Implications of the widespread use of electric vehicles

D Naberezhnykh, W Gillan, C Visvikis, J Cooper and M Jones
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Executive summary

Many commentators believe that at some stage electric vehicles (EVs) will overtake conventional internal combustion engine vehicles, which have dominated personal transport for almost a century, as the main personal method of transport. There are a number of reasons why this appears inevitable, such as the increased cost of oil extraction, the fact that oil is a limited resource and the need to shift to a decarbonised form of transport in order to reduce the impact of transport on the environment. However, the difficulty lies in trying to determine the time scales in which this change will take place. A number of key factors have been identified in this Insight Report that are believed to have an effect on how EV technology is developed and the rate at which it is adopted. The UK Climate Change Act 2008, tax incentives, European new-car CO₂ regulation, the price of oil, the European Union’s Renewed Sustainable Development Strategy, consumer attitudes, the automobile industry and technology development were selected as the key factors. These factors were used to assess models and scenarios for possible UK vehicle fleet composition by 2030.

A number of scenarios that were adopted by the Department for Transport and the Department for Business, Enterprise and Regulatory Reform were selected as a possible range of outcomes by 2030. Based on TRL assessment, the most probable scenario was selected. Within the range of scenarios proposed in this report, the high-range scenario was deemed to be the most probable. This scenario projects that by 2030, the UK vehicle fleet will include over 20 million EVs, which would make up over 27% of the UK vehicle fleet at that time. The scenario makes a number of assumptions and predictions that appear to be in line with what the analysis of the main factors suggests, such as continued and increased government support, rapid development of battery technology, the increasing price of oil-derived fuel (petrol and diesel) and consumer willingness to adopt EV technology given appropriate incentives.

This Insight Report also highlights the difficulty in making any such predictions as a large number of assumptions have to be made. It is possible that even a relatively small change to key assumptions could result in a different outcome for the model. For example, a lack of appropriate incentives offered by the government for consumers to adopt EVs early on could lead to a lack of critical mass being built up sufficiently quickly. This could lead to a longer delay before consumers are willing to switch to EVs. Another difficulty is that many of the key factors are linked and therefore an unexpected change in one could lead to a knock-on effect in others. As part of this project, a model was produced that aimed to assess the impact of changes in key parameters on the number of EVs in the UK vehicle fleet by 2030. Results of the modelling suggest that the combined percentage of fully electric and plug-in hybrid electric vehicles in the UK vehicle fleet could be as little as just over 6% or as high as 55% by 2030, with the majority of the difference arising as a result of different assumptions on the development of charging infrastructure and cost of vehicles.

This Insight Report also discusses the implications of large numbers of EVs in the UK vehicle fleet on traffic, transportation and safety-related issues. It was generally found that current development trends for EVs suggest that they will remain sufficiently similar to existing vehicles in terms of performance and characteristics and should not cause considerable change in driver behaviour. Therefore, the impact on traffic and transportation of an increased number of EVs is likely to be limited. The most substantial change may arise as a result of improved routing software and devices used in EVs to take into account the availability of charging points.

There are, however, a series of issues that have been highlighted as potentially having a significant impact on the safety of passengers and accident rates. Issues such as increased mass, different vehicle layout, the presence of high-voltage components and harmful chemicals on board an EV all need to be considered in the context of safety during normal operation and abnormal operation such as incidents and crashes.
Abstract

Electrification of personal transport is anticipated to be a natural progression in the process of the decarbonisation of transport. This Insight Report aims to evaluate possible scenarios that already exist, in order to determine the most likely scenario for the introduction and adoption of electric vehicles in the UK by 2030. A number of scenarios have been assessed based on a selection of key factors that could influence a possible 2030 scenario. Based on assumptions of how key factors, such as oil price and government policy, are likely to develop in the years leading up to 2030, the most probable scenario is selected for the composition of the UK vehicle fleet by that time.

This Insight Report was written as part of an internal reinvestment project for the TRL Academy, *The implication of the widespread use of electric vehicles for TRL*. Its main purpose is to identify the most probable scenario for the composition of the UK vehicle fleet by 2030, in order to gain an understanding of how widely electric vehicles will be adopted. Based on that scenario, an examination of the possible characteristics of electric vehicles in the UK vehicle fleet by 2030 is described and the implications that this may have on traffic, transportation and safety are discussed.
1 Introduction

1.1 Background

The reinvestment project from which this Insight Report derives is part of the TRL 2010–2011 research programme. Formal work commenced at the start of the financial year. This Insight Report also includes material and information gathered from earlier work, including attendance at the Green Vehicle Congress (24–25 March 2010) and LCV 2010 (15–16 September 2010), as well as information gained in discussions with TRL experts in vehicle safety, low-carbon vehicles and carbon-reduction strategies.

The work reported consists of two parts:

• Stage 1 is aimed at identifying scenarios for the composition of the UK vehicle fleet in 2030, including the total number of vehicles and the proportions of each type, e.g. internal combustion engine (ICE) vehicles (including those that operate on alternative fuels), hybrid vehicles and electric vehicles (EVs). This stage includes identifying the likely characteristics of the various types of vehicle with a particular focus on the range, dynamic characteristics and factors that might impact on traffic and transport. The objective is to draw on a range of sources that are likely to have a particular impact on government support for strategy on EVs and give an authoritative picture of market development.

• Stage 2 utilises results from Stage 1 to identify characteristics and the impact of a 2030 vehicle mix on a range of traffic and transport issues that might be covered by current and future TRL programmes. Additionally, a simple MS Excel model was created, which attempted to analyse the individual impact of key factors on the proportion of EVs in the UK vehicle fleet by 2030.

1.2 Why 2030?

The year 2030 was selected for a variety of reasons. It is half way between 2010, the current year at the time of writing, and 2050, the year for which long-term CO₂ output targets are set. It is the period when vehicles that are starting to enter production today will be nearing their end of life. An individual mass-market car model is normally in production for up to seven years (ACEA, 2009), with a facelift at year 4. The average life of a car is 13.5 years (Waste Online, 2004) with the average car being registered for 7.1 years (Transport Statistics, 2009). What this means is that the last cars off the production line (seven years after introduction to market) could be on the road for, on average, 13.5 more years.

Over the last two years, these figures may have been affected (in the UK) by the scrappage scheme, but that does not need to be taken into account for the modelling of future scenarios, unless a similar incentive is repeated over a more substantial time period. In comparison, the US figure is even greater with the average lifetime of a car spanning 16 years (light commercial vehicles or LCVs) (US Department of Transport, 2010). Hence, ICE vehicle models that are being launched now, such as the new Vauxhall Astra, could remain as a component of the vehicle fleet up to 2030.

In addition, the year 2030 is a reference point in the King Review (King, 2008) of low-carbon cars. By 2030 there should be clarity on whether the UK is on a trajectory to cut CO₂ by 80% by 2050 over the 2000 value, the baseline used by Professor King. In addition, 2030 is also a likely deadline for when car manufacturers may need to meet new European new-car CO₂ emission targets, to be set in the future.

2030 is also the year in which Professor John Beddington, the Government Chief Scientist, has predicted that the world faces a “perfect storm” (Beddington, 2009) of crises caused by food shortages, climate change and energy shortages. In this context, the “perfect storm” is important as it will be one of the contributing factors to the possible scenarios for composition of the UK vehicle fleet by 2030. It is noted that the “perfect storm” scenario is only one of many potential scenarios, some of which may be contradictory to, or not in complete agreement with, the “perfect storm”. It is important that various opinions are taken into consideration and, based on those, this report will reach conclusions regarding possible scenarios.

1.3 What is meant by “electric vehicles”? In this report, the term “electric vehicle” (EV) is used as an umbrella term that covers plug-in hybrid electric vehicles (PHEVs), fully electric vehicles and fuel cell vehicles. These types of vehicle are considered to have the potential to be substantially different in their performance and parameters from current ICE vehicles and to have a non-negligible impact on TRL programmes, specifically on traffic, transportation and safety. The properties of each type of vehicle are described below along with some key parameters and characteristics.

1.3.1 ICE vehicles – the baseline

These vehicles have evolved to meet our current needs and demand for transportation, utilising what has been, until now, a relatively cheap resource – oil. ICE vehicles (in this report only cars and LCVs are considered for simplicity) are generally multipurpose. They are capable of completing both long and short journeys and typical passenger cars have five seats, although that may vary from two to seven seats.

Although ICE vehicles have been around for over a century, most developments on the ICE technology have, up until now, concentrated on improving power and speed and increasing reliability. However, more recently, largely as a result of EU emission-reduction targets and emission-linked taxation, the developments have given more emphasis to reducing fuel consumption. In this respect, there are still several areas of improvements for energy efficiency that have not yet been fully explored. The main areas of improvement for ICE vehicles are expected to be in the engine and transmission, as well as downsizing and weight reduction. Thus, while some improvements are primarily associated with technological advances, such as improved engine technology and new materials to reduce weight, others are primarily driven by consumer behaviour as demonstrated by the wide range of CO₂ emissions that exists within the current vehicle fleet and registrations of new cars (Figure 1.1). It is worth noting that all vehicles registered during 2009 are included in Figure 1.1, including hybrids and alternatively powered vehicles, such as bio fuels and compressed natural gas.
1.3.2 Hybrid vehicles – transition stage

Hybrid vehicles represent the transition stage between ICE vehicles and EVs. They allow for a gradual transition away from vehicles relying on oil-derived fuels to electrification of road transport, while limiting the disadvantages of still-developing technology, such as high costs, reduced range and lack of infrastructure.

A hybrid vehicle consists of a smaller ICE, generally, and a battery. The battery is larger and more powerful than the auxiliary battery found in an ICE vehicle; the actual size of the battery depends on the level of hybridisation. Typically, hybrid vehicles are divided into the following categories (Lytton, 2010):

- **Micro-hybrids** – These vehicles are in essence ICE vehicles with a slightly larger battery. Micro-hybrids are not capable of propulsion using the battery alone but do use a number of innovations that improve the ICE's efficiency, mainly "stop-and-start" and "stop-and-go" systems. Stop-and-start systems use energy in the battery to start the engine again quickly, allowing it to be turned off automatically instead of idling, while stop-and-go systems recover energy from braking and use it to start the vehicle again.

- **Mild hybrids** – These hybrid vehicles include the same systems as micro-hybrids and, in addition, regenerative braking and acceleration assistance. This requires a slightly larger battery than micro-hybrids, of approximately 10 kWh capacity, but also allows for a downsized ICE.

- **Hybrid electric vehicles** – In addition to the features of micro-hybrids and mild hybrids, hybrid electric vehicles (HEVs) are also capable of electric propulsion at low speeds for a limited range. This capability requires larger batteries of up to 30 kWh capacity. The Toyota Prius is currently the most widely adopted HEV, with over 1.0 million vehicles sold worldwide as of 2008 (Toyota, 2008).

- **Plug-in hybrid electric vehicles** – PHEVs still incorporate an ICE as well as a battery, generally of up to 40 kWh capacity. The major difference between a PHEV and other hybrids is that as well as having the capability to be charged by the ICE, the battery can also be charged directly from the grid. The electric-only range of such vehicles can be up to 50 miles, generally based on speeds up to 50 mph. It is possible that a PHEV could be used predominantly as an electric vehicle in a city environment if the charging infrastructure is available.

- **Fully electric vehicles** – These vehicles do not include an ICE and, therefore, rely entirely on the battery to ensure sufficient range and power. A battery of at least 16 kWh, and typically more than 40 kWh, is required for these vehicles, and often larger, depending on the size and range of the vehicle. An infrastructure of charging points and possibly improvements to the National Grid are needed in order for these vehicles to be viable and practical. One of the main reasons for incentivising switching to fully electric vehicles is the potential for significant carbon savings. However, these are dependent upon significant decarbonisation of the electricity supply.

- **Fuel cell vehicles** – A fuel cell vehicle is essentially an EV with the capability to produce its own electricity from a fuel source, typically hydrogen. Unlike a HEV, where an ICE could be used to turn a generator and charge a battery, a fuel cell vehicle uses a process of generating electricity by separating a hydrogen molecule into electrons and positively charged ions (protons in this case). The only by-products of a fuel cell engine are water and heat. This has the advantages of high energy density of fuel (compared with batteries) and rapid refuelling (minutes like fossil-based fuels rather than hours to charge batteries). The disadvantages are that there is no hydrogen distribution network and it is more difficult to handle and store that fuel.
It is recognised that there are other types of propulsion systems and fuels, such as a hydrogen ICE and bio fuels. However, it is not anticipated that vehicles based on these fuels would be very different from current ICE vehicles. Their parameters and characteristics are expected to be very close to those of current ICE vehicles as the technology would not require drastic changes to the personal vehicle model. In this report, mostly EVs are considered as they could potentially be very different from the vehicles that are manufactured today, in terms of performance, characteristics and use. As such, they could have an impact on traffic and transportation, and other areas of TRL work.

1.4 Assumptions and limitations

1.4.1 Travel demand

Travel, in terms of vehicle-km/pa, has approximately doubled in the UK every 20 years over the last 60 years (Figure 1.2). Demographic factors and an expanding population suggest that growth will continue. Eddington (Eddington, 2006), who is cited in the King Review (King, 2008) and appears to be accepted as the government’s base assumption, indicated that traffic is expected to double once more between 2007 and 2050 (i.e. growth in future will be less than half the long-term growth rate).

Travel demand may be modified by a range of factors. Economic growth clearly has a role, as does the price of fuel, or more accurately energy, and the fuel consumption of vehicles. The price and availability of public transport alternatives to personal travel play a part for some travel.

If the fuel consumption of the vehicle fleet does not improve at the rate predicted in the King Review (King, 2008) due to slower technical progress or reluctance by vehicle purchasers to “downsize”, then even higher fuel prices (compared with the doubling of fuel price discussed in Section 2.2.1.2) would be required to reduce demand and encourage the use of lower-carbon vehicles. Department for Transport (DfT) research (Hanly et al., 2002) suggests that the long-term elasticity of traffic is about 0.3, i.e. a 10% increase in fuel prices will result in a long-term reduction of 3% in traffic volumes.

Hence it is assumed that travel will double by 2050, with a 50% increase by 2030. That is consistent with the figures of Eddington (Eddington, 2006) and King (King, 2008) and is the “do nothing” scenario. It implies that fuel prices will increase to compensate for the improvements in the economy that result from greater efficiency of travel, either through technical development or “downsizing” of the vehicle. The King Review suggests that emissions per mile per vehicle in 2030 would be about 50% of the 2000 level. Hence the real price of fuel, to maintain a constant real price for travel, would be double the 2000 value, also increased in line with incomes. The impact of fuel prices is discussed further in Section 2.2.1.2.
2 Research methodology

2.1 Literature review
Before a set of scenarios were identified and selected as the most plausible and probable, based on an assessment of key parameters that affect the scenarios, a literature review was carried out.

Relevant reports were identified via conversations with key TRL staff working on projects on electric and low-carbon vehicles, literature available from the TRL Library and internet research. The aims of the literature review were to understand the various approaches that have been taken for predicting possible scenarios for vehicle fleet compositions in future years, in particular 2030, to understand the parameters that have been taken into consideration when developing those scenarios and to gain an understanding of the variations between scenarios.

2.2 Scenario selection process
A number of scenarios were examined during the literature review stages of this project. Each scenario was assessed on its plausibility for meeting a set of defined criteria that are likely to influence the 2030 scenario.

The approach initially adopted in this project was to draw on a range of existing scenarios to attempt to identify a “consensus” scenario that could be used as a basis for further work and Stage 2 of this project. However, a study of the literature reveals that scenarios depend critically on the underlying assumptions. It seems that a range of divergent scenarios could be produced by appropriately selecting and varying those assumptions. In order to be able to reach a decision on which scenarios seem to be the most plausible, it was essential to understand the factors that lead to a particular scenario, because that might also influence the end point, i.e. the traffic and transport implications.

A possible way of illustrating this is as follows. One of the key drivers for the adoption of EVs in the UK will be the target of reducing CO2 emissions by 80% by 2050. In part that might be achieved by technical improvements to vehicles, but this is unlikely to achieve all the required reduction by itself. It will therefore be necessary to support technological improvements with measures to shift travel to more efficient modes and to reduce the total amount of travel, e.g. through a range of fiscal instruments, possibly including some form of selective road pricing, and changes in land-use planning that reduce the need for travel. It is also likely that other measures to increase the efficiency of vehicles in use might be needed, such as “eco-driving” and speed management. Regulations and charges might be targeted at particular types of vehicle – a current example is the exemptions that electric and hybrid vehicles enjoy in the London Congestion Charging Scheme. Not only do these affect the vehicle fleet composition, but they also modify traffic levels on the road (i.e. they have traffic and transport outcomes).

2.2.1 Parameters that influence scenarios
During this project, a number of factors were determined that are thought to have an influence on the possible 2030 scenarios for the UK vehicle fleet composition. Figure 2.1 shows the main influences that are considered to have an impact on a possible 2030 scenario. These factors were used to determine the most likely scenario(s) based on information found during the literature review.

Each of the main components of Figure 2.1 is expanded on below, and their perceived influences on possible 2030 scenarios are described.

2.2.1.1 UK Climate Change Act 2008
The UK Climate Change Bill was passed through parliament, followed by the passing of the UK Climate Change Act 2008. The Climate Change Act 2008 creates a legally binding framework to cut CO2 emissions and to develop a capability for the UK to adapt to climate change.

One of the purposes of the Act is for the UK to be seen as an international leader in taking action on reducing carbon emissions. Although the Act does not emphasise the transport sector in particular, it states that clear targets need to be established for reducing CO2 emissions in the UK. In order to ensure that these targets are reached and to establish a framework for doing so, the Act outlines four main elements:
1) Setting targets in statute and carbon budgeting – In order to achieve the 80% reduction (on 1990 levels) in CO₂ and other selected greenhouse gases (GHGs) by 2050, carbon budgets have been set that form a roadmap to meeting the 2050 target. An intermediate 34% target reduction on 1990 carbon levels by 2022 has also been set. Carbon budgets are to be set in successive five-year periods, starting from 2008–12. The budgets will limit the total CO₂ emissions within that five-year period. It is proposed that at least three consecutive five-year periods are set in advance.

2) Establishing a committee on climate change – The Committee on Climate Change is an independent body that advises government on how to reduce emissions over time and across the economy. This expert body will advise on the optimum trajectory to 2050 by giving advice on the level of carbon budgets and on how much effort should be made in the UK and overseas.

3) Creating enabling powers – The Act grants the UK government the power to require “bodies with functions of a public nature” and “statutory undertakers” (companies like water and energy utilities) to report on how they have assessed the risks of climate change to their work, and what they are doing to address these risks. It also enables the government to introduce new domestic emissions trading schemes through secondary legislation. Such trading schemes will consist of government regulation that encourages the reduction of GHG emissions and an increase in activities that contribute to the reduction of GHGs.

4) Reporting requirements – The Committee on Climate Change will produce an annual public report to parliament on progress towards meeting the carbon budgets and targets. The government will in turn be required to lay before parliament a response to this independent report.

In October 2009, the Committee on Climate Change presented its first progress report to parliament, entitled Meeting carbon budgets – the need for a step change (Committee on Climate Change, 2009). The report is a key indicator of UK government policy on planned measures for reducing carbon emissions from the transport sector. For the purpose of determining the most likely scenario(s) in this project, the following elements of the report are considered to be key points that are likely to have a strong influence on a 2030 scenario:

- It is anticipated that carbon-reduction targets for the first three budget terms, up until 2022, could be met largely by changing driver behaviour, as well as by wide adoption of non-powertrain-based vehicle technologies such as gearshift indicators, weight reduction and low-resistance tyres. A target should be established to have 3.9 million drivers trained and practising eco-driving by 2020.
- From 2020 onwards, significant importance will be placed on the integration of EVs, PHEVs and, later, fuel cell vehicles. Government policy should be strengthened to include support for EVs and PHEVs. A comprehensive strategy for rolling out EVs and PHEVs, including a funded plan for charging infrastructure and large-scale pilots starting at the end of the first carbon budget period, should be adopted. There is a target of 240,000 EVs and PHEVs delivered through pilot projects by 2015, and 1.7 million by 2020.
- The UK should aim to converge on the EU trajectory for average new-car emissions by 2015 and aim to reduce the carbon intensity of new cars to 95g CO₂/km in 2020 from the current fleet average of 158g CO₂/km.

Adoption of the UK Climate Change Act 2008 could be seen to be an indicator that the UK government is committed to reducing CO₂ and other GHG emissions, 18% of which come from the transport sector (Office for National Statistics, 2009). It appears that the UK government will be willing to intervene and introduce further legislative measures if the targets for reducing emissions are not being met. In addition, according to the report by the Committee on Climate Change, recommendations are made to the government to incentivise the introduction and adoption of EVs through the implementation of pilots, in preparation for a full-scale introduction across the UK starting in the mid-2020s. This is likely to have a significant impact on scenarios leading up to 2030 and has been considered when selecting possible scenarios.

2.2.1.2 Price of fuel at pump
It is possible that the world’s current oil production rates have either already peaked or will do soon; this situation is known as “peak oil” (Branson et al., 2010). The term “peak oil” describes a situation where the maximum rate at which oil can be extracted no longer meets demand. It is not to be confused with the depletion of the world’s oil reserves, as this is currently understood to be unlikely to happen in the near future. However, the issue seems to be that as an oil well get past its peak output, which generally occurs when around one-third of the well’s resources have been extracted, oil becomes more difficult and costly to extract. This – combined with the fact that in recent years most newly discovered oil fields were either small, in difficult-to-access environments or in a form that is more difficult to extract from, such as Canadian tar sands – could lead to a situation where oil, although not running out, is becoming much more costly to extract.

The result of oil becoming more costly to extract from its source, combined with the anticipated rise in demand (Figure 2.2), could result in the prices at the fuel pumps rising significantly in the near future. Although it is anticipated that demand for oil from Organisation for Economic Cooperation and Development (OECD) countries is likely to fall by 0.5% per year to approximately 43 million barrels per day (Mb/d) by 2030, demand from non-OECD countries, which currently make up approximately five-sixths of the world’s population, is likely to increase, leading to a projected global oil demand levels of 105 Mb/d by 2030.

Dr Robert Falkner (Branson et al., 2010) describes the impact that the “peak oil” situation is likely to have on the UK economy, and in particular the transport sector. This element is considered to be important when selecting possible scenarios in this project, as increasing oil prices, and hence increasing prices of fuel at the pumps, could force a more rapid shift to non-oil-derived fuels.
Dr Falkner points out that the UK is becoming increasingly dependent on oil imports and thus it is more susceptible to rising and volatile oil prices than other nations. “Peak oil” is expected to have a significant impact on the UK transport sector and the rest of the economy by 2030. At the current rate of development of alternative energy sources for transportation, it is unlikely that suitable substitutes will be found in time. The result of such an overlap could be either a reduction of the UK economy or government intervention to support and accelerate the introduction of low-carbon transport alternatives.

In selecting possible scenarios for the UK vehicle fleet composition by 2030, the points laid out above are considered to be plausible and are thought to have an impact on the most likely scenario. Regardless of what other alternatives to ICE vehicles are likely to be available by 2030, the price of oil and thus oil-derived fuel is likely to increase to the point where projected fuel demand may no longer be economically sustainable. This could result in a sharp reduction in the number of vehicles in the UK vehicle fleet that use petrol or diesel.

The assumption that travel will double by 2050, with a 50% increase by 2030, could imply that fuel prices will need to increase to compensate for the improvements in the economy that result from greater efficiency of travel, either through technical development or “downsizing” of the vehicle. The King Review (King, 2008) suggests that emissions per mile per vehicle in 2030 would be about 50% of the 2000 level. Therefore, in order to maintain a constant real price for travel, the real price of fuel could be double the 2000 value and also increased in line with incomes.

There are, however, risks with this assumption. A key factor is whether the UK government would be prepared to actively intervene to increase travel costs if it seemed necessary. That might be achieved by some form of road pricing or by significantly increasing the price of fuel by fiscal means. However, the fuel duty protests in September 2000 following the price increases produced by the fuel price escalator (FPE) suggest that there are limits to public acceptability of taxation-induced fuel price increases. Another consideration is the effect of demographic change: as the population ages and the percentage of the population that is in work declines, income tax makes a smaller contribution to national revenues so there could be pressure to use fuel taxes, or other forms of tax such as road user charging, as an alternative source of revenue.

The term “fuel price escalator” describes the practice of automatically increasing hydrocarbon oil duty (better known as “fuel tax”) in the UK ahead of inflation. The FPE was introduced as a measure to stem traffic growth and cut emissions, and also resulted in significant increases in revenue for the Treasury. The FPE was introduced by the UK government in 1993 and set at an annual increase of 3% ahead of inflation, later rising to 5% and then to 6% per year in 1997. The last rise due to the FPE was confirmed in the budget on 9 March 1999. The end to the FPE was announced on 9 November 2000, following public protests about the latest increase including refinery blockades. When the FPE ended, fuel in the UK was the most expensive in Europe, with fuel tax representing over 75% of the retail price of fuel.

Experience with the FPE suggests it is unlikely that governments will go beyond a “what the market will bear” approach to energy taxation for travel. If, however, the predictions of Professor John Beddington (Beddington, 2009) are accurate and there is major “oil shock” as global oil production turns down after peaking, that would result in significant increases in the non-tax component of the price. Fuel price rises seen as due to “natural causes” may be more acceptable than those prompted by taxation increases.

2.2.1.3 Consumer attitudes and behaviour

The benefits of low-carbon vehicles, and EVs in particular, have much in common with many traffic management measures in that they generate community benefit at the expense of some perceived disadvantage to individuals. It is clearly in the public interest to reduce CO₂ emissions. On the other hand, a low-carbon vehicle may involve some compromises in comparison with a conventional ICE vehicle for the individual purchaser. Consumer demand is a major element in potential mass-market take-up.

**Figure 2.2** Oil demand split by OECD and non-OECD countries extrapolated to 2030, using IEA’s projected 1% global growth and ITPOES’s projected 0.5% decline (Source: DfT, 2008)
Consumer attitudes to EVs are the subject of an in-depth study by a consortium that includes TRL, the results of which are expected to be published in 2011. As always it is difficult to predict consumer behaviour. The current generation of low-carbon vehicles, such as the Toyota Prius, has achieved some market penetration with approximately 1.6 million vehicles sold worldwide (Los Angeles Times, 9 February 2010), even though the benefits are relatively limited in comparison with a conventional turbo diesel ICE vehicle. Consumer behaviour is based on a variety of factors. Some of these, such as the appearance and design of the vehicle, are intangible.

The factors that are most important in deciding which car to purchase are listed in the King Review (King, 2008), drawing on sources from the Low-carbon Vehicle Partnership.

Although vehicle price and direct running cost are important, the investigations also reveal that other costs, such as road tax and insurance, are of low importance, emphasising that consumer behaviour is difficult to predict and not always rational.

In an attempt to assess the potential market for EVs, the key parameters used by consumers in deciding which car to purchase (King, 2008) have been assessed to determine whether they are better, neutral or worse in comparison with an ICE vehicle. The results are shown in Table 2.1. Note that performance and power were rated as medium priority and therefore are not included in this table.

It is difficult to compare some of the parameters directly. For example, a well-designed EV should be more reliable than an ICE vehicle as there are fewer moving parts. On the other hand, a recent Cenex trial (Carrol, 2010) found that drivers were, on average, only using up to 25% of the potential range of the vehicle due to "range anxiety", i.e. fear that they would be left stranded with a flat battery. Development and integration of intelligent transport system (ITS) technologies with routing applications and charging infrastructure, as well as provision of better real-time information to the driver regarding the state of charge of the battery, could help to alleviate range anxiety. There are also concerns about battery life and failures. Hence, the fear of being stranded at the roadside has changed in nature but still exists.

The case for selecting an EV in preference to an ICE vehicle will depend on the travel pattern and aspirations of the user. These may produce contradictory results. For example, a high-mileage driver might be attracted by the low running costs of an EV but deterred by the limited range.

There may also be technical barriers to EV ownership, particularly for charging at home: not every home consists of a house with a drive or garage where a charging facility can be set up. Over 60% of households in the UK have off-street parking (Committee on Climate Change, 2009), but even in such properties it is not unusual for every adult to own a vehicle and the need to charge multiple vehicles is likely to exceed the capacity of the domestic supply. Also, practical and safety limitations of issues such as trailing cables and the streetscape implications of multiple on-street charging points would have to be considered.

Additionally, research carried out by Ecolane for the DfT (Anable et al., 2008) suggests that the car buyers’ decision process is driven firstly by the car size and body type, as well as available budget, and then by secondary factors such as running costs and fuel economy. It seems that lack of confidence in the published fuel economy figures, as well as difficulties associated with converting fuel economy figures to fuel costs, are some of the reasons why consumers often put less emphasis on this information when making a purchasing decision. The conclusion of the report is that an economic incentive of at least £1100 per year would be required to significantly alter car consumer choice.

Another aspect to consider is that most consumers will form an opinion about the available EVs based on their experiences and expectations from ICE vehicles. In this sense, an ICE vehicle can be regarded as a baseline against which EVs will be compared. If the UK government chooses to adopt measures such as reductions in speed limits, this could change the baseline performance against which EVs might be compared. For example, reducing the national speed limit to 55 miles per hour (mph) may result in a smaller perceived gap in performance between early EVs and ICE vehicles. In addition, the increased use of technological, telematic and ITS features in ICE vehicles aimed at reducing emissions, such as cruise control, intelligent speed adaptation and automatic gearboxes, could lead to ICE vehicles becoming more like EVs in the ways in which they are driven and their performance. This could lead to consumers perceiving EVs as less of a risk in terms of performance and handling.

Table 2.1 Vehicle parameter comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EV compared with ICE vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle price</td>
<td>Probably inherently worse (due to battery cost)</td>
</tr>
<tr>
<td>Size</td>
<td>Neutral (worse if downsizing needed)</td>
</tr>
<tr>
<td>Reliability</td>
<td>Possibly better (fewer moving parts, mechanically simpler)</td>
</tr>
<tr>
<td>Comfort</td>
<td>Neutral</td>
</tr>
<tr>
<td>Safety</td>
<td>Possibly neutral</td>
</tr>
<tr>
<td>Direct running costs</td>
<td>Better (unless new fiscal regime developed)</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>Better</td>
</tr>
<tr>
<td>Appearance</td>
<td>Neutral</td>
</tr>
</tbody>
</table>
2.2.1.4 Technology development

Factors that could have an effect on the possible 2030 scenario for UK vehicle fleet composition discussed so far have concentrated primarily on technology-independent influences or influences where technology availability was not the primary driving influence. This section aims to describe the technologies that are currently available, the developments expected in the near future and the technologies that could potentially be available by 2030. It is noted that development of technologies is closely linked with other influencing factors such as government policy and customer demand. In order to reflect this, the scenario(s) selected in Section 3 will take into consideration all of the factors described in Figure 2.1. This section, however, aims to describe the likely scientific and engineering advances that could be achieved by 2030 in terms of making new or improved low-carbon technologies available.

It can be seen from Figure 2.3 that all technologies likely to be part of a potential 2030 UK vehicle fleet are either already introduced (ICE), are in the process of being introduced (micro-, mild and full hybrids) or are in the pilot and demonstration stages (EVs and fuel cell vehicles). It can also be seen that most of the technological developments and advances will overlap, or will be developed simultaneously. This leads back to the point that car manufacturers will have to make choices based on other influencing factors, such as customer demand and government policies, regarding how to prioritise their research and development (R&D) funding and what technologies to pursue. According to NAIGT (NAIGT, 2009), by 2030 all of the major technologies will be sufficiently developed to begin their introduction into the UK vehicle fleet. However, in determining the possible 2030 scenarios, the relative maturity, drawbacks and benefits of those available technologies are compared in this section in order to attempt to gauge possible adoption rates.

ICE

Further developments of the ICE technology are likely to play an important role in how other technologies are developed and how much emphasis is put on them. One of the key driving factors for car manufacturers to develop low-carbon vehicles is the desire to meet the CO₂ emission targets set by the EU new-car emission legislation, adopted in April 2009. Developments in ICE (Lytton, 2010), such as variable valve actuation, direct fuel injection and lean burn, downsized engine capacity, reduced friction components and improved transmission, as well as vehicle improvements like weight reduction, better aerodynamics and low rolling-resistance tyres, could deliver reductions in the order of 15–30% by 2020 (King, 2008). In addition, incorporation of micro-hybrid functionality could reduce CO₂ emissions by a further 9%. It is possible that improvements to ICE technology alone could meet EU new-car emission targets for 2015 and possibly even go some way to meeting the 2020 target.

Ultimately, however, ICEs are limited by the thermodynamic limit to around 50% efficiency and most current engines achieve between 20% and 40% (E4tech, 2007). This means that ICEs are unlikely to achieve much less than 50–70 g/km emissions. This in turn could mean that ICE vehicles are unlikely to be able to meet 2030 EU emission targets for new vehicles, and other technologies may need to be introduced.

Figure 2.3 NAIGT technology road map outlining technology introduction (Source: NAIGT, 2009)
Based on the above, it seems that ICE technology will continue to undergo further development that will reduce CO₂ emissions from ICE vehicles up to 2030. Combined with the lower cost of development (compared with EVs), ICE vehicles are likely to remain as the dominant propulsion technology of road vehicles in the UK fleet within the timeframe considered in this report, i.e. up to 2030.

**Hybrids and electric vehicles**

For fully electric vehicles and hybrids, the main areas of technological development, and to some extent uncertainty, are the developments in battery technology. Currently, the production of a lithium-ion battery costs in the order of £650/kWh (Committee on Climate Change, 2009). This means that a small battery for a mild hybrid results in a price increase for the vehicle of up to £6500. Each of a Tata-developed range of small four-seater EVs with performance in urban environments equivalent to that of ICE vehicles has a 26 kWh battery that weighs 160 kg (Royal Academy of Engineering, 2010).

Currently, most high-performance batteries are based on lithium-ion group products with variations such as lithium sulphide and lithium tantalite (Lyton, 2010). Most of the developments in the near future are likely to focus on improving the capacity of batteries, thus increasing the vehicles’ range and reducing the charge times. Advances in infrastructure will also be necessary in order to allow fast charging of PHVs and EVs.

Fully electric vehicles, and to a lesser extent PHEVs, depend on the existence of infrastructure that will enable convenient and rapid charging of the batteries. Developing such infrastructure by 2030 will not only require government action, but also require the development of standardisation for battery and charging technology. Improvement to the National Grid will also be required to cope with large numbers of EVs being charged at the same time (Royal Academy of Engineering, 2010). Some cost estimates (Committee on Climate Change, 2009) suggest that infrastructure for 1.7 million fully electric vehicles introduced in the UK by 2020 could cost between £150 million and £1 billion depending on the types of charging station introduced and their locations.

ITS will also likely need to be developed further to allow smart selection of charging stations and route planning that takes account of the vehicle’s range.

Another possibility is to introduce battery exchange stations, where discharged batteries could be swapped for fully charged ones. This could be a cheaper alternative to developing vast charging infrastructure, but would likely require a high level of standardisation of car batteries and car design. Such standardisation could prevent innovation and competitiveness among car and battery manufacturers.

Hybrid vehicle technology is already available: its flexibility to allow for unlimited ranges could make it a consumer favourite, not taking into account possible increases in fuel prices. Fully hybrid vehicles, like the Toyota Prius, could become widely adopted by 2030 and make up a significant proportion of the UK vehicle fleet.

PHEVs and EVs are also currently available but are more dependent on developments in battery technologies and charging infrastructure. It is likely that significant developments in battery costs, capacity and lifetime need to be made, as well as infrastructure development, before they can be widely introduced. It is difficult to determine, or even estimate, how soon these technological breakthroughs may come about but it seems unlikely that these types of vehicle will make up a significant proportion of the UK vehicle fleet by 2030 if travel patterns and consumer attitudes remain as they are today.

**Hydrogen fuel cell**

Fuel cell technology is less well developed than hybrid technology, but it does appear to be well suited as a replacement for ICE vehicles due to its range of up to 300 miles (Lyton, 2010). This is approximately three times as much as the range of a current fully electric vehicle. In addition, fuel cell vehicles can be refuelled much like an ICE vehicle in terms of time and do not require the installation of charging points.

Honda has released a pilot fuel cell vehicle in the US, the Honda FCX Clarity. According to Honda (Honda, 2010), the vehicle achieves efficiencies of 60%. The only emission from a fuel cell vehicle is water. However, before fuel cell vehicles can be widely adopted a number of technological developments need to be made. As the fuel cell is still a relatively new technology, further development needs to be carried out on durability and reliability (US Department of Energy, 2011).

Further developments that can reduce the cost of fuel cell systems are needed before fuel cell vehicles can be competitive against ICE vehicles, i.e. fuel cell costs need to drop from £35/kW to £21/kW. This is anticipated to happen around 2015. However, the developments in infrastructure required to produce and distribute hydrogen to end users are not likely to happen within this time frame. Realistically, infrastructure and required improvements in hydrogen storage and distribution technology are not likely to be in place until the 2020s. This limits how widespread fuel cell vehicles could become by 2030 and therefore, for the purpose of this project, fuel cell vehicles are not anticipated to constitute a large proportion of the UK vehicle fleet in a possible 2030 scenario.

2.2.1.5 Automobile industry

The automobile industry is facing many challenges. Most notably, the global financial crisis is having a profound effect. In 2009, total vehicle production in Europe (cars, trucks and buses) decreased by 17% compared with 2008 and by 23% compared with the pre-crisis level of 2007 (ACEA, 2010a). However, there were signs of improvement by the fourth quarter of 2010: a total of 12.6 million motor vehicles were produced in the EU, which is 15% more than in the same period of 2009. Compared with the first three quarters of 2008, total production was down 14% in 2010 (ACEA, 2010b).

Demand has also decreased. During 2009, European demand for passenger cars was 1% lower than 2008 and 9% lower than before the crisis in 2007 (ACEA, 2010a). However, once again there are emerging signs of an upturn. Another possible effect of the financial crisis is the rise in the demand for smaller cars. The market share of small cars increased from 39% in 2008 to 43.4% in 2010 (ACEA, 2010b). These were the only segments to increase their market share over the course of the year.
It seems there is a market pull for smaller, more fuel-efficient vehicles that are cheaper to run. The number of new registrations of vehicles emitting 120 gCO₂/km and less increased by 59% in 2009, compared with 2008 data. This resulted in a market share of 25% for these vehicles (ACEA, 2010a). This may be a direct result of the financial crisis, but it is likely that many consumers are also starting to recognise the need to protect the environment. For their part, automobile manufacturers are adapting their product ranges. ICEs will probably remain the primary powertrain for many years, but the automobile industry recognises the potential for further improvements to engines (and fuels). Nevertheless, most (if not all) of the leading manufacturers have EV programmes.

EVs are undergoing various tests and trials throughout Europe and several vehicles are scheduled for mass-market production in 2011 and 2012.

EVs have been around since the beginning of the automobile, but the ICE became dominant in the early part of the 20th century. Attempts to develop EVs in the past have been frustrated by their poor range and performance, high cost and lack of charging infrastructure. The automobile industry has made considerable improvements in EV technology, but is currently dependent on government subsidies. At the present time, there seems to be a political will to support car manufacturers to develop this technology. The industry needs subsidies to survive the financial crisis. Governments can therefore specify conditions on their support that help to stimulate the industry and secure jobs, but in the longer term might also help them to meet their own targets on CO₂.

The European Automobile Manufacturers Association (ACEA) represents the interests of 15 European car, truck and bus manufacturers. ACEA is committed to developing low- (and ultimately zero-) carbon vehicles, but identifies the following challenges (ACEA, 2010c):

- Customers will have to get used to some specific characteristics of new technologies such as different driving or charging requirements
- The energy sector will have to build a suitable recharging infrastructure, as this will be the prerequisite for customers’ acceptance of electrically chargeable vehicles
- National governments need to provide appropriate market incentives, particularly during the introductory phase of new technology
- The automobile industry is competing to offer attractive electrically chargeable vehicles, while maintaining high safety and comfort standards
- Standardisation bodies and the industry need to agree quickly on standards and common interfaces to avoid fragmentation

While ACEA is generally optimistic about EVs, most stakeholders assume a realistic market share for new, electrically chargeable vehicles (i.e. pure EVs, extended-range EVs and PHEVs) in the range of 3–10% by 2020–2025 (ACEA, 2010c). This corresponds to between 450,000 and 1,500,000 vehicles, based on today’s market.

The European Council for Automotive Research and Development (EUCAR) is an industry association for collaborative R&D. Its membership comprises 12 major European manufacturers of cars, trucks and buses. EUCAR has identified three R&D priorities for the electrification of vehicles (EUCAR, 2009):

- An affordable and safe battery system with improved performance
- An efficient vehicle and energy management system
- A dedicated vehicle-to-infrastructure interface

The progress made in battery technology in recent years is one of the reasons why EVs are starting to become more viable. Nevertheless, further improvements are needed. EUCAR estimates that the range needed for a pure EV under everyday conditions (including energy for comfort functions such as heating and air conditioning) in 2015 will be 150 km (250 km under ideal conditions) (EUCAR, 2009). The corresponding targets quantified by EUCAR that need to be met for lithium-ion battery systems are:

- Performance – Energy density has to be improved to at least 200 Wh/kg by 2020 (150 Wh/kg in 2015); current technologies achieve below 100 Wh/kg
- Durability – Batteries must last 15 years or 5000 deep charge/discharge cycles by 2020 in order to operate the vehicle over its lifetime (without replacement)
- Costs – A cost of less than 150€/kWh has to be achieved by 2020 (300€/kWh in 2015) for a widespread distribution of EVs

Developing a new vehicle (from start of development to end of production) takes time: up to 12 years (ACEA, 2009). The development of a car from design to production takes up to five years. The production phase can last up to seven years. Manufacturers are very keen to emphasise, therefore, the importance of an appropriate lead-time for any change to the legislation to come into force. For example, the European new-car CO₂ regulation was adopted in 2009, but the target of 130 gCO₂/km applies from 2015 and the more stretching target of 95 gCO₂/km applies from 2020 (see Section 2.2.1.7).

2.2.1.6 European Commission strategy and roadmap The overall objective of the Renewed Sustainable Development Strategy of the European Union with regard to sustainable transport, as proposed and developed by the European Commission’s (EC) strategy and roadmap, is “to ensure that our transport systems meet society’s economic, social and environmental needs whilst minimising their undesirable impacts on the economy, society and the environment” (Council of the European Union, 26 June 2006). The related operational objective and targets are to ensure the decoupling of economic growth and the demand for transport with the aim of reducing environmental impacts, achieving sustainable levels of transport energy use and reducing transport GHG emissions and “in line with the EU strategy on CO₂ emissions from light duty vehicles, the average new car fleet should achieve CO₂ emissions of 140 g/km (2008/2009) and 120 g/km (2012)”.

In an accompanying document to the Proposal from the Commission to the European Parliament and Council for a regulation to reduce CO₂ emissions from passenger cars – impact assessment (EC, 2007), the EC described how, in its view, the most appropriate strategy for reducing CO₂ emissions is to place the responsibility with the car manufacturers.
According to the EC, member states are well placed to use fiscal measures to encourage the purchasing of greener vehicles, for example through taxation and fuel duty. However, they have little control over the actual cars that are manufactured. The EC has therefore taken the decision to place the responsibility on car manufacturers for producing “greener” vehicles through the development of new powertrain technologies, while continuing to encourage individual member states to implement fiscal measures that would encourage consumers to buy the “greener” vehicles.

Decarbonisation of the transport system was highlighted as one of the key objectives of the EC in its Roadmap to the Transport White Paper (EC, 2009a), which is expected to be adopted in early 2011. In terms of the development of new, “greener” vehicle technologies, the following issue was highlighted as one of the key points that will be addressed by the White Paper:

- “Market failures in the development of technologies for alternative fuels (setting of standards, funding of demonstration projects, creation of supportive infrastructure).”

The EC appears to be dedicated to meeting its CO₂ reduction targets in the short to medium term and working towards the decarbonisation of transport. As such, it could be expected to intervene in the future and introduce further legislative measures to aid this process, in a similar manner to the new-car regulation.

2.2.1.7 European new-car CO₂ regulation

The EC adopted new legislation in 2009, as part of its New Car Framework, that sets out new-car emission targets for car manufacturers. The targets for average fleet emissions from new cars have been set as 130 gCO₂/km by 2015 and 95 gCO₂/km by 2020. Current average new-car emissions across Europe are 153.5 gCO₂/km (Committee on Climate Change, 2009). From 2011, the EC will set individual targets for each car manufacturer against which their progress will be tracked. Penalties will be put in place for those car manufacturers who fail to meet the targets as follows:

- Between 2012 and 2018, a penalty for each car, of:
  - 5€ for the first gCO₂/km over the target will be imposed
  - 15€ for the second gCO₂/km over the target will be imposed
  - 25€ for the third gCO₂/km over the target will be imposed
  - 95€ for each subsequent gCO₂/km over the target will be imposed
- From 2019, a penalty of 95€ for each gCO₂/km over the target will be imposed
- Penalties for not reaching the 2020 target are to be confirmed by 2019

For the purposes of determining each manufacturer’s average specific emissions of CO₂, the following percentages of each manufacturer’s new passenger cars registered in the relevant year will be taken into account:

- 65% in 2012
- 75% in 2013
- 80% in 2014
- 100% from 2015 onwards

This legislation came about following the failure of the automobile industry to meet its voluntary, self-imposed target of 140 gCO₂/km by 2008/2009 (EC, 2009b). This appears to be a sign that the EC is committed to undertaking the necessary measures to ensure that significant reductions in CO₂ emissions from the road transport sector can be achieved by 2020.

The targets of 130 gCO₂/km and 95 gCO₂/km by 2015 and 2020, respectively, are to be achieved by means of improvement in vehicle motor technology. A further reduction of 10 gCO₂/km is to be achieved by additional measures.

2.2.1.8 Tax incentives

As discussed previously, fuel/energy prices are one means by which the UK government might encourage a move to low-carbon vehicles. That might be achieved by universal measures, which apply for all vehicles. However, a variety of market-changing measures may be used to complement these. Current examples include:

- Electric and hybrid vehicles enjoy exemption from the London Congestion Charging Scheme
- EVs enjoy the use of untaxed fuel, i.e. mains electricity, whereas the fuel for ICE vehicles is heavily taxed
- Electric and low-carbon vehicles enjoy a zero-rate road fund licence
- EVs and other low-carbon vehicles are subject to a UK government subsidy of 25% of the purchase price of the vehicle, up to £5000; this is due to expire in 2014

There are two overlapping issues that any government will need to address:

- What level of subsidy is appropriate and affordable for low-carbon vehicles?
- What should the taxation framework for LCVs be?

At present, the UK government is able to take a benign approach in answering both questions. However if, for example, EVs took over 10% of the car market, this would add to expenditure due to increased subsidies, and would cut revenue in the form of reduced fuel duty and vehicle tax. Careful balancing of the subsidy and taxation framework would be required to prevent a dip in total net revenue.

The approach currently adopted by the UK government of subsidising the purchase of EVs consists of a discount of £2000–£5000 per car, being made available from 2011. According to the Committee on Climate Change (Committee on Climate Change, 2009), this measure is sufficient to encourage EV uptake, under the assumption that purchasers fully value the operating cost savings of EVs and PHEVs. However, it is possible that consumers value the initial purchase price of a vehicle more than the long-term running costs. As a result, the Committee’s report suggests that additional funding should be allocated by the government in order to offer stronger incentives for early adopters, and to enable the establishment of business models such as battery leasing and the education of consumers on the long-term financial benefits of EVs compared with ICE vehicles.

Fuel duty is another possible way to influence consumers’ buying behaviour and ICE vehicle use. In the 2009 UK budget, fuel duty was set at £0.54 per litre. The previous government
did intend to increase the fuel duty by 6p per litre by 2014. However, partly due to the soaring price of fuel in 2011, the UK coalition government announced in its 2011 budget that fuel duty will be reduced by 1p per litre. In addition, the planned increase in fuel price due to inflation has been postponed until January 2012 [Directgov, 28 March 2011].

In addition to fuel duty, the Committee on Climate Change (Committee on Climate Change, 2009) also suggests that road pricing could discourage the use of ICE vehicles, if implemented appropriately. The Committee’s report makes a recommendation to the government to seriously consider the option of road user charging on a national level.
3 Scenarios

3.1 Influencing factors
As discussed in Section 2, there are numerous factors that will influence the attractiveness and take-up of the various types of low-carbon vehicle, including EVs, PHEVs and vehicles powered by alternative fuels, including bio fuels. The influences can be categorised as:

- Policy and legislation – Including the Climate Change Act 2008 and successive legislation, EC regulations and new-car CO₂ output regulations, subsidies and tax incentives.
- Macroeconomic developments – Notably the price of oil and alternative fuels on the world market. Both price and reliability of supply are uncertain in future decades.
- Technical development – In particular, a higher-capacity, inexpensive, lightweight battery could make EVs significantly more attractive.
- Marketing strategies followed by manufacturers’ repricing – For any new consumer product, manufacturers will set a high initial price, both to recoup upfront investment and to exploit the enthusiasm of the early adopters. Normally the price is then reduced to maximise profit, generally by setting a price that keeps demand a little below the normal production capacity. The trajectory depends strongly on the market attractiveness of the product, which influences consumer preference.
- Consumer preferences – Cars are a consumer product and purchase behaviour for private consumers is partly based on logic, i.e. comparison of attributes such as price, including perceptions of potential depreciation, performance and partly on a range of intangible factors, which may or may not be predictable in advance. Prediction is particularly challenging if fashion influences the purchase decision. That is true of the car market.
- New cars sold to fleet and business users – Approximately half of new cars are sold to fleet and business users. Although subject to most of the constraints of private buyers, they are likely to give a higher priority to low maintenance and depreciation costs. It is also worth noting that fleets could provide an entry route into the market for more specialised/niche vehicle types. For example, a shorter-range EV may be less of a problem when used as a pool car for short journeys around an urban area. It could be easier for a business fleet to have a range of different types of vehicle for different types of journey and to have centralised charging and maintenance services. In addition, a business may find it more appealing to have the lower running costs of EVs in the long term (due to lower maintenance and fuel costs) than the comparatively lower initial price of an ICE vehicle in the short term.

All of these factors govern the types of vehicle sold in a particular year. However, the key factor in determining the vehicle mix at a particular time is the sales of a particular model in previous years (Equation 1):

\[
\text{Number of vehicles in category} = \sum (\text{sales} - \text{number scrapped}) \text{ in previous years}
\]

Hence, attempting to develop scenarios for the proportion of EVs in the UK fleet by aggregating these influences and analysing their market impact is likely to be complex and depend on a large number of assumptions. It is unlikely to generate a reliable forecast.

An alternative is to extrapolate from current market conditions. Total car sales in the UK between 2002 and 2007 averaged approximately 2.4 million units per annum, although that dropped to 2.13 million in 2008 and 1.99 million in 2009, as the impact of the economic crisis provoked caution in buyers. Approximately 15,000 of the vehicles sold in 2009 were classified as alternative fuel vehicles (AFVs), and the breakdown is shown in Table 3.1.

Table 3.1 indicates that less than 1% of registrations in 2009 were AFV vehicles and of those only a tiny fraction were pure EVs, dominated by experimental purchases. Hence these figures do not provide a basis for predicting future EV sales although they do indicate market interest in hybrid vehicles. None of the hybrid vehicles on sale are PHEVs, which should retain the low tailpipe CO₂ advantages of EVs for short journeys. Short journeys account for the majority of travel, while removing some of the limited range and range anxieties of pure EVs associated with longer journeys. The low tailpipe CO₂ of EVs and PHEVs will translate to low overall CO₂ emissions if recharging is by green electricity.

Table 3.1 Alternative fuel vehicle sales in the UK in 2009 (Source: SMMT, 2010)

<table>
<thead>
<tr>
<th>Vehicle model/type</th>
<th>Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota Prius</td>
<td>7941</td>
</tr>
<tr>
<td>Honda Insight</td>
<td>2471</td>
</tr>
<tr>
<td>Other</td>
<td>4529</td>
</tr>
<tr>
<td>Electric vehicles</td>
<td>55</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>14,996</td>
</tr>
</tbody>
</table>

Note: The “Other” category includes a range of vehicles, such as liquefied petroleum gas-powered vehicles, gas/electric vehicles and special hybrids including experimental taxis.
Clearly, manufacturers are likely to prepare their own market predictions as part of the development of their manufacturing strategy. At a press launch on 17 May 2010, Simon Thomas of Nissan announced that the company expected that “electric cars would account for no more than a tenth of global car sales by 2020”. However, Warren Buffett, who has invested in BYD, a Chinese EV manufacturer, has predicted that 100% of cars sold in 20 years’ time will be electric.

Most of these predictions are in press reports of one form or another, not formal publications. A scan of internet sources reveals a range of predictions, summarised in Table 3.2.

Table 3.2 reveals two key findings. One is that the predictions span a broad range of scenarios, from one where EVs have a marginal impact on the car market to another where they dominate it. The most conservative prediction comes from a body that advises investors, while the others are from organisations that arguably have an interest in “talking up” the potential market.

These figures are for the proportion of sales that will be gained by EVs in the relevant year. As discussed above, the proportion of vehicles in the UK car fleet depends on the history of sales minus scrappage over a period of years. If the 2020 figures were maintained indefinitely and EVs had the same life expectancy as other vehicles then the proportion in the fleet would be the same. In reality, 2020 is so close to the present day that the sales trajectory would still be increasing so the proportion of EVs in the fleet would also be increasing. Hence, there is considerable uncertainty attached to any scenario for the introduction of EVs.

### 3.1.1 Possible scenarios

The broad uncertainty over the number and trajectory of the sales of EVs over the next 20 years suggests that almost any scenario for market penetration is valid. Hence, in the absence of figures to the contrary, for the remainder of this Insight Report we have adopted the scenarios adopted by the Department for Business, Enterprise and Regulatory Reform (BERR) and the DfT (BERR and DfT, 2008). The report emphasises that “the scenarios do not represent forecasts or estimates of the future” and that their main use is to allow calculations of energy use and CO2 output. However, adoption of these figures for this report ensures consistency and allows potential linkage of the results of this study and those conducted for that report.

The BERR/DfT model uses four possible scenarios described in Table 3.3. Their main characteristics are described below.

#### 3.1.1.1 Business as usual

**This scenario is based on the assumption that no further action is taken to encourage EVs and that only existing incentives continue. This leads to a number of following assumptions:**

- **Limited charging point infrastructure exists only in London and a few other major cities**
- **The oil-to-electricity price differential is maintained, or becomes more favourable to electricity**
- **Whole-life cost parity is reached around 2030**
- **The major obstacle to widespread adoption of EVs is the availability of cheaper ICE and hybrid vehicles**

### Table 3.2 Electric vehicle take-up predictions

<table>
<thead>
<tr>
<th>Source</th>
<th>Market predictions for electric vehicles</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nissan (Simon Thomas)</td>
<td>Up to 10%</td>
<td>2020</td>
</tr>
<tr>
<td>HSBC Analysts</td>
<td>4.75%</td>
<td>2020</td>
</tr>
<tr>
<td>Renault (Carlos Ghosn)</td>
<td>20%</td>
<td>2020</td>
</tr>
<tr>
<td>Warren Buffett</td>
<td>100%</td>
<td>2030</td>
</tr>
<tr>
<td>Better Place Ltd (Shai Agassi)</td>
<td>50%</td>
<td>2020</td>
</tr>
</tbody>
</table>

Note: Better Place Ltd is a supplier of software to manage charging infrastructure.

### Table 3.3 Number of electric vehicles in the UK vehicle fleet (Source: BERR and DfT, 2008)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EV</td>
<td>PHEV</td>
<td>EV</td>
</tr>
<tr>
<td>Business as usual</td>
<td>3000</td>
<td>1000</td>
<td>70,000</td>
</tr>
<tr>
<td>Mid range</td>
<td>4000</td>
<td>1000</td>
<td>600,000</td>
</tr>
<tr>
<td>High range</td>
<td>4000</td>
<td>1000</td>
<td>1,200,000</td>
</tr>
<tr>
<td>Extreme range</td>
<td>4000</td>
<td>1000</td>
<td>2,600,000</td>
</tr>
</tbody>
</table>

Note: There are major discrepancies between the figures in the DfT report and those provided by the SMMT. For example, the SMMT indicates that only 55 electric vehicles were sold in 2009 whereas the DfT report indicates that 1000 were sold in 2007. One explanation may be that the SMMT does not include vehicles with only B1 type approval, such as the G-Wiz. It has not yet been possible to fully resolve the discrepancies.
This scenario is an example of an extreme outcome that could result from lack of additional incentive to car manufacturers and consumers. This scenario appears to be unlikely as UK government incentives, such as the Climate Change Act 2008, and European policies, such as new-car emissions legislation, combined with possible increases in fuel prices, suggest that additional measures could be taken as it appears to be in all parties’ best interests. This type of scenario, however, is a useful reference case.

### 3.1.1.2 Mid range

This scenario is based on the current trend for environmental measures being maintained. The report used a figure that suggested a target of 11.7% of all cars being able to connect to the National Grid by 2030. However, since the report was written in 2008, new targets suggested by the Committee on Climate Change (Committee on Climate Change, 2009) could lead to a larger number of cars being connected to the grid by 2030, up to 27% of all vehicles (cars and light vans).

This scenario also assumes that most new EVs by major manufacturers will not come onto the market until 2014 or 2015. However, a brief internet search, summarised in Table 3.4, shows that currently a number of EVs are expected to be available from 2011 in the UK.

Although initial production volumes of these vehicles are expected to be low – in the region of 20,000–30,000 vehicles per year – if numerous models are launched around the same time aggressive marketing and manufacturing strategies could be adopted by the manufacturers in order to remain competitive and not lose market share to competitors. Even in such a situation, EVs are not expected to be widely available prior to 2014 at the earliest, due to manufacturing constraints. Some expected dates for the introduction of EVs are shown in Table 3.4.

This scenario also assumes that whole-life costs of an EV are comparable to those of an ICE vehicle by 2015. However, in the absence of strong incentives and higher cost of EVs compared with similar ICE vehicles, adoption rates for EVs would not pick up considerably until 2030. Much like the point made on the business-as-usual scenario, this scenario does not take into account recent developments in government and European policies, as well as reports suggesting a rapidly approaching “peak oil” scenario. As a result, it is possible that higher adoption rates of EVs could be seen in the UK by 2030.

### 3.1.1.3 High range

This scenario is based on strong incentivising for grid-connected vehicles, not only by the UK government but also by other countries so that it is economically viable for car manufacturers to produce EVs in large volumes. Once again it is assumed that whole-life costs of EVs will attain parity with ICE vehicle by 2015, and that with the addition of incentives and infrastructure development EVs can start becoming widely adopted post-2020.

This scenario appears to be in line with the recommendations made in the Committee’s report (Committee on Climate Change, 2009) to the government while remaining realistic according to the predictions, in Table 3.2, of around 4% of the vehicle fleet. A combination of this level of EV take-up and the possibility of the increase in fuel prices reported by ITPOES (Branson et al., 2010) and Professor John Beddington (Beddington, 2009) suggests that this could be a very possible scenario.

### 3.1.1.4 Extreme range

Similar to the business-as-usual scenario, this scenario is unlikely but does demonstrate the full possible potential of EV adoption rates. It is a useful reference case that sets an upper boundary on the possible number of EVs in the UK vehicle fleet by 2030. Such a scenario is only possible by renewing 8% of the UK vehicle fleet each year with new cars. In addition, after 2025 almost all of the cars sold each year would have to be EVs.

Table 3.3 estimates the number of vehicles in the fleet, but the authors of this Insight Report wish to stress that the figures are likely to be dominated by cars or light vans. The table illustrates the difficulty of predicting sales of EVs. It predicts 1000 PHEVs in 2010 but the first of these was not available on the market until early 2011. The first UK-made electric hybrid capable of running solely on an electric motor will be launched in 2011 but it lacks the capability for external charging.

The other key parameters in determining the proportion of EVs and PHEVs in the typical traffic stream are the total number of vehicles in the UK fleet and the travel patterns of these vehicles, in terms of distance covered and the location of driving.

The size of the UK vehicle fleet can be extrapolated from the current figures. Future growth is very uncertain and will be influenced by the population and rate of individual vehicle ownership, which will in turn depend on a range of economic and social factors.

### Table 3.4 Electric vehicles expected to enter the market from 2011

<table>
<thead>
<tr>
<th>Car</th>
<th>Expected to be on sale from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volkswagen Golf Twindrive</td>
<td>2011</td>
</tr>
<tr>
<td>Toyota Prius PHEV</td>
<td>2011</td>
</tr>
<tr>
<td>Mitsubishi i-MiEV</td>
<td>2011</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>2011</td>
</tr>
<tr>
<td>BYD F3DM</td>
<td>2011</td>
</tr>
<tr>
<td>Vauxhall Ampera</td>
<td>2012</td>
</tr>
<tr>
<td>Volkswagen E-UP</td>
<td>2013</td>
</tr>
</tbody>
</table>

Note: This is not an exhaustive list but rather a demonstration of current expectations.
Traffic growth and vehicle ownership forecasts are prepared by the DfT. These suggest that the total number of cars on British roads will increase by 19.8% between 2010 and 2025 and the total distance travelled by car will increase by 14.4%, i.e. the average distance travelled per vehicle will reduce (DfT, 2009a). Linear extrapolation suggests that the total number of cars will increase by 13.2% by 2020 and by 26.4% by 2030 and the total distance travelled by 19.2% by 2030.

Again all of these figures are subject to considerable uncertainty. They will depend on a range of social and economic factors as well as government policy and the price of the various fuels.

There were 32.5 million cars and light vans on UK roads in December 2009. If that is scaled up by 26.4% it gives a figure of 41 million. The figures in Table 3.5 and Figure 3.1 have been divided by the relevant car fleet size figure to show the percentages of vehicles on the road that are EVs and PHEVs under the various scenarios.

If it is assumed that the average annual miles driven by EVs and PHEVs is the same as for ICE vehicles then the primary conclusion from Table 3.5 is that under the majority of scenarios EVs are likely to make up a relatively small proportion of the vehicle fleet and traffic stream. In practice EVs may be likely to cover smaller annual mileages than PHEVs or ICE vehicles and the proportions of the distance covered will be lower than the proportions of vehicles in the fleet.

Both EVs and PHEVs are likely to appear to drivers with particular patterns of vehicle use. EVs are likely to be clustered in urban areas, where journeys tend to be shorter, so reducing the potential impact of range limitations and where there may be financial incentives to adopt vehicles with zero tailpipe emissions. Since about 54% of all driving currently takes place on urban roads, it seems reasonable to assume that the proportion of EVs on those roads will be approximately double the figures shown above and close to zero for interurban roads.

The need to cluster PHEVs is less clear cut. Current hybrids, such as the Prius, Auris and Insight, tend to have engines little smaller than the equivalent fully ICE-powered car and will be able to match one in terms of acceleration and maximum speed. However, since the onboard ICE will only be used for some journeys, and even then for only part of the time, it would seem sensible to use a smaller, lighter engine to optimise economy and maximise range while running on battery.

The absence of mass-market PHEVs makes it difficult to determine how drivers’ preferences and the marketing specialists of companies will shape development. In principle it will be possible to develop a PHEV with much the same range and performance as a current ICE-powered car. However, economy would be optimised by accepting a slightly lower constant power output on long journeys at constant high speeds, e.g. long-distance motorway travel.

In terms of meeting the targets set by the Committee on Climate Change (Committee on Climate Change, 2009), the high-range scenario appears to be in line with those targets. The report set a target of 240,000 EVs and PHEVs to be delivered through pilot projects by 2015, and 1.7 million by 2020. From Figure 3.1 it can be seen that if the government meets the target proposed by the Committee’s report for 2020, it would then be following the high-range scenario; in which case, it is possible that by 2030 there will be over 20 million EVs in the UK vehicle fleet, over 5 million of which could be fully electric vehicles.

3.1.2 Are these scenarios consistent with the CO₂ reduction targets?

The key requirement for the UK is to meet the CO₂ reduction targets set out in the Climate Change Act 2008. This requires a reduction of 80% in CO₂ emissions by 2050. The Royal Academy of Engineering has concluded that if transport (all modes) continues to grow in line with current trends and the 80% figure is applied to that, it implies a cut of 92% cut in CO₂ generated per mile travelled in comparison with 1990 levels (Royal Academy of Engineering, 2010). That implies a 92% cut in fossil fuel use, at current extraction efficiencies. If high-carbon fossil fuels, notably those extracted from tar sands, come into general use then a greater cut would be required.

The Term 2009 report (EEA, 2010) reached the conclusion that in order to meet the 2050 target a range of measures would need to be implemented. Measures should encompass continued development of technology and the adoption of new government policies, such as a reduction in speed limits and changes in land use, that reduce the need for extensive travel. It is outside the scope of this project to discuss the possible ways in which the 2050 target could be met but it is recognised that electrification of transport alone is unlikely to meet that target.

It is debatable how far the residual 8% can be allocated to car travel. Liquid hydrocarbon fuels, i.e. the residual 8% and sustainable bio fuels, are likely to be required by the aviation and shipping industries, which have limited scope to electrify their motive power and are likely to be able to pay a premium for such fuels. It might also be difficult to develop electrically powered long-distance goods vehicle road transport although there is scope to move some types of freight to electrically

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2010 EV</th>
<th>2010 PHEV</th>
<th>2020 EV</th>
<th>2020 PHEV</th>
<th>2030 EV</th>
<th>2030 PHEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business as usual</td>
<td>0.01%</td>
<td>0</td>
<td>0.19%</td>
<td>0.54%</td>
<td>1.2%</td>
<td>6.1%</td>
</tr>
<tr>
<td>Mid range</td>
<td>0.01%</td>
<td>0</td>
<td>1.5%</td>
<td>0.54%</td>
<td>3.9%</td>
<td>6.1%</td>
</tr>
<tr>
<td>High range</td>
<td>0.01%</td>
<td>0</td>
<td>3.01%</td>
<td>0.95%</td>
<td>8.0%</td>
<td>19.2%</td>
</tr>
<tr>
<td>Extreme range</td>
<td>0.01%</td>
<td>0</td>
<td>7.06%</td>
<td>1.35%</td>
<td>14.1%</td>
<td>36.1%</td>
</tr>
</tbody>
</table>
powered rail for at least part of the journey. Hence, a business-as-usual transport scenario for 2050 implies fossil fuel consumption per mile travelled at less than 8% of the current figure, possibly significantly less. The King Review (King, 2008) suggests that fuel economy improvements/CO₂ output reductions for personal car transport in the period up to 2030 can mainly be achieved by smaller, more efficient vehicles augmented by the various categories of EV. That is compatible with all of the vehicle ownership scenarios implied by the EV and PHEV penetrations in 2030 outlined in Table 3.3. Beyond that there would be a shift to EVs and PHEVs primarily powered by green electricity.

Table 3.3, extracted from the BERR/DfT report, suggests that by 2030 PHEVs are likely to dominate the market and outsell conventional EVs by a factor of 2:1 or more. A PHEV is attractive because it should largely eliminate range anxiety. Also, the ability to bring in the ICE at points where the battery is nearing exhaustion should mean that a smaller, lighter battery may be used. However, if the battery is too small and the onboard motor generator is used excessively then the targets for fossil fuel reductions are unlikely to be met. These will need to become progressively lower in the period between 2030 and 2050. Hence, even for PHEVs it will be desirable that the majority of vehicle use is in the electric-only mode.

The characteristics of EVs and PHEVs required to satisfy the road transport requirements can be estimated using the distribution of trip lengths. These are shown in Table 3.6. Analysis by Element Energy (Element Energy, 2009) suggests that, based on UK National Travel Survey 2006 figures, an EV capable of an electric-only range of 40 miles would be able to cover 80% of all trips, which corresponds to 44% of total distance driven, due to the large proportion of short trips. Table 3.7 shows how this compares with anticipated electric-only ranges of some EVs expected to be introduced in the UK from 2011 onwards.

It can be seen from Table 3.7 that maximum electric-only ranges of this selection of EVs vary from 14.5 to 100 miles. However, the figures are not directly comparable as they are derived using a variety of maximum speeds and test cycles ranging from low speeds in urban cycles to high speeds in interurban cycles. As well as highlighting the issue of uncertainty at what type of use EVs should be aimed at, these data also show that a wide range of more specialised EVs could be available to consumers. This would enable consumers to make a purchase decision based on available budget and the type of travelling the EV would be required for. Out of the list of EVs in Table 3.7, five out of seven would be capable of achieving a 40-mile range using only electric power.

A more thorough examination of possible combinations of vehicles in the UK vehicle fleet by 2030, their specifications and characteristics, and the impacts that those may have on traffic and transportation for TRL will be carried out in Stage 2 of the project.

![Figure 3.1 Possible 2030 scenarios](image_url)
### Table 3.6 Individual car/van trip length distribution (Source: DfT 2009b)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Proportion of all trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 mile</td>
<td>6%</td>
</tr>
<tr>
<td>&lt; 2 miles</td>
<td>22%</td>
</tr>
<tr>
<td>&lt; 5 miles</td>
<td>56%</td>
</tr>
<tr>
<td>&lt; 10 miles</td>
<td>77%</td>
</tr>
<tr>
<td>&lt; 25 miles</td>
<td>94%</td>
</tr>
<tr>
<td>&lt; 50 miles</td>
<td>98%</td>
</tr>
<tr>
<td>&lt; 100 miles</td>
<td>99%</td>
</tr>
<tr>
<td>All lengths</td>
<td>100%</td>
</tr>
</tbody>
</table>

Note: A trip is defined as a one-way stage. For example, a drive to a destination five miles away would count as one trip, the return as another.

### Table 3.7 Maximum electric-only ranges

<table>
<thead>
<tr>
<th>Car</th>
<th>Expected to be on sale from</th>
<th>Maximum range (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vauxhall Ampera¹</td>
<td>2012</td>
<td>40</td>
</tr>
<tr>
<td>Toyota Prius PHEV²</td>
<td>2011</td>
<td>14.5</td>
</tr>
<tr>
<td>Nissan Leaf³</td>
<td>2012</td>
<td>100</td>
</tr>
<tr>
<td>Mitsubishi i-MiEV⁴</td>
<td>2011</td>
<td>80</td>
</tr>
<tr>
<td>BYD F3DM⁵</td>
<td>2011</td>
<td>68</td>
</tr>
<tr>
<td>Volkswagen E-UP!⁶</td>
<td>2013</td>
<td>80</td>
</tr>
<tr>
<td>Volkswagen Golf Twindrive⁷</td>
<td>2011</td>
<td>30</td>
</tr>
</tbody>
</table>

1 Source: www.vauxhall-ampera.co.uk/index.php/eng/ampera/how_it_works/erev_volttec
2 Source: http://en.wikipedia.org/wiki/Toyota_Prius
3 Source: www.nissan.co.uk/?cid=pselectricvehicleUK_en#electricvehiclelocuk&kw=Nissan_leaf#vehicles/electricvehicles/leaf/leaf-engine/
specifications
4 Source: www.mitsubishi-cars.co.uk/imiev/introduction.aspx#imievContentContainer
5 Source: www.byd.com/showroom.php?car=F3dm
6 Source: www.volkswagen.co.uk/volkswagen-world/news/item/181/futures
4 Modelling of electric vehicle take-up

As described in Section 3.1.1, a high-range prediction for the number of EVs in the UK vehicle fleet was selected from a DfT report (BERR and DfT, 2008) as the most probable scenario for EV adoption by 2030. In order to understand how different factors that contributed to this outcome affect the overall uptake, a model was created to examine the sensitivities of those factors.

The model is based on a parity approach, where any new technology is compared with the market-dominant technology in terms of key factors that would enable a consumer to make a decision to switch to the new technology. In the case of this report, pure EVs and PHEVs are considered, and are compared with ICE vehicles, as these are believed to be the dominant types of vehicle within the timeframe of this report. It is assumed that in most cases the dominant technology in the market is also the best performing. It should be noted, however, that around the year 2030 other technologies such as fuel cells may begin to be best performing in certain areas. However, vehicles based on this technology are not likely to be ready for mass-market penetration at this stage and are therefore not considered in the model.

This model attempts to simulate how consumers will perceive EVs when compared with ICE vehicles as these are likely to remain the dominant vehicle type up to 2030, and therefore, how likely they would be to switch away from ICE vehicles. Figure 2.1 shows factors that are considered to be key in influencing a possible 2030 scenario. Those factors can be grouped further into areas of influence. Table 4.1 maps those factors identified in Figure 2.1 to the areas of influence to which they are expected to contribute.

In the model, each of those primary areas of influence is considered separately in terms of its parity with the market-leading vehicle type. Then the overall parity is determined based on those individual component parities. Using the overall parity effect combined with the elasticity effect of fuel price, a model was created for EV adoption up to 2030. A more detailed explanation of how the model works can be found in Appendix A.

Once parities were determined for each area of influence, the output of the model was calibrated to match the adoption rates of the high-range scenario in Table 3.5. A graph was then produced that represents consumer behaviour as a mechanism for checking that the model follows logical adoption behaviour for a given technology parity.

Two separate models were produced to represent pure EV and PHEV adoption rates. Below are some examples of modelled adoption rates and the effects on them of different potential scenarios.

Table 4.1 Areas of influence used in the model

<table>
<thead>
<tr>
<th>Primary areas of influence</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>UK Climate Change Act 2008</td>
</tr>
<tr>
<td></td>
<td>EC strategy and road map</td>
</tr>
<tr>
<td></td>
<td>Technology development</td>
</tr>
<tr>
<td></td>
<td>Consumer attitudes and behaviour</td>
</tr>
<tr>
<td>Running costs</td>
<td>UK Climate Change Act 2008</td>
</tr>
<tr>
<td></td>
<td>Tax incentives</td>
</tr>
<tr>
<td></td>
<td>Technology development</td>
</tr>
<tr>
<td></td>
<td>Consumer attitudes and behaviour</td>
</tr>
<tr>
<td>Performance</td>
<td>European new-car CO₂ regulations</td>
</tr>
<tr>
<td></td>
<td>Technology development</td>
</tr>
<tr>
<td></td>
<td>Automobile industry</td>
</tr>
<tr>
<td></td>
<td>Consumer attitudes and behaviour</td>
</tr>
<tr>
<td>Range</td>
<td>European new-car CO₂ regulations</td>
</tr>
<tr>
<td></td>
<td>Technology development</td>
</tr>
<tr>
<td></td>
<td>Automobile industry</td>
</tr>
<tr>
<td></td>
<td>Consumer attitudes and behaviour</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>Price of fuel</td>
</tr>
<tr>
<td></td>
<td>Consumer attitudes and behaviour</td>
</tr>
</tbody>
</table>
4.1 Extreme case scenario 1: slow uptake
Slower-than-anticipated development and installation of charging infrastructure, through lack of government incentives and private initiatives, could lead to a significant drop in the uptake of pure EVs. In such a scenario, infrastructure parity for EVs will not rise above 25% of the leading technology, the ICE vehicle. This would mean that EV infrastructure, charging stations or battery swap stations, specialised garages, etc., would be perceived to be only developed to 25% of a complete infrastructure by 2030.

If this is then combined with a slower-than-expected decrease in the price of EVs and battery technology, and lower levels of government incentives for purchasing EVs, the effect is that EVs may only make up 1.73% of the UK car fleet in 2020 and 3.25% in 2030, as Figure 4.1 shows.

It is noted that for the period 2010–2015 the model is not considered to be accurate, due to the formula used to model adoption rates being better suited for later years.

The adoption rates in this case are approximately half of those in the selected scenario for this report and are believed to be the lowest probable adoption rates assuming other parities remain unchanged.

The model also shows that the effect on PHEV uptake is more extreme than that on EV uptake. Although infrastructure is not considered to be as key for PHEVs as for EVs due to the fact that they are still able to use existing ICE vehicle infrastructure, the effect of having less well developed infrastructure than anticipated still has a considerable impact on PHEV adoption. Assuming infrastructure for PHEVs will be perceived to be 70% of that for ICE vehicles and assuming that PHEVs will not be perceived as better value than they are currently, the overall adoption of PHEVs will be very limited by 2030. Figure 4.2 shows that PHEVs may make up only 0.30% of the car fleet in 2020 and less than 3% in 2030 based on those assumptions.

Reduced PHEV adoption in this scenario is explained by the underlying assumption in the modelling that the period 2020–2030 will see a rapid growth of the PHEV installed base due to a number of key-factor parities becoming sufficiently high to facilitate mass-market penetration. This, then, also holds true in reverse: inability to achieve those key parity values will lead to significantly reduced PHEV adoption rates, as the adoption never quite makes it into the mass-market penetration phase. This suggests that even a small change in the perceived parity of any one of the key areas of influence can lead to very large changes in 2030 adoption rates for PHEVs.

The combined percentage of EVs and PHEVs by 2030 in this case could be around 6.11%. This percentage is comparable with that identified in Table 3.5 for the lowest proportion of EVs and PHEVs in the UK vehicle fleet of 7.3%, which the DfT report referred to as the business-as-usual case.

4.2 Extreme case scenario 2: fast uptake
The other extreme case is that EVs and PHEVs may go through a much faster adoption by consumers than is anticipated in the next 20 years. This could happen as a result of charging and other relevant infrastructure for EVs being developed at a faster-than-anticipated pace. If, by 2030, infrastructure for EVs is perceived to be 80% fully developed, then that would likely increase the total number of EVs and PHEVs in the UK car fleet by 2030, as Figure 4.3 shows.

Modelling suggests that in such a scenario, the proportion of EVs in the UK car fleet could be 4.6% in 2020 and up to 15.4% in 2030. The reason for the large increase is that, assuming the rest of the factors and parities remain as in the base-case scenario, EV charging and other essential infrastructure is a key factor for many people in choosing to switch to EVs and, therefore, a perceived improvement in the parity of the EV infrastructure may lead to significant increases in EV adoption rates. This is especially true for pure EVs, as they are not able to use existing refuelling infrastructure. As the shape of the curve in Figure 4.3 suggests, even in this extreme scenario EV adoption rates are not likely to increase significantly until after 2020. This appears to make sense, as the development of infrastructure is likely to take some time. Programmes such as OLEV’s PiP are scheduled to run for three to four years, starting in 2010, and are being developed as catalysts for further government, independent and private development of infrastructure.

A similar trend can be seen in PHEV adoption rates, as shown in Figure 4.4, where an increase in infrastructure parity to a very high level of 90% by 2030 can lead to the percentage of PHEVs in the UK car fleet being as high as 39% by 2030. Such a scenario is thought to be very unlikely due to the difficulty associated with creating PHEV infrastructure to be almost on par with ICE infrastructure. In addition, almost a 35% rise in the proportion of PHEVs between 2020 and 2030 would be very difficult to achieve with current new-vehicle buying trends: assuming new vehicles registered each year correspond to approximately 7% of the UK car fleet, it would mean that more than half of all new vehicles registered each year between 2020 and 2030 would have to be PHEVs.

Although this scenario is considered to be extreme and unlikely, it does highlight the sensitivity of the market to faster-than-anticipated developments in key factors, such as cost and infrastructure.

The combined percentage of EVs and PHEVs by 2030 in this case could be around 55%. This percentage is comparable to that identified in Table 3.5 for the highest proportion of EVs and PHEVs in the UK vehicle fleet of 50.2%, which the DfT report referred to as the extreme case.
Figure 4.1 Electric vehicle adoption rates – extreme case scenario 1

Figure 4.2 Plug-in hybrid electric vehicle adoption rates – extreme case scenario 1
Figure 4.3 Electric vehicle adoption rates – extreme case scenario 2

Figure 4.4 Plug-in hybrid electric vehicle adoption rates – extreme case scenario 2
5 Implications for traffic and transportation

5.1 Characteristics of electric vehicles
As identified earlier in this report, it is likely that by 2030 PHEVs and pure EVs will be the only types of AFV sufficiently developed for significant market penetration to take place. This section of the report therefore ignores fuel cells as a potential fuel source.

Most EVs and hybrids currently in production or close to production have been designed to be as similar as possible to ICE vehicles and are marketed as such. This appears, at least in part, to be an attempt to provide comfort to drivers that these cars will behave and operate in a manner they are familiar with. If this trend continues, changes to the nature of traffic and transportation may be subtle.

There are a variety of hybrid vehicles at or near to market, and these operate in several different ways. Conventional hybrids such as the Toyota Prius require the use of both an ICE and an electric motor depending on the journey length and characteristics, but the forthcoming Vauxhall Ampera is an extended-range electric vehicle, using an ICE to generate electricity once the battery has run out, which still results in the vehicle being powered by the electric motor. It is assumed that when a hybrid is driven in electric-only mode it behaves like a pure EV, otherwise it behaves like an ICE-powered vehicle.

In order to understand what implications there may be on traffic and transportation in a scenario where a wide adoption of EVs is taking place by 2030, an understanding of the likely characteristics of upcoming EVs is required. Some of the characteristics of the EVs either near to market or already available are discussed below (in practice this is a combination of pure EVs and hybrid vehicles operating in electric-only mode).

5.1.1 Acceleration
An electric motor has continuous torque and therefore has almost the same horsepower at any speed, though an electric motor is more efficient at high rotational speeds. For this reason, an EV can usually be expected to have better acceleration from standstill than an ICE vehicle.

5.1.2 Top speed
Among the new models about to enter production, top speed varies between approximately 80 mph and 100 mph. This, although lower than most ICE vehicles, is likely to be perceived as sufficient by the majority of drivers.

5.1.3 Coasting/regenerative braking
EVs do not experience engine braking so would coast when not under acceleration. However, mild regenerative braking can be applied to produce a similar effect in EVs to that encountered in ICE vehicles. This could have the dual benefit of charging the battery while keeping performance and handling of the vehicle close to what is expected by drivers based on their experience with ICE vehicles.

5.1.4 Braking
Whether the car is powered by electricity or liquid fuel, the braking system must comply with United Nation’s Economic Committee for Europe (UNECE) Regulation 13. Therefore, braking systems in EVs are likely to be similar to those in ICE vehicles.

5.1.5 Weight
The smallest ICE “superminis” such as the Smart Car and Toyota Aygo tend to weigh in the region of 800 kg. For slightly larger cars, such as the Ford Fiesta or Vauxhall Corsa, the weight rises to around 1000 kg.

Many EVs at or near to market are superminis. Due to the weight of the batteries they have typically weighed more than ICEs of equivalent size. Because it is crucial to minimise the vehicle weight to increase the range, they tend to have less interior space for passengers and luggage. It is worth noting that the weight of many near or new-to-market EV superminis is similar to comparable ICE vehicles, such as the Citroen C1 ev’ie (900 kg), THINK City EV (1038 kg) and Mitsubishi i-MiEV (1080 kg). The slightly larger EVs, such as the Vauxhall Ampera or Nissan Leaf, are likely to be heavier than their ICE counterparts, at around 1600 kg.

5.1.6 Range
The quoted range varies greatly, from approx 40 miles to 100 miles or more. However, the range reported depends upon the drive cycle used for testing. Electric motors are generally most efficient at about 75% of rated load (US Department of Energy, n.d.), although larger motors such as those found in cars have a wider range of good efficiency. Some 75% of rated load is reported to correspond to approx 65 mph for the Nissan Leaf (Tverberg, 2010) so operating at this speed should be most efficient. It is worth noting that although EVs are suitable for driving at low speed, stop-start driving conditions working at loads down to 25% of the rated load are less efficient, so the range of such vehicles would improve if the power (and therefore maximum speeds) were lower. In general, there appears to be a trade-off between the maximum power of the electric motor and its efficiency at lower loads.

The range is also heavily dependent on what demands other than propulsion are placed on the battery. An ICE is so inefficient because much of the chemical energy is converted to heat, but this does mean that in winter there is a ready source of heat available. EVs produce very little heat, so to warm the car requires an auxiliary heater, which could drain a lot of power from the battery. In a similar manner, the use of air conditioning in an EV will have a strong impact on the vehicle’s range if used while in transit.

A potential solution could be to use a remote connection (3G or GSM) to a vehicle to control and pre-set desired temperature in the vehicle while it is charging, through a device such as a Smartphone. This approach has been adopted by the Nissan Leaf with the introduction of a dedicated “app” on the iPhone that can be used to pre-heat or pre-cool the car remotely (Fehrenbacher, 2010). With such a solution, a much smaller amount of energy will be required to maintain the temperature inside the vehicle.
5.1.7 Fuel efficiency
Unlike ICE vehicles, EVs are more efficient in stop-start driving conditions than on the highway, as they have a near-constant tank-to-wheel efficiency at all speeds, use no power when idling and regenerate energy to the batteries when braking. This would therefore imply that EVs would be best suited, at least in their current state and in the near future, for urban travel. However, even if the EV is not as efficient on longer journeys at higher speeds, it is still more environmentally friendly than an ICE, as long as its electricity comes from renewable sources.

5.1.8 Winter
Batteries have an optimum operating temperature range and winter temperatures can drop below this. Older EVs therefore had decreased range on a full charge in winter compared with summer (Didik, 1992). This phenomenon is little reported now, so it is probable that the development of batteries has eliminated or reduced this problem significantly. Therefore, lower operating temperatures may not be a significant problem but the issue of keeping the vehicle at comfortable temperature remains, as discussed in Section 5.1.6.

5.1.9 Maintenance
Because EVs have fewer working parts they are expected to prove more reliable than ICE vehicles in the long term. However, the longevity of batteries used in EVs remains a potential issue. It is understood that most batteries’ ability to store charge will decrease with charge cycles. How this may affect the maintenance of EVs is not yet clear but is likely to depend on the type of business models adopted for EVs. For example, who owns the battery? Or, are batteries recharged or is a battery swap system adopted? In any case, the battery is likely to be the part of an EV, out of the key powertrain and drivetrain components, that requires the most maintenance.

5.2 Implications of pure electric vehicles
5.2.1 Urban driving
5.2.1.1 Suitability
Due to their compact size and relatively quick acceleration, not to mention their increased efficiency in such conditions, EVs seem entirely suited to the crowded and stop-start nature of urban driving. Most journeys undertaken within urban environments tend to be short, either for commuting to work or elsewhere within the locale, allowing for the vehicles to be charged solely at home overnight. It has been reported that current users prefer the comfort of charging the vehicles at home (Carney, 3 April 2010), but this is likely to be at least in part due to the current lack of suitable charging infrastructure so current users of EVs are those who are content to charge batteries at home and have the facilities to do so.

In the time frame that is considered in this report – up to 2030 – it is likely that the majority of EVs in the UK vehicle fleet will be similar to the ones that are currently being planned for release by 2015. As such, EVs will probably be most used for urban driving. This could lead to a higher percentage of EVs making up shorter journeys than longer, motorway-based ones. It was pointed out earlier that EVs are likely to have higher acceleration than similar ICE vehicles. However, there also appears to be a trend towards making EVs as familiar to users as possible in terms of performance. Therefore, in an urban context, the performance of EVs is unlikely to be drastically different to that of their ICE equivalents. This leads to the conclusion that the impact on traffic and transportation may be very limited.

A potential area that could be affected by the introduction of EVs is the urban traffic control (UTC) system. Systems such as SCOOT (Split Cycle Offset Optimisation Technique) rely on estimating traffic progression between signalised junctions. As part of this estimate, typical vehicle acceleration is included in the calculation. However, due to user familiarity and potential safety concerns, EVs used in urban environments are unlikely to have acceleration much greater than that of current ICE vehicles. Combined with the estimate, derived from modelling, that EVs are likely to make up approximately 10% of the UK vehicle fleet, the overall impact on UTC such as SCOOT is likely to be very small.

If a more substantial proportion of the UK vehicle fleet, in urban environments, consisted of EVs, either at a later date or through a higher-than-anticipated EV uptake, then further modelling could be performed to determine how UTC systems could be optimised for increased average acceleration.

5.2.1.2 On-street parking infrastructure
As increased adoption of EVs occurs, more specialist parking with charging points will be required. This could lead to conflict in areas of high parking demand. If separate spaces have to be set aside for EVs and ICE-powered vehicles, it will be necessary to carefully balance the supply of charging points with demand. If too few charging points are provided in areas of high demand then this may prove a disincentive to the take-up of EVs, while too many could disenfranchise ICE vehicle owners.

Development of publicly available charging infrastructure for EVs will require a coordinated development of ITS that is able to provide a link between the “intelligent” charging infrastructure and the vehicle. In order to address the issue of range anxiety and optimise the use of limited charging infrastructure, an EV driver should be aware of what charging spaces are available, where and when. This would then be linked to a booking system, such that a driver could check where the nearest available charging points are and could book one. Such a system could, in theory, be based on ITS such as CVIS (Cooperative Vehicle-Infrastructure Systems) technology trialled in London as part of CVIS Cooperative Fleet and Freight Applications (CVIS project, n.d.). As part of the trial, a specially equipped loading bay could be booked via an online application and provide data on its availability for delivery drivers in time for their arrival to the location.

5.2.1.3 Car clubs
Car clubs are a growing trend within urban environments. Users who do not regularly require a car may hire vehicles for periods from half an hour through to several days. EVs may well be suitable for such applications and along with fleet lease companies these clubs may be some of the first purchasers and large-scale adopters of EVs. This potentially exposes a large number of people to EVs, and if they enjoy driving them and see benefit in doing so this could increase early uptake.
Currently, car clubs use allocated parking spaces that are reserved for their use. Such spaces could be equipped with charging infrastructure to enable the hire vehicle to be charged between consecutive hires.

5.2.2 Highway driving

5.2.2.1 Suitability

With a limited range and, in the case of most currently available EVs, little space for luggage and fellow passengers with possible knock-on effects for comfort, it is easy to dismiss the use of pure EVs for longer journeys. In such conditions PHEVs are likely to dominate AFV usage in the period up to 2030. However, battery technology is continually being researched and developed, and if some sacrifices are made in power and top speed, it is feasible that the range of EVs could increase significantly in a reasonably short period of time.

Although it is unlikely that a sufficiently large number of EVs will be part of the UK vehicle fleet by 2030 to have an impact on motorway flows, a potential impact could still exist. Most EVs are likely to have a lower top speed and be slightly heavier than their ICE counterparts. The implication of this on traffic could be increased congestion, as is discussed further in Section 5.2.2.4.

5.2.2.2 Routing

Routing on long-distance journeys will potentially be more complex, as recharge breaks will have to be built into a driving schedule. There will certainly be a requirement for charging points at existing service stations, and possibly new stations will be required, unless the range of EVs significantly improves. Fast charging stations, in which 80% of the battery can be recharged within half an hour, would allow this to be undertaken in a reasonable timescale.

Charging points are likely to be a mixture of grid-connected and locally powered points. There is a possibility variation in the availability of charging throughout the day, as grid-powered charging areas may allow use of less charging points simultaneously during peak hours, while off-grid-powered points may depend on local generation and storage. As discussed in Section 5.2.1.2, it is likely that it will be necessary to book charging points prior to arrival, which will require drivers to stick to a schedule and reduce some of the freedom associated with driving.

Navigation systems will most likely evolve to perform this routing and booking function. This means that EVs could have a positive impact on overall congestion levels as the adoption of EVs may also result in a larger proportion of vehicles being equipped with intelligent navigation systems that take into account live traffic conditions to determine the least congested routes. One impact of this could be a better distribution of traffic across the road network with less congestion and more predictable journey times.

5.2.2.3 Range anxiety

Because of the widely publicised limited range of EVs, in tests many participants have not driven the vehicles anywhere approaching the limit of their range as they anticipate and fear the battery running out. “Range anxiety” is a term coined to describe this phenomenon. Public faith in quoted ranges is necessarily limited by the fact that the ranges given are calculated from various drive cycles that may or may not be representative of the typical journeys that a particular driver undertakes (Webster, 8 June 2010). Once a driver uses the vehicle for a period of time, a better understanding of the vehicle’s range in everyday use will be developed, and many articles indicate that drivers lose their range anxiety over time (Sunderland, 2010).

In terms of the impact on traffic and transportation, range anxiety may lead to the EV proportion of the UK vehicle fleet making shorter journeys than ICE vehicles, which could, in turn, lead to a reduction in average journey length. Public transportation, such as trains, could see a rise in the number of people using them to make longer journeys as an alternative to using their EVs.

5.2.2.4 Potential effect on speed differentials

Restricting the speed of EVs to correspond to approximately 75% of the rated motor load would improve efficiency, and given range anxiety it is likely many drivers would voluntarily opt for this whether or not the speed was physically restricted. This opens up the possibility of EVs travelling on highways at 50–65 mph, which is significantly slower than most ICE vehicles during free flow conditions. It is generally considered that higher speed differentials between vehicles lead to increased congestion through more lane changing and braking manoeuvres. There is little empirical data available to support these observations due to the difficulty in obtaining measurements. It is noteworthy, however, that the introduction of active traffic management on the M42, which results in traffic speeds being equalised, has improved the capacity of that road.

Speed differentials can also lead to shockwaves developing. A shockwave tends to form in congested periods through a vehicle braking then each subsequent vehicle braking slightly more than the vehicle in front of it until speeds are significantly reduced.

5.2.2.5 Running out of fuel

It is feasible that an increased take-up of pure EVs could result in an expansion of stopped vehicles due to running out of battery charge. However, range anxiety is likely to significantly reduce the occurrence of this. Nonetheless, when this does occur in rural or highway environments the vehicle will either need to be towed away to the nearest available power point or charged at the roadside by a mobile charging unit. For safety and practical reasons the former seems more likely, and so there may be an increased need for suitable vehicles to perform this task.

A consideration is the discharge rate of the batteries. Some battery types gradually reduce their discharge as the charge in the battery decreases while other batteries (such as nickel cadmium) maintain a near continuous output until they have very little charge left and then almost immediately stop functioning. For safety and practical purposes it would be desirable that EVs do not very quickly cease function, so there is the possibility of EVs travelling at reduced speeds as they struggle to reach the next charging point. This could have an effect on safety and congestion on highways and rural roads.
5.2.2.6 Breakdowns
Broken down vehicles can cause congestion. It is in principle likely that, with fewer working parts, EVs could be more reliable and break down less. Electric motors already in use in other applications are known for reliability and durability. However, if EV vehicles remain a relatively small minority of vehicles, as is anticipated within the next 20 years, then any positive effect of this is likely to be very small. It is also not proven that the first generation of widely used EVs will be as rugged as the current, heavily developed range of ICEs, as the technology is still in development.

5.2.2.7 Charging infrastructure and travel patterns
There is excess capacity in the grid during the night, and this would seem the optimum time of day to charge vehicles as electricity is relatively cheaper. It is very difficult to start and stop some power plants at short notice so, in practice, many run all night when not strictly required, and hence there is spare capacity.

During the day when demand is higher, if a higher load is connected to the grid in the form of charging vehicles then additional generation capacity may be required, thus increasing the cost of electricity. Therefore, it is often assumed in discussions about EVs that they will be predominantly charged overnight at home. This is fine for many users, but would have implications for those that work or travel at night and who would be unable to charge their vehicles at home in such hours. This may prove a disincentive to a minority of the public to consider the use of EVs.

When talking about charging EVs, typically two options are presented. A long charge option, suitable for charging vehicles when they are parked for a prolonged period of time – at work or at home for example – can typically take up to 6 to 8 hours. The other option is the quick charge, which is most likely to be the one used at service stations and other areas where EVs cannot be left for a prolonged period of time.

Quick charge can typically take between 15 and 30 minutes to charge the battery to 80%. This option, however, could lead to faster battery degradation.

The availability of either regular or quick-charge charging points may affect travel patterns and demands on electricity, particularly if the electricity for charging vehicles is charged at different rates for different times of day and different types of charging. For example, people may be reluctant to use their EVs during their lunch break if they think that may not leave enough charge for their trip back home from work, if they have no access to a charge point at work. Once European or worldwide standards for EV charging infrastructure have been agreed, it will be clearer how long typical charging may take and how available charging points will be.

5.3 Implications of plug-in hybrid electric vehicles
Hybrids do not suffer from one of the potential drawbacks of pure EVs – limited range. As soon as the power of the battery is exhausted, an ICE is used to provide power to the vehicle and in most cases recharge the battery. As some journeys will be predominantly ICE powered, and the driver is unaffected by the battery becoming flat, it is likely that PHEVs will have a smaller effect on traffic and transportation than pure EVs.

There is likely to be a limit to the environmental benefit that can be achieved by the use of hybrids – as discussed previously, the theoretical maximum efficiency of an ICE is limited by the thermodynamic limit to around 50%. Furthermore there is an inbuilt inefficiency in such vehicles, as when running on the batteries the additional weight of an ICE must be carried and vice versa when running on the ICE. Therefore although hybrids can offer significant fuel efficiencies compared with conventional ICEs, they are ultimately unlikely to be able to lead to meeting carbon reduction targets close to 2050. Research in future is likely to concentrate on producing pure EVs and fuel cell vehicles, and it is anticipated that hybrids are a natural evolution, and an interim step on the path of conversion from ICEs to electric power.

5.3.1 Urban driving
5.3.1.1 Suitability
Within the urban environment, some PHEVs are likely to operate in electric-only mode, and therefore share all the advantages of pure EVs. Because it is not imperative that PHEVs maintain electric charge in order to operate, it will be of less critical importance that suitable charging infrastructure is provided in parking areas, though this is still desirable if the maximum environmental benefit of such vehicles is to be realised. It is anticipated that PHEVs will be much like regular ICE vehicles in terms of their performance and suitability for urban driving. However, having the capability to be plugged in to the grid for charging could mean that PHEVs may form part of the demand for charging infrastructure in urban areas; in which case, the issues discussed in Sections 2.1.2 and 2.3 are also applicable to PHEVs. It should also be noted that the model adopted in this report suggests that PHEVs are likely to make up a larger proportion of the UK vehicle fleet by 2030 than pure EVs: around 20% of the total passenger car fleet.

Although versatility of PHEVs may mean that their use is not concentrated in urban areas, unlike pure EVs, their potential wider adoption may mean they could have a similar demand on charging infrastructure in urban environments to pure EVs.

With that in mind, it is probable that charging infrastructure will not be as crucial for PHEVs as for pure EVs, because PHEVs are still able to use regular petrol stations if a charging point is unavailable or out of range.

5.3.2 Highway driving
5.3.2.1 Suitability
In order to maximise efficiency of both the electric motor and ICE, it would be prudent to limit speeds to correspond to about 75% load for the electric motor or 60 mph for an ICE. However, this is equally true for current ICE vehicles but many drivers travel much faster, so there seems little reason to assume that use of hybrids will lead to drivers choosing to travel at lower speeds. The fact that ICEs in such vehicles will be smaller and lower powered could naturally reduce cruising speeds to some extent, although that will depend on the exact setup of the hybrid vehicles and how the powertrains are combined and managed.

Since PHEVs will not have a range significantly shorter than ICE vehicles, it is not anticipated that their impact on traffic will be any different to that of ICE vehicles. It is likely that if
quick-charge infrastructure will be available on the most direct route, then PHEVs will use it but, unlike pure EVs, will not need to plan a route specifically to take account of available charging points.

5.3.2.2 EV-/PHEV-only lanes on motorways
In future the use of active traffic management technology on motorways is likely to become more widespread. This technology potentially allows individual management of each lane, such that there could be a specific lane for EVs. This could be operated in peak hours as an incentive, similar to the current high-occupancy vehicle or car-share lanes. Enforcement of this could potentially be problematic, however, and may well rely on automatic number plate recognition technology.

Such dedicated lanes could have lower speed limits of 60 mph, to allow for greater efficiency of PHEVs and EVs. This could have a negative impact on the overall traffic and congestion if the proportion of EVs in the UK vehicle fleet is not sufficiently high as fewer lanes will be available for the remaining traffic. In this report, the combined pure EV and PHEV proportion of the UK fleet is assumed to be around 30% by 2030. Although it is anticipated that a comparatively smaller percentage than this will be of longer journeys on motorways, the demand could still be sufficient to justify such dedicated lanes on certain busy routes.
6 The potential effects of electric vehicles on road casualty statistics

Road casualty rates in Great Britain are among the lowest in Europe (European Transport Safety Council, 2010). Nevertheless, 2538 people were killed in 2008 and 26,034 were seriously injured (DfT, 2009c). Many countries (including Britain) set national targets for reducing road casualties. Research shows that targets are an effective means of improving road safety (Wong et al., 2006). Britain is currently working towards a set of targets for 2011 (Department of the Environment, Transport and the Regions, 2000). The latest data show that 2010 targets were in fact achieved in 2008 (DfT, 2009c).

In Britain, casualty reduction targets are developed (for the most part) by forecasting, taking into account any factors that might have an influence (Broughton and Buckle, 2005). This approach was used by Broughton (2009) to forecast the number of fatal and serious casualties on British roads in 2020 and 2030. These forecasts suggest that it should be possible to reduce the number of people killed in road accidents in 2020 by about one-third relative to the 2005–2007 average, and to reduce the number seriously injured by almost half. The corresponding reductions for 2030 are almost half and almost two-thirds. Broughton included predictions about secondary safety improvements and about the distances travelled in future. However, the analysis did not extend to the potential effects on safety (or on distance travelled) of alternative energy sources for vehicles, such as electricity. It is possible that any effects were considered to be negligible.

The DfT’s next road safety strategy was due to be published at the end of 2010. However, at the time of writing this strategy had not been published. A consultation document seeking views on the vision, targets and measures beyond 2010 was published in 2009 (DfT, 2009d). The consultation proposed targets to reduce road deaths by at least 33% by 2020 compared with the 2004–2008 average, and to reduce the number seriously injured by almost half. The corresponding reductions for 2030 are almost half and almost two-thirds. Broughton included predictions about secondary safety improvements and about the distances travelled in future. However, the analysis did not extend to the potential effects on safety (or on distance travelled) of alternative energy sources for vehicles, such as electricity. It is possible that any effects were considered to be negligible.

The DfT noted:

“Over the period of the strategy, environmental considerations are likely to increase and will impact significantly on the automotive industry and road users in general. We anticipate a sizeable shift to lighter, cleaner, quieter vehicles and this creates both opportunities and risks for safer vehicles. Faced with increasing pressure to improve fuel consumption, manufacturers will look to reduce vehicle weights, amongst other technical solutions. Vehicle manufacturers will undoubtedly create safe but light vehicles that meet all relevant legislation, but these vehicles will be used in mixed traffic flows with other, heavier vehicles. This size and weight mismatch could present new challenges for crash safety.”

We also expect to see a growth in the use of alternative energy sources such as electric power, fuel cells or hydrogen, particularly in the later stages of the strategy period. These present a considerable opportunity for safer vehicle design through, for example, the creation of larger safety cells that protect occupants better. Any risks from these technologies will also need to be considered.”

It will be important to maintain Britain’s progress on road safety, particularly if new targets are introduced for post-2010. EVs will offer benefits to society such as improved air quality in towns and cities and reduced CO₂ emissions from road transport (depending on the source of the electricity). However, the potential of EVs to influence casualty statistics needs to be understood. At present, it appears that no such research has been carried out in the UK.

Part of the challenge is that forecasting the future often involves looking at the past to build a statistical model. However:

- EVs are not widespread and hence there are few real-world data to demonstrate their effects on vehicle safety
- There is uncertainty about the attitude of consumers towards EVs, which makes it difficult to predict their contribution to future traffic levels
- It is unclear how the technology will evolve and how that might affect both the safety of the vehicles in the future and also their sales

Without this information, even the most rudimentary predictions about the potential effects of EVs are very difficult. For these reasons, this study did not attempt to quantify these effects. Instead, it provides a broad discussion of the key factors that are likely to influence the safety of EVs between now and 2030 and comments on their possible effects on casualty statistics.

6.1 Road vehicle legislation

All road vehicles sold in the UK are subject to some form of mandatory approval or certification. This ensures that the vehicles meet certain technical and administrative requirements and that subsequent production vehicles are manufactured to conform to the approved design. This legislation reflects not only the current fleet, but also new vehicles and technologies that emerge. Vehicle legislation is therefore very important in shaping current and future EV safety and the potential effects of these vehicles on casualty statistics.

European Community Whole Vehicle Type-Approval (ECWVTA) is the main form of vehicle certification in Europe. Directive 2007/46/EC (the framework directive) applies to powered four-wheel vehicles including passenger cars, goods vehicles and trailers (lightweight, low-powered four-wheeled vehicles referred to as quadricycles are not included; instead, they fall within the type-approval system for powered two- and three-wheeled vehicles). The directive lists over 40 separate technical EC directives and regulations that the vehicle must comply with in order to gain type-approval. These specify performance requirements and tests for various aspects of the vehicle ranging from tyres through to exhaust emissions and braking systems. The framework directive also lists UNECE regulations that are considered to be acceptable alternatives to certain EC directives.

A vehicle that has achieved full ECWVTA may be sold throughout the Europe Union in unlimited numbers. No further inspections are needed for vehicles of the same “type”, but ongoing conformity of production requirements must be met. ECWVTA is relatively expensive and is therefore intended primarily for mass-produced vehicles. European
Community Small Series Type-Approval (ECSSTA) is another EC type-approval route (for passenger cars only). The ECSSTA route is potentially less expensive because certain technical directives and regulations are not required, such as the primary directives for frontal impact, side impact and pedestrian protection. However, a rudimentary assessment of the protection afforded to the driver only in a frontal impact is required in the directive for protective steering systems. A vehicle that has achieved ECSSTA may be sold throughout Europe, but there is a limit of 1000 vehicles per type per year.

Individual EU member states can implement national schemes to allow companies to manufacture and sell limited numbers of vehicles annually within that member state. In the UK, National Small Series Type-Approval (NSSTA) offers reduced technical requirements compared with ECWVTA and ECSSTA, but the number of vehicles that can be sold is limited to 75 per type per year (for cars). There is also Individual Vehicle Approval (IVA), which relies on a physical inspection of each vehicle produced. It is the least onerous of the type-approval routes, but there is potentially a higher cost per vehicle (depending on the number produced). IVA is therefore suitable only for one-off or bespoke vehicles. A NSSTA or an IVA may be accepted in other member states according to the mutual recognition principle, but it would not be guaranteed.

Directive 2007/46/EC allows EC type-approval to be granted to vehicles that incorporate new technologies (subject to authorisation by the EC). This is a key change from earlier versions of the directive that effectively restricted approvals for such vehicles to national schemes. Nevertheless, there are no specific technical requirements in the framework directive to deal with the characteristics and risks of EVs. UNECE Regulation 100 comprises specifications and test procedures for electrical powertrains in four main areas: protection against electric shock; rechargeable energy storage systems; functional safety; and determination of hydrogen emissions. UNECE Regulation 100 is not included in the list of separate technical directives and regulations in the framework directive and is not, therefore, mandatory for type-approval. However, an EC proposal for a Council decision to apply Regulation 100 on a compulsory basis was adopted on 15 June 2010.

Once the proposal is adopted by the Council, UNECE Regulation 100 will be incorporated into the EC type-approval system. However, most of the remaining technical directives and regulations that vehicles must also meet were generally written with ICE vehicles in mind. In some cases, the performance tests and technical requirements are unrelated to the powertrain and can be applied irrespective of the type of vehicle. However, others refer explicitly to the powertrain or assess some other aspect of the vehicle that might be affected. These directives and regulations are likely to be incompatible with EVs in the short term (although this would not prevent an EV from gaining type-approval). The process of amending such regulations is already under way in various international working groups. There may be a short “safety lag” in the coming years if certain EVs have gained type-approval before the amendments come into force, but by 2030 it is likely that the overwhelming majority of EVs on the road will meet the new requirements.

The type-approval legislation is the basis for the main aspects of vehicle safety and establishes a minimum standard of performance. However, when it comes to crashworthiness and occupant protection, the European New Car Assessment Programme (EuroNCAP) applies more stringent requirements. The programme has had a major influence on vehicle safety in Europe since its launch in 1997. At the present time, it is unclear what, if any, amendments will be made to the EuroNCAP crash test protocols for EVs. Nevertheless, manufacturers of EVs will strive to achieve a good EuroNCAP rating. Within the next two to three years, it is likely that EVs produced by the major car manufