Glasgow, Edinburgh and Aberdeen produce reports on air quality in the cities that is more detailed (includes more monitoring sites) than the UK Air Quality Archive reports.

<http://www.airquality.co.uk/>

http://www.edinburgh.gov.uk/internet/Environment/Environmental_health/Pollution/Air_pollution/CEC_air_quality

http://www.aberdeencity.gov.uk/Pollution/nc_pol/pol_air_poll.asp

<http://www.glasgow.gov.uk/en/Residents/Environment/Pollution/Air/LocalAirQualityManagement.htm>

9.5 The Climate Change Delivery Plan

The Climate Change Delivery Plan (CCDP) is a Scottish government publication which sets out the high level measures that are necessary for each sector to meet the Scottish climate change targets for 2020. The CCDP assesses the policies and measures needed in each sector to achieve an overall reduction in emissions of 42% by 2020 from 1990 levels.

<http://www.scotland.gov.uk/Publications/2009/06/18103720/0>

9.6 Committee on Climate Change

The Committee on Climate Change (CCC) was established under the Climate Change Act as an independent body to advise the UK government on setting carbon budgets and to report to Parliament on the current progress in reducing green house gas emissions. The CCC produces reports and target based (target driven) emissions projections across all sectors that emit greenhouse gases.

<http://www.theccc.org.uk/>

9.7 Land Use and Transport Integration in Scotland

The Land-Use and Transport Integration in Scotland (LATIS) toolkit is a combination of two models that interact with one another: The Transport Model for Scotland (TMfS) and the Transport, Economic and Land-use Model of Scotland (TELMoS). The TMfS is a multi modal transport demand and assignment model that interacts with the TELMoS model to give traffic predictions for Scotland. One output from the model is the vehicle (and car) km travelled in a given year.

<http://www.latis.org.uk/index.html>

9.8 Arup / Cenex report for DfT and BERR: Investigation into the scope for the transport sector to switch to EV and PHEVs

This report was commissioned to provide an improved understanding of the potential of EVs and PHEVs to reduce the long term UK CO₂ emissions. Focusing on the car and light vehicle market, this study examined a number of factors which influence the uptake and development of EVs. The study found that EV uptake in the short to medium term will be centred on urban environments and will start with city markets. PHEV penetration in the medium to long term will be greater due to increased vehicle flexibility.

www.berr.gov.uk/files/file48653.pdf

10 Appendix B: CO₂ saving in non-road transport sectors

Whilst cars are responsible for the majority of CO₂ emissions from road transport emissions in Scotland, there are a number of other large contributors, as shown in Figure 21.

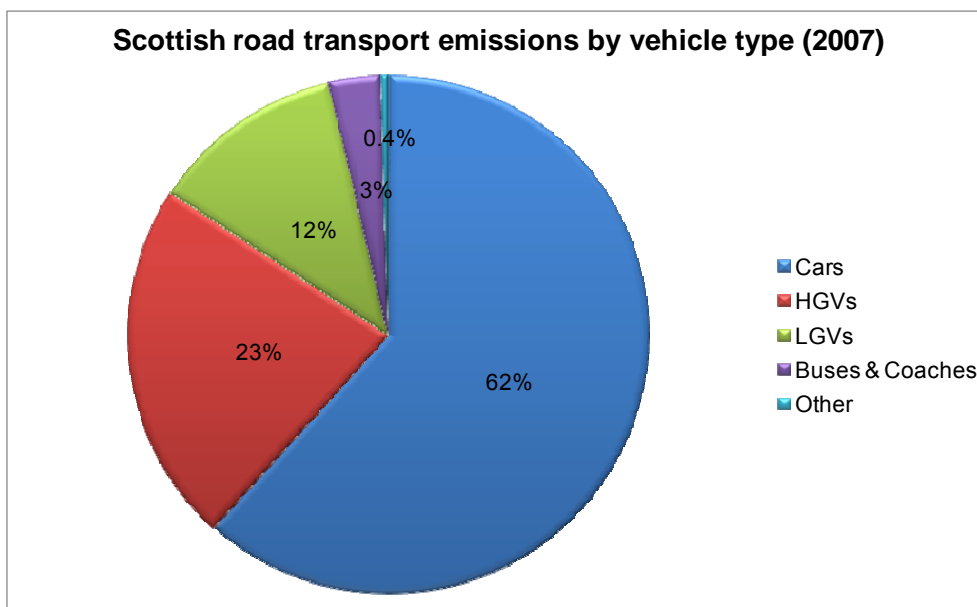


Figure 21: Road transport emissions in Scotland by vehicle type (2007)

To meet the emissions reduction targets in the Stretch scenarios, road transport must deliver a 43% saving by 2020 (see section 11.1.1). This work considers the passenger car market only and an implicit assumption is that the non-passenger car sectors of road transport will make a contribution to this target in proportion to their emissions, i.e. a 43% saving must be delivered across all road transport. This section considers the opportunities for reducing emissions in other road transport sectors.

10.1 Common improvement approaches

Many of the approaches to improving the fuel efficiency of cars discussed in section 2.3 are also applicable to other vehicle types. These include:

- Modal shift
- Improved aerodynamics
- Improved tyres
- Biofuels
- Gear shift indicators
- Regenerative braking
- Stop-start and hybrid technology

The following section presents a discussion of issues that pertain to specific vehicle types within the road transport sector.

10.2 Vehicle-specific considerations

10.2.1 Heavy goods vehicles

Heavy goods vehicles (HGVs) were responsible for 23% of CO₂ emission from the road transport sector in Scotland in 2007 (see section 3.1). High specific energy demands (kWh/km) and long range requirements make HGVs fundamentally ill suited to electric vehicle technology. The batteries required for an electrically powered HGV with a useful range would be unfeasibly large and heavy. This means that a change in powertrain technology in HGVs requires an alternative technology with a higher specific fuel energy density (kWh/kg). Hydrogen fuel cells offer potential in this area, however the commercialisation of this technology is yet to be realised.

Non-technological approaches to reducing emissions from HGVs include strategic planning to reduce the distances that goods are transported and a shift of freight from road to rail transport.

10.2.2 Light goods vehicles

Light goods vehicles (LGVs) cover vehicles in the range from 3.5–7.5 tonnes and contributed 12% of total CO₂ emissions from road transport in Scotland in 2007. As with HGVs, the opportunities for BEV technology in this sector are relatively limited due to the energy demands of the vehicles and typical drive cycles. However, hybrid technologies can be applied in the larger vehicle sector, for example with diesel hybrid electric powertrains. This technology can be used to significantly improve the efficiency of the diesel ICE by running the engine at its optimal efficiency point to drive a generator and using an electric motor to provide power to the wheels.⁴⁶

While the opportunities for reducing emissions from larger vehicles (LGVs, HGVs etc) may be more limited than for cars, one potentially important advantage in these sectors is the fact that the vehicles are typically owned and operated by commercial organisations. Companies are typically more economically rational than individuals in that they can take a longer-term view and are more likely to value on-going savings when considering capital expenditure.

10.2.3 Buses and coaches

Being responsible for around 3% of road transport CO₂ emissions in Scotland in 2007, buses and coaches are the lowest overall polluters of all the large vehicle sectors. However, diesel fuelled buses in cities are a major contributor to particulate and NO_x emissions, which provides further incentive to seek alternative fuels. There is much on-going work in the area of hydrogen fuel cell buses and the UK is heavily involved, with hydrogen buses trialled in London as part of the CUTE (Clean Urban Transport for Europe) programme.⁴⁷

⁴⁶ Eaton provides one example of a company working on hybrid power solutions for the non passenger car market. www.eaton.com/EatonCom/ProductsServices/Hybrid/index.htm.

⁴⁷ For further details of other hydrogen bus trials see: www.netinform.net/H2/H2Mobility/H2MobilityStart.aspx?CATID=2.

11 Appendix C: key assumptions

11.1 CO₂ savings

11.1.1 Target CO₂ saving in 2020 and 2030 for Stretch scenario

The Stretch scenarios are designed to meet a specific CO₂ reduction target, which was derived based on emission reduction targets set out in Scotland's Climate Change Delivery Plan (CCDP).⁴⁸ The CCDP sets a target CO₂ saving of 27% by 2020 for transport relative to 1990 emission levels. No specific targets for each component of the transport sector (road, rail, shipping etc) have been set, which means the only clear target is a 27% reduction in emissions overall from transport by 2020.⁴⁹ Nevertheless, it is recognised that road transport will have to make the largest contribution towards meeting this target (see for example the recent CCC report).⁵⁰ Therefore, for the purposes of this study the Stretch ambition scenario is designed such that emissions reductions from road transport are sufficient for the transport sector as a whole to meet the 27% target (i.e. with no savings coming from the other sub-sectors within transport). This approach therefore represents the most ambitious in terms of the levels of carbon saving that may be required from road transport.

Road transport is further sub-divided by vehicle type (motorcycles, passenger cars, LGVs, HGVs, buses etc). The focus of this study is on the passenger car market and for the purposes of this work it is assumed that each of the sub-sectors within road transport makes a CO₂ saving in proportion to their contribution to total emissions.

The target setting for 2020 is summarised in the following figure.

⁴⁸ The CCDP sets out high level measures required in each sector to meet Scotland's statutory emissions targets (which in turn are set out in the Climate Change (Scotland) Bill. See: <http://www.scotland.gov.uk/Publications/2009/06/18103720/0>

⁴⁹ CCDP, Chapter 2, Table 1.

⁵⁰ *Meeting Carbon Budgets – the need for a step change*, p.189, Committee on Climate Change (October 2009).

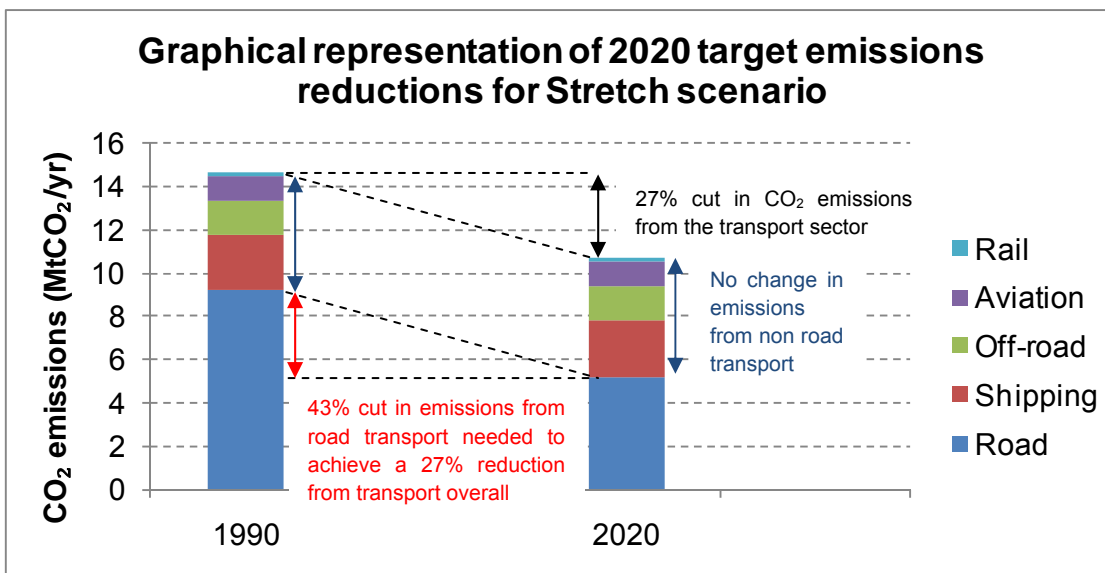


Figure 22: CO₂ reduction target in 2020 for Stretch scenarios (all reductions relative to 1990 emission levels)

Achieving a 27% emissions cut for transport from savings in road transport only requires a 43% reduction in emissions from road transport. This figure sets the 2020 target for CO₂ emission reductions from cars in the Stretch scenario. Looking further ahead, 2030 targets are currently less well defined. For demonstration purposes only a target of a 70% reduction in road transport emissions by 2030 relative to 1990 levels has been assumed.

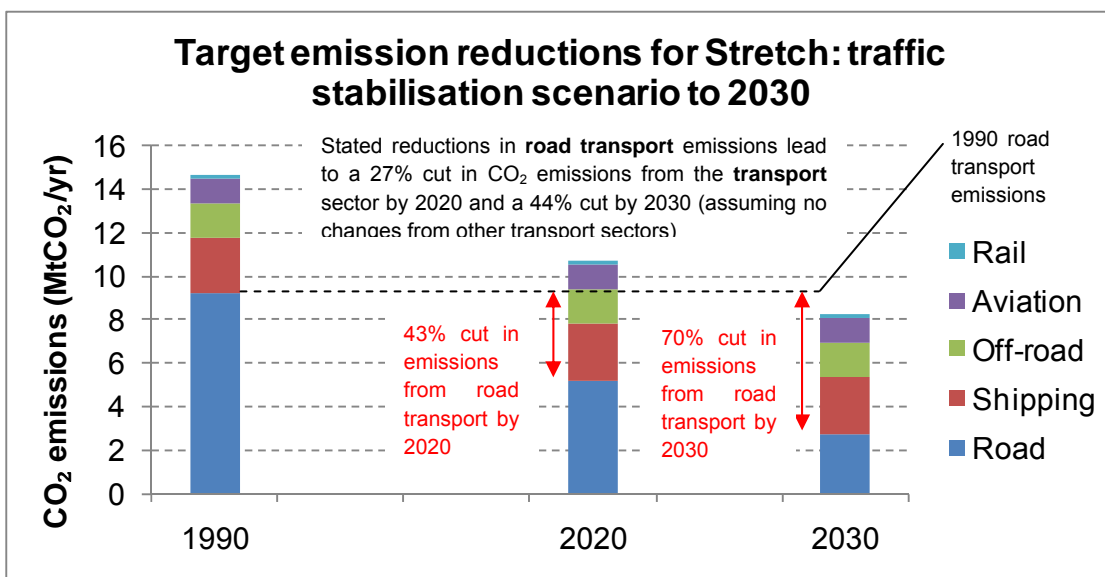


Figure 23: CO₂ reduction targets in 2020 and 2030 for Stretch: traffic stabilisation scenario (all reductions relative to 1990 emission levels)

11.1.2 Electric vehicles’ contribution to meeting the targets

A range of measures exists for reducing carbon emissions in the transport sector and many CO₂ reduction strategies will have to be employed in parallel to meet these ambitious targets. The contribution of non-drivetrain technology measures towards the carbon saving targets are summarised in the following table.

Table 14: CO₂ savings from non-drivetrain technologies

Data source ⁵¹	Source of improvement	Relevant data	Percentage improvement on baseline value
TRS	Baseline 2022	Emissions: 11.7MtCO ₂	-
TRS	Active traffic management	0.02MtCO ₂ reduction in 2020	0.2%
TRS	Speed reduction (to 60mph on trunk roads)	0.18–0.3MtCO ₂ reduction in 2020	1.5–2.5%
CCDP	Bio fuels	8% by energy in 2020	5%
CCDP	Eco driving	40% of drivers achieve a 10% improvement in 2020	4%
Total reduction relative to 2020 baseline emissions			11%

Given a lack of data on target figures for these measures by 2030, this 11% reduction has been used for both 2020 and 2030. It is appreciated that eco driving offers further scope for improvement by 2030, however in the absence of further evidence or predictions, no further uptake of eco driving has been assumed from 2020 to 2030. According to the King Review the level of sustainable bio fuels in the 2020 target cannot at present be improved upon.⁵²

For an overall saving of 43% from passenger cars, with 11% coming from the non-drivetrain measures summarised above, 32% must come from changes in demand for car travel and drivetrain technology, which includes a switch to electric vehicles.

In addition to the sources of improvement summarised in Table 14, CO₂ savings are expected from advances in efficiency of internal combustion engine vehicles. These improvements will be mainly driven by new EC regulation which sets limits to the new car fleet average specific CO₂ emissions in the period to 2020.⁵³ Details of the assumptions made regarding ICE vehicle efficiency improvements are given in section 11.3.

The following table summarises the 1990 emission levels and absolute saving required from the passenger car sector to meet the 2020 target.

⁵¹ TRS is Transport Research Series: Mitigating Transport’s Climate Change Impact in Scotland. CCDP is Scotland’s Climate Change Delivery Plan.

⁵² http://www.hm-treasury.gov.uk/king_review_index.htm.

⁵³ Regulation (EC) number 443/2009: *setting emission performance standards for new passenger cars as part of the Community’s integrated approach to reduce CO₂ emissions from light-duty vehicles.*

Table 15: Road transport and car emissions in 1990 and 2020 target

Description	Value (MtCO ₂ /yr)
Total emissions from road transport in 1990	9.20
Total emissions from cars in 1990	5.70
Total saving from car-sector to meet 2020 target of 43% saving from 1990 car emission levels (27% saving from transport overall)	2.45

Table 16: Contribution required from EVs towards meeting the 2020 target in the traffic stabilisation scenario⁵⁴

Measure	CO ₂ saving relative to 1990 emission levels in 2020 (MtCO ₂ /yr)	% saving relative to 1990 emission levels (in 2020)
Change in total car-km and gCO ₂ /km for ICEVs	1.87	32.9%
Non-drivetrain improvements	0.42	7.4%
Saving from change in car-km, gCO ₂ /km and non-drivetrain improvements	2.30	40.3%
Saving from BEVs & PHEVs required	0.16	2.7%

Table 17: Contribution required from EVs towards meeting the 2020 target in growth scenario⁵⁵

Measure	CO ₂ saving relative to 1990 emission levels in 2020 (MtCO ₂ /yr)	% saving relative to 1990 emission levels (in 2020)
Change in total car-km and gCO ₂ /km for ICEVs	0.71	12%
Non-drivetrain improvements	0.55	10%
Saving from change in car-km, gCO ₂ /km and non-drivetrain improvements	1.26	22%
Saving from BEVs & PHEVs required	1.19	21%

⁵⁴ Traffic stabilisation scenario: total car-km in 2020 are set to 2001 levels (31.9bn car-km), i.e. Scottish target of curbing demand for car use is met.

⁵⁵ Traffic growth scenario: the total car-km figure in 2020 grows to 42.5bn car-km (from LATIS model).

11.2 Forecast carbon intensity of grid electricity

The carbon impact of EVs is a function of the carbon intensity of the electricity used to recharge their batteries. A pertinent and recent study into the future grid intensity of electricity in Scotland was conducted by Wood Mackensie.⁵⁶ This work considered the future generation mix (and therefore grid carbon intensity) for electricity production in Scotland, taking into account the targets for 50% of electricity to come from renewable sources by 2020. The Wood Mackensie work considered the period to 2020 only and gave a carbon intensity figure for electricity for this date. A lack of Scotland-specific data regarding the carbon intensity of grid electricity in 2030 has led to a UK value from the recent CCC report being used.⁵⁷ Given the relatively high levels of renewable resources in Scotland, and the Scottish government’s commitment to decarbonise the power sector by 2030 the actual Scotland-specific figure for 2030 could be somewhat lower than this.

Table 18: Predicted carbon intensity of grid electricity in Scotland

	Year			Notes / data source
	2006	2020	2030	
Average carbon intensity of grid electricity in Scotland (gCO ₂ /kWh)	429	193	80	Scotland-specific value for 2006 and 2020 taken from Wood Mackensie study. The 2030 figure is taken from CCC projections for the UK (no Scotland-specific data were available for this study).

These figures represent average grid CO₂ intensity over the year. In practice the carbon intensity of grid electricity varies between seasons and throughout the day (as different generation plant is brought online at different times to meet constantly changing demands). A detailed analysis of the effect of the timing of charging EVs on CO₂ emissions was not possible in this study due to a lack of data. However, analysis at the UK level in a previous study showed that in an uncontrolled charging regime demand for EV recharging tends to coincide with the evening peak electricity demand.⁵⁸ This work also explored the potential benefits of delaying the demand for electricity for EV recharging in terms of reducing the in-use CO₂ emissions of EVs.

⁵⁶ *The future of electricity generation in Scotland*, Wood Mackensie (December 2008).

⁵⁷ *Meeting Carbon Budgets – the need for a step change*, p.107, Committee on Climate Change (October 2009).

⁵⁸ *Strategies for the uptake of electric vehicles and associated infrastructure implications*, Element Energy for the CCC, p.63–65, (October 2009).

11.3 Technical characteristics of vehicles

11.3.1 Technical data: summary

The key data relating to the technical characteristics of the vehicles considered in this study are summarised in the table below.

Table 19: Key technical assumptions

		Year			Notes / data source
		2006	2020	2030	
Technical range (km)	BEV	120	180	210	Values from UK MARKAL model. ⁵⁹ See also Table 20, below.
	PHEV	N/A	60	60	
Utilisation factor	BEV	25%	60%	75%	2006 figure based on survey of EV owners by Element Energy. No restrictions to using full PHEV electric range.
	PHEV	100%	100%	100%	
Utilised range in electric mode (km)	BEV	30	108	158	Calculated from technical range and utilisation factor.
	PHEV	N/A	60	60	
Charging efficiency (grid to battery)		85%	90%	90%	Typical value for 2006, with potential for improvement in future. ⁶⁰
Battery to wheel energy demands (kWh/km)	BEV	0.16	0.13	0.11	Data from Arup / Cenex study. ⁶¹
	PHEV	0.16	0.13	0.11	
Average emissions in electric mode (gCO ₂ /km)	BEV	81	28	18	Calculated based on kWh/km, charging efficiency and grid carbon intensity given in Table 18.
	PHEV	81	28	18	
Average PHEV emissions in non-electric mode (gCO ₂ /km)		130	100	95	Based on assumption that PHEVs will meet EU targets for new car emissions in non-electric mode.

⁵⁹ The MARKAL model was used as part of the analytical underpinning of the 2007 Energy White Paper. BEV technical range figures were taken from Table T5, p.10 of: www.ukerc.ac.uk/Downloads/PDF/07/0705MARKALChapters/0705%20MARKALdocCH8.pdf.

⁶⁰ See for example, Dynasty IT technical datasheet, which shows 5kWh required for a full charge of 4.26kWh (85.2% efficiency). www.itiselectric.com/images/sedan-specification.pdf. See also *On the road in 2020: a lifecycle analysis of new automobile technologies*, Weiss et al., MIT, p.3-17 (October 2000). An overall battery charging efficiency of 85% is assumed.

⁶¹ *Investigation into the Scope for the Transport Sector to Switch to Electric Vehicles and Plug-in Hybrid Vehicles*, Arup / Cenex (October 2008). www.berr.gov.uk/files/file48653.pdf.

Overall average PHEV emissions (gCO ₂ /km)	97	51	43	Based on emissions in electric and non-electric mode and proportion of distance covered in electric mode (see following section).
Fleet-average ICEV emissions (gCO ₂ /km)	180	107	85	2006 value calculated from total car-km (DfT data) and emissions from cars (NAEI data). 2020 value based on CCC figures and adjustments for non-drivetrain measures. 2030 value based on anticipated improvements in ICE technology (see below).

The energy demands of BEVs and PHEVs are from figures presented in the October 2008 Arup / Cenex report. The reductions over time reflect anticipated advances in battery and motor efficiencies, energy recovery and vehicle lightweighting. For a further discussion of these figures, see section 11.3.3.

11.3.2 Fleet average emissions from internal combustion engine passenger cars

The fleet average emission figure from all ICE cars in the stock in 2020 was based on data provided by the CCC, which predicts fleet average emissions in 2020 of around 120gCO₂/km. Adjusting this figure by 11% to take account of non-drivetrain measures (see Table 14) leads to the value in the table above. This figure takes into account EC regulation which sets maximum new car fleet average CO₂ emissions from 2012 to 2020. The effect of this regulation is summarised in the following figure. The figure has been adjusted to reflect the estimated savings from non-drivetrain technology discussed in section 11.1.

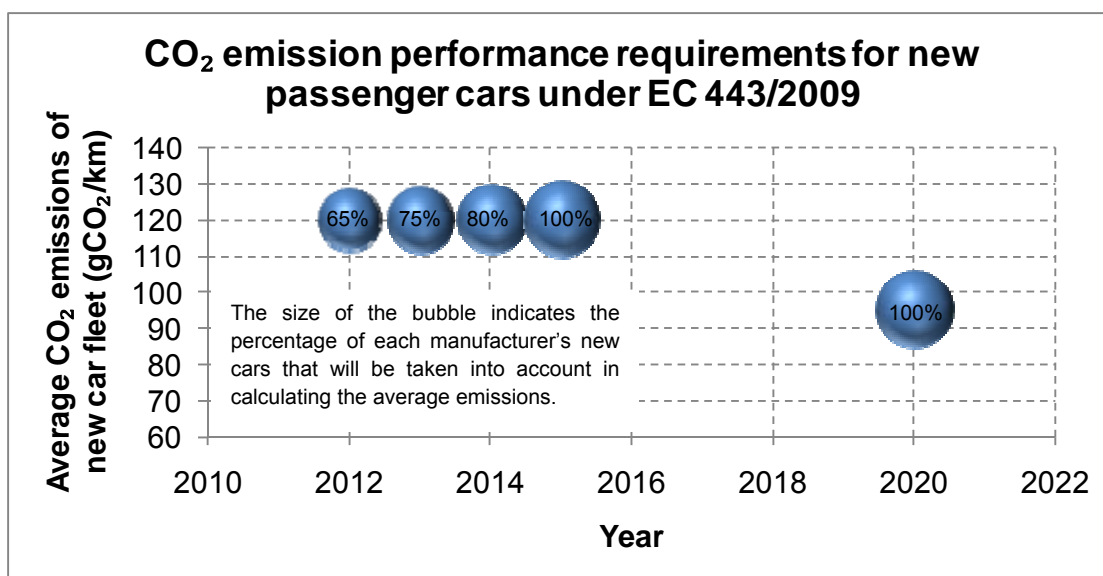


Figure 24: Summary of EC regulation to limit new car CO₂ emissions

At present there are no regulations prescribing how the new car fleet average CO₂ emission targets must be reached. A manufacturer could therefore offer a range of BEVs with average

specific CO₂ emissions well below the mandatory target along with ICE cars with emission levels above the target level. However, evidence that new ICE cars in 2020 could achieve emission levels that meet the 2020 new car standard of 95gCO₂/km comes from an MIT paper which analysed new car technologies in detail. In this paper, simulation test results suggest that average CO₂ emissions could be in the range 120–70gCO₂/km for new ICE cars in 2020.⁶² The higher figure corresponds to the 2020 ‘baseline’ (i.e. relatively modest improvements in technology that existed in the 1990s), while the lower figure is for an advanced hybrid compression ignition engine car, with lightweighting measures, lower drag coefficient, lower rolling resistance and technology such as continuously variable transmission.

This evidence suggests that even without BEVs or PHEVs, a target of 95gCO₂/km is achievable through improvements in ICE technology. For the purposes of this work, it is therefore assumed that by 2030 the fleet average emissions of all ICE cars in the stock reach 95gCO₂/km. This figure has been further adjusted to take into account non-drivetrain measures, which leads to the figure of 85gCO₂/km presented in Table 19.

11.3.3 Energy demands of electric vehicles

The key results of a review of claimed energy demands from electric vehicle manufacturers are summarised in the table below.

Table 20: Energy demands of EVs as claimed by car manufacturers⁶³

Vehicle name	Manufacturer	Type	Size	Range in electric mode (km)	Claimed kWh/km
G-Wiz	REVA	BEV	Micro car	120	0.12
Think	Think	BEV	Small car	200	0.20
Electric smart car	Daimler	BEV	Small car	110	0.12
Dynasty IT	Dynasty Electric Car	BEV	Small car	50	0.23
i MIEV	Mitsubishi	BEV	Small car	160	0.10
Ze-0 MPV	NICE	BEV	Small car	80	0.25
Mega city	NICE	BEV	Small car	100	0.12
Energy CS prius	Energy CS	PHEV	Medium car	80	0.05 (urban) 0.18 (highway)
Escape plug-in	Ford	PHEV	Medium car	32	0.21
Chevy volt E-rev	General Motors	PHEV	Medium car	65	0.25
Mini-e	BMW	BEV	Medium car	165 (normal)	0.20 (urban)

⁶² *On the road in 2020: a lifecycle analysis of new automobile technologies*, Weiss et al., MIT (October 2000). Table 3.4, p.3-24. Note, simulation results from this work were verified against a set of production and prototype vehicles that existed at the time (p.3-21).

⁶³ Data in part from *Sustainable Energy – without the hot air*, Chapter 20, p.137, Mackay (2008). www.withouthotair.com.

				250 (idealised)	0.23 (highway)
Ampera	Vauxhall	PHEV	Medium car	65	0.25
EV1	General Motors	BEV	Sports	120–240	0.11 (urban) 0.22 (highway)
Lightning	Lightning Car Company	BEV	Sports	300	0.11
Kangoo battery van	Renault	BEV	Van	100	0.17
Electricque 500E	Berlingo	BEV	Van	100	0.25
Phoenix SUV	Phoenix vehicles	BEV	SUV	160	0.22
RAV4 EV	Toyota	BEV	SUV	130–190	0.14–0.21

These figures should be regarded as lower bounds on EVs’ energy demands based on current technology. They apply under idealised driving cycles and it should be noted that actual demands are highly sensitive to driving conditions. For example, use of air conditioning, heaters and other electricity-consuming devices in the vehicle has a significant impact on overall kWh/km demand figures. The drive cycle (in terms of average and maximum speed and frequency of starts/stops) is also an important consideration. The following table summarises the results of real-world driving conditions for a selection of EVs.

Table 21: Energy consumption of EVs from empirical data

Vehicle	kWh/km in electric mode			Notes/ data source
	Best	Worst	Average	
G-Wiz	0.16	0.33	0.21	Figures include charging efficiency (electricity consumed measured at socket). Data from 19 charging events. http://withouthotair.blogspot.com/2008/07/performance-data-for-gwiz-in-london.html .
Berlingo electric van	No data	No data	0.45	Electric van trialled in Stockholm. Figure considered high relative to other studies. Main reason: high frequency of starts/stops. http://www.elcidis.org/elcidisfinal.pdf p.17.
Audi duo (A4-sized hybrid car)	0.13	0.70	0.36	From trail in Erlangen, Germany between 1999 and 2001. http://www.elcidis.org/elcidisfinal.pdf p.24.
Peugeot electric van	No data	1.20	0.20–0.35	From EV trail in Stavanger, Norway. http://www.elcidis.org/elcidisfinal.pdf p.32.
Mitsubishi i MIEV	No data	No data	0.17	Average data from a single test drive (urban driving conditions with heater on). For comparison, the claimed ‘idealised’ kWh/km value is 0.10. http://www.edmunds.com/insideline/do/Drives/FirstDrives/articleId=124867 .

12 Appendix D: methodologies

12.1 Sales and stock model

The results presented in section 4.2 were produced using a simple stock model which was developed purely to give an indication of sales required to meet the target uptake levels. This model included the assumption of a constant increase in total number of cars in the Scottish parc (see section 3.2.1), and a consistent assumption regarding the increase in annual sales over time. For transparency purposes all vehicles were assumed to have the same mean lifetime (ten years), and demolition of cars was based on the year in which they were sold and the mean lifetime (i.e. cars introduced into stock in one year are removed ten years later).

The target numbers of each vehicle type in the stock in 2020 and 2030 were defined by the scenarios. The sales required in any given year were found by assuming sales begin from 2011 and that the proportion of new car sales due to EVs increases linearly each year to the target year (2020). A similar approach was taken for finding the sales required in the second period (2020–2030), with a linear increase in percentage of sales due to EVs from 2021.

Sales and stock in the model were tracked according to the following formulae:

$$\begin{aligned} \text{New car sales} &= \text{Net new additions} + \text{Number of cars demolished} \\ \text{Net new additions} &= \text{No. of cars in stock at end of year} - \text{No. of cars in stock at end of previous year} \end{aligned}$$

12.2 Calculation of annual mileage of BEVs and PHEVs

12.2.1 Introduction

Compared to ICE vehicles, the equivalent CO₂ emissions from electric vehicles on a gCO₂/km basis are favourable due to the higher efficiency of the electric drivetrain. The following simple calculation demonstrates that even when EVs are recharged from grid electricity with relatively high carbon intensity, CO₂ reductions are possible.

Table 22: Calculation of specific CO₂ emissions of EVs

Parameter	Value
Typical BEV energy demand (battery to wheel) (kWh/km)	0.20
Typical recharging efficiency (grid electricity to battery)	85%
BEV energy demand (grid to wheel) (kWh/km) (From battery to wheel demand / recharging efficiency)	0.235
CO ₂ impact of BEV charged from grid electricity at 430gCO ₂ /kWh (gCO ₂ /km)	100 gCO ₂ /km = gCO ₂ /kWh x kWh/km

As Table 22 shows, the specific CO₂ emissions of an EV charged with electricity with a carbon intensity of 430gCO₂/kWh equate to around 100gCO₂/km. This is comparable with the most efficient new ICE cars, and significantly below the average new car emissions of 165gCO₂/km in 2007.⁶⁴

However, this improvement in specific emissions only translates into carbon savings in practice when electric vehicles are used in place of ICEVs. Plug-in hybrid electric vehicles can be considered a direct replacement for ICEVs due to the fact that they include a conventional internal combustion engine and fuel tank and thus do not suffer the same range restrictions as pure electric vehicles. BEVs on the other hand do have limited range and cannot therefore be used as a direct replacement for ICEVs.

12.2.2 Average annual mileage of BEVs

The calculation of expected average annual mileage of BEVs and PHEVs in electric mode was based on data from Scotland-specific results from the National Travel Survey.⁶⁵ A full set of survey results was obtained from the Department for Transport for the years 2004–2006. These data were filtered to retain only records relating to trips made by car for drivers living in Scotland (information concerning trips by other transport modes was not relevant for this analysis).⁶⁶

The NTS data include details of each trip made by each individual on each day of the travel diary week, including the distance of each trip made. A database of drivers was created from the data resulting from the filtering process described above. This database facilitated the calculation of outputs such as daily driving distance of each individual, number of days car was used out of the seven day travel diary week and maximum daily distance in the travel week.

Since BEVs have a relatively limited range compared to traditional vehicles, it is expected that they will be used most by low mileage drivers (i.e. those who rarely exceed the BEV's usable range). The useful BEV range is found from the technical range and the BEV utilisation ratio (see section 11.3). Given the assumption that BEVs will typically be used by low mileage drivers, it was necessary to create a sub-set of drivers whose driving patterns are well-suited to BEV use. This sub-set was defined as those individuals who did not exceed the BEV usable range on any day of the travel diary week.

The average daily distance of BEVs was calculated as the mean daily distance of the sub-set of low mileage drivers. This was converted into an average weekly distance by multiplying by the mean number of days per week that car trips were taken, and the estimated average annual distance per BEV was found by multiplying this figure by fifty-two.

The following figure shows the effect of increasing BEV usable range on mean annual distance per BEV, as calculated by the method described above.

⁶⁴ Source: <http://www.lowcvp.org.uk/news/866/bulletin/>.

⁶⁵ For further details of the NTS, see section 9.

⁶⁶ The variable p2g (Government Office Region) in the Primary Sampling Unit (psu) data set was used to filter out non-Scottish data.

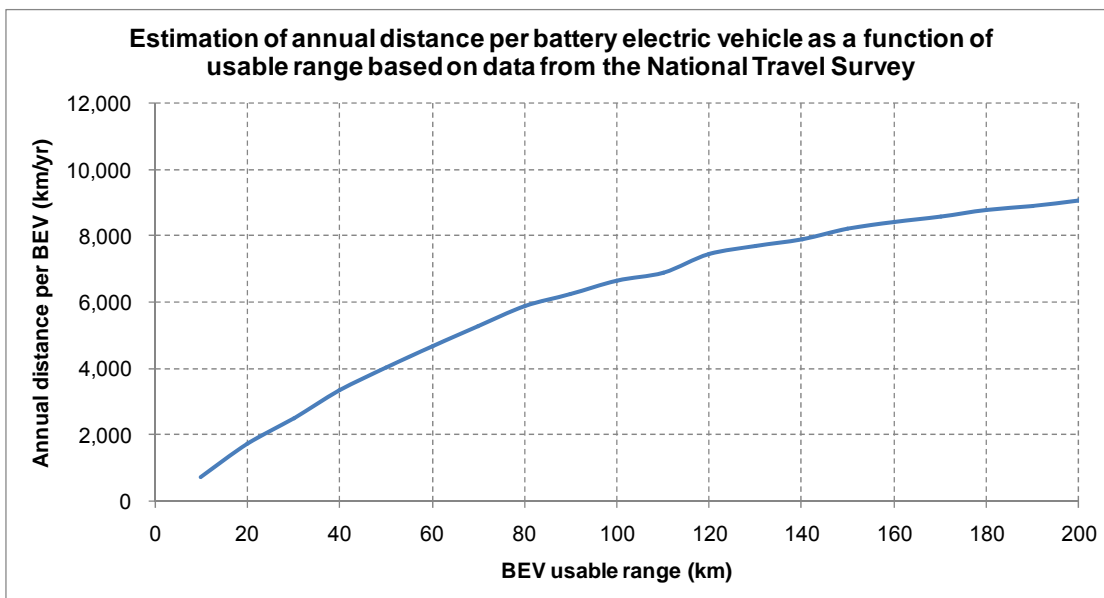


Figure 25: Average annual distance per BEV as a function of usable range

The methodology described above includes an implicit assumption that the maximum daily range of each BEV is set by the technical range and the utilisation ratio, i.e. each BEV is charged at the driver’s home but no further recharging infrastructure is available. The methodology for determining the impact of alternative infrastructure solutions is set out in section 12.2.4.

12.2.3 Average distance by PHEVs in electric mode

Unlike BEVs, the range of PHEVs is not limited by the energy storage capacity of the batteries. PHEVs can therefore be considered a direct replacement for internal combustion engine vehicles in that there is no reason for drivers to modify their behaviour when using a PHEV. For the purposes of this work it was assumed that all PHEVs are series hybrid vehicles, which means that the internal combustion engine is used to power the car only after the full range of the batteries has been used. The total mileage done in electric mode by PHEVs was calculated by finding the proportion of overall distance that could be done in electric mode, given the electric range of the car and the driving patterns of individuals in the NTS.

The same database of drivers (described in section 12.2.2) was used to find the proportion of a PHEV’s daily distance that would be done in electric mode by the following logic:

For example, for a PHEV with a range of 20km

$$\text{Total daily distance in electric mode (km)} = \text{Sum of daily distances of drivers who drove up to 20km in day (km)} + \text{Sum of first 20km of daily distance of all drivers who exceed 20km in day (km)}$$

The proportion of distance that could be done by PHEVs in electric mode was then found by dividing the total daily distance in electric mode for all drivers by the total distance done by all

drivers in the travel day. The results of following the above methodology and varying the PHEV electric range are shown graphically below.

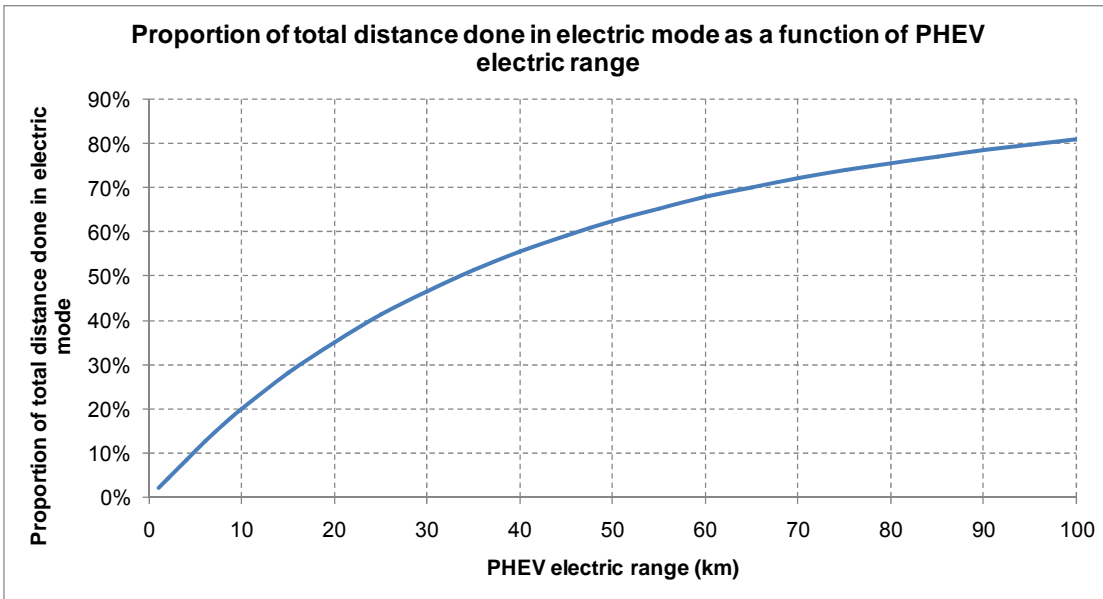


Figure 26: Proportion of PHEVs' annual mileage done in electric mode

12.2.4 Effect of workplace recharging infrastructure on average annual mileage of BEVs

The following graph shows the effect of workplace charging on average annual distance per BEV. This is derived based on the assumption that BEVs are generally used for commuting and that every BEV driver has access to workplace recharging facilities.

The results arise from the methodology described in section 12.2.2, with the only difference being that the 'sub-set' of drivers from which the mean daily distance is calculated changes on weekdays, since the workplace charge points effectively double the range of BEVs.

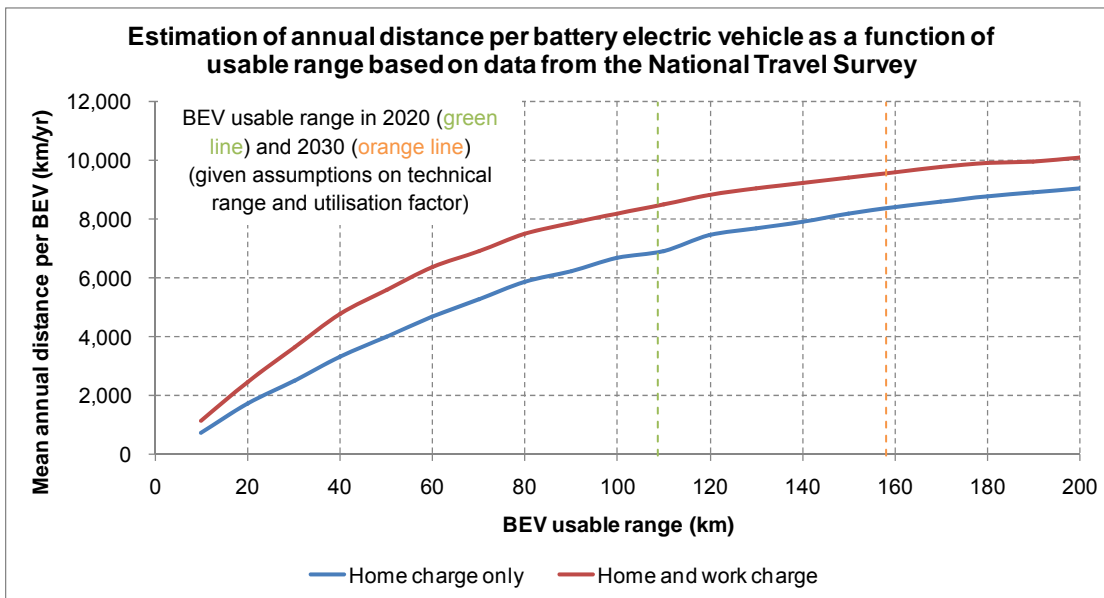


Figure 27: Effect of workplace charge points on mean annual distance per BEV

The calculation method used leads to additional CO₂ savings under the home and work charge scenario due to the difference between the red and blue lines plotted above. For example, in 2030 the effect of adding workplace charge points is to increase the mean annual distance of BEVs by around 1,200km per year. The carbon savings associated with such a change are fairly marginal, however, workplace charge facilities have an important role to play in stimulating the market and increasing consumer confidence in the technology (alleviating range anxiety), as discussed in section 5.3.

12.3 Impacts of EVs on urban air quality

12.3.1 Emissions from road transport: methodology

Emissions from vehicles for each of the cities were calculated from 1x1km emissions data, which were taken from the UK's National Atmospheric Emissions Inventory (NAEI). The NAEI provides emissions data disaggregated by sector (power generation, road transport etc). By summing all the emissions from the 1x1km data a figure for total emissions from road transport can be found along with the total emissions for each pollutant.

12.3.2 Emissions from cars: methodology

Since the focus of this work is on the passenger car market an assessment of the relative importance of cars to overall emissions from road transport is necessary. The emissions of each pollutant from cars are estimated from the following:

$$\begin{aligned} \text{Emission of Pollutant Y} &= \text{Average emissions from} && \times && \text{Distance driven by cars} \\ \text{by car type X (g/year)} &= \text{car of type X (g/km)} && && \text{of type X (km/year)} \end{aligned}$$

$$\begin{aligned} \text{Total emission of} &= \text{Sum of emissions of Y for} && / && \text{Grams per tonne} \\ \text{pollutant Y from cars in} &= \text{all car types X (g/year)} && && \text{(1,000,000 g/tonne)} \\ \text{city (tonnes/year)} & && && \end{aligned}$$

To estimate the emissions of cars in each of the cities the million car km values (from the estimated traffic flows for cars by Unitary Authority: Scotland 2008)⁶⁷ for each city was used. The estimated split of vehicle types in Scotland⁶⁸ and the diesel/petrol mix of cars (35/65) were then used to calculate the car km travelled by each vehicle type in each city. The average emissions of each of the vehicle types⁶⁹ (for both urban and suburban categories from NAEI's 2007 model) were used to estimate the pollutant contribution by vehicle type. This was then summed to give the total pollutant emissions from cars in each of the cities.

12.3.3 Effect of EVs in reducing emissions in cities: methodology

The total distance covered by BEVs and PHEVs is calculated under each scenario. These data are used to calculate the percentage reduction in emissions from the 2008 emission levels. The methodology used directly replaces ICE cars km with EV and PHEV km, and does not take into account any increases in vehicle km in the cities. This approach does not take into account any improvement in ICE emissions over time but instead leads to an estimation of the potential reduction in car emissions (and total emissions), from the 2008 levels attributable to BEVs and PHEVs.

- This assessment considers the benefits from replacing ICEVs with BEVs and PHEVs only – i.e. ignoring changes in traffic levels and savings from other technologies (improvement in ICE technology, stop-start etc).

⁶⁷ www.dft.gov.uk/transtat/roadtraff.

⁶⁸ www.scotland.gov.uk/Topics/Statistics/Browse/Transport-Travel/TrendMotorVehicles.

⁶⁹ www.naei.org.uk/datawarehouse/3_9_222_77552_vehicle_emission_factors_grammes_per_kilometre.xls.

- Estimated car-km from BEVs and PHEVs under each scenario in 2020 and 2030 are calculated. These results are used to estimate the extent to which ICEV-km are replaced by BEV and PHEV-km in each city.
- With a knowledge of emissions of each pollutant from ICEVs, and given that BEVs and PHEVs (in electric mode) are zero emission at point of use, the resulting change in emissions as a result of EV uptake can be calculated.

13 Appendix E: types of recharging infrastructure

This section gives a brief overview of different types of recharging infrastructure.

13.1.1 Home charge points

Domestic charging uses single phase grid electricity to recharge the battery pack. Two distinct methods of domestic charging are summarised in the table below.

Table 23: Summary of domestic charge points

Description	Power	Time to recharge a 16kWh battery ⁷⁰	Notes
Simple adapter plugged into domestic socket	3.1kW (240V, 13A)	5 hours	No change in domestic wiring required, cheap to implement
Direct connection to domestic supply (single phase)	16.8kW (240V, 70A)	1–2 hours	Specialised charging point required

The vast majority of EV users are expected to recharge their vehicles at home. For the majority of drivers a simple adapter to connect to a standard domestic socket should suffice since most cars are parked at home overnight, which allows ample time for a full recharge.

13.1.2 Public recharging

Public recharging points may be categorised as either ‘slow’ or ‘fast’ charge. Slow charge points connect to a single phase electricity supply and offer a full recharge time for a typical EV of around 5–6 hours. Fast charge involves taking power from a three-phase supply and fast charge points can offer a significant increase in battery charge level over a period of minutes rather than hours. However, fast charge points are significantly more expensive to install (due to wiring upgrades required) and due to the limited number of transformers that support three phase power slow charge is likely to be the more common solution, at least in the short to medium term.



Figure 28: On-street electric vehicle charge point⁷¹

⁷⁰ A 16kWh battery pack would give an EV with average battery to wheel energy demands of 0.15kWh/km a technical range of just over 100km.

⁷¹ Images by kind permission of Elektromotive.

Table 24: European standards for single and three phase charge points

Parameter	Europe IEC 62-196-2 type II standard ⁷²	
	Single phase	Three phase
Maximum voltage (V)	240	480
Maximum current (A)	70	63
Maximum power output (kW)	19.2	49.9

In addition to ‘slow’ and ‘fast’ charge points, a third type is currently being investigated: ‘rapid’ charge. Rapid charge involves supplying power at 500V and 200A from a three phase supply and would be capable of providing a full recharge in a matter of minutes.⁷³

13.1.3 Workplace charge points

In terms of infrastructure the charge points used for workplace charging need not differ from public slow charge points. The principal difference between public and workplace charging is that charge points at workplaces tend to be private and dedicated to specific EV users (or groups of users). This results in significantly higher utilisation rates for workplace charge points compared to publicly available charging infrastructure.

13.1.4 Battery exchange and Project Better Place

Battery exchange refers to removing the battery pack from the EV once it is depleted to below a certain level and replacing it with a different fully charged unit. The battery exchange model has been developed in some detail by a company know as Better Place.

Better Place’s innovative solution to the challenges of recharging facilities, high battery costs, and limited range is through a single framework that:

- i. Installs public charge spots prior to the cars being marketed.
- ii. Pays for and own batteries – charging a monthly subscription based on mileage.
- iii. Provides geographically dispersed battery switch stations, which allow depleted batteries to be replaced within a couple of minutes with charged batteries, thereby providing unlimited range.
- iv. Provides in car information on the need and potential opportunities for recharging/swapping.

Better Place is planning to roll out infrastructure in a number of countries/regions around the world.⁷⁴ However, for the Better Place approach to be widely adopted a great degree of coordination between car manufacturers, battery suppliers, and policymakers would be required.

⁷² <http://www.greencarcongress.com/2009/09/emobility-harmonize-20090926.html> and <http://www.ecofriendlymag.com/sustainable-transportation-and-alternative-fuel/bmw-daimler-and-vw-propose-global-e-mobility-standardization-on-vehicle2grid-communication-harmonization-of-chargers/>.

⁷³ See for example, the Mayor of London’s Electric Vehicle Delivery Plan: <http://www.london.gov.uk/mayor/publications/2009/docs/electric-vehicles-plan.pdf> p.14.

⁷⁴ These include Israel, California, Denmark, Ontario, Hawaii, Australia and Japan.

The major barriers to be overcome for any battery exchange infrastructure solution to be realised are:

- Standardisation of vehicle design (e.g. standard chassis) to allow automated battery exchange.
- Battery standardisation: certain manufacturers have expressed concerns at the prospect of sharing batteries with rival companies. However, a high degree of standardisation is required for the battery exchange model to be viable.

13.1.5 Public recharging infrastructure: economic analysis

In a recent report for the CCC the costs of a number of types of recharging infrastructure were estimated.⁷⁵ This work suggests that public slow charge points have a capital cost of around £5,500 (fully installed), and a maintenance cost of around £200 per year. The capital cost of fast charge points was estimated at c.£40,000, but the total installed cost could rise to over £90,000 if a new transformer is required.

Table 25: Impact of infrastructure costs on EV running costs

	Slow charge (10%)	Slow charge (15%)	Fast charge (low capital)	Fast charge (high capital)
Capital cost	£5,500	£5,500	£40,000	£90,000
Cost of capital	10%	10%	10%	10%
Payment period (years)	10	10	10	10
Power delivered (kW)	3.2	3.2	50	50
Utilisation rate	10%	15%	10%	10%
Energy delivered (kWh/yr)	2,803	4,205	43,800	43,800
Margin required (p/kWh)	39.1	26.0	15.3	33.9
Commercial electricity price (p/kWh)	8.0	8.0	8.0	8.0
Minimum electricity sale price (p/kWh)	47.1	34.0	23.3	41.9
Cost of 'fuel' for EV (p/km)	9.4	6.8	4.7	8.4
Cost of fuel for ICEV (p/km)	5.6	5.6	5.6	5.6

The table above presents a simple analysis of the implications of capital cost of infrastructure on cost of electricity from EV charge points. Four cases are presented:

- Slow charge (10%): this represents a slow charge point with a utilisation rate of 10% (i.e. it delivers electricity for 10% of the time, 2.4 hours per day).
- Slow charge (15%): slow charge point with a utilisation rate of 15%.

⁷⁵ *Strategies for the uptake of electric vehicles and associated infrastructure implications*, Element Energy for the CCC, p.68, (October 2009).

- Fast charge (low capital): this represents a lower estimate of the installed capital cost of a fast charge point.
- Fast charge (high capital): this is an upper estimate of the cost of a fast charge point.

In this analysis a typical cost of capital (interest rate) of 10% has been used. The margin required is the 'profit' on each unit of electricity sold that is needed to cover the capital and on-going maintenance costs (assumed to be £200 per year for both types of charge point).

The minimum electricity sale price is the lowest price that electricity could be sold for from the charge point such that the costs of capital and maintenance are met. This is based on a cost of electricity (into the charge point) of 8p/kWh.

The cost of electricity to the EV driver is translated into a p/km fuel cost based on energy requirements of 0.2kWh/km (this equates to 0.17kWh/km battery to wheel energy demands with a charging efficiency of 85%). For comparison the fuel cost of a traditional car is also given. This is based on an efficient petrol car (50mpg) and a fuel price of 100p/litre.

These results show that in order to cover the costs of the recharging infrastructure the required electricity price leads to 'fuel' costs for EVs comparable to or above fuel costs of an efficient ICEV. High utilisation rates are required to reduce the per unit price that must be charged for the electricity sold from recharging points.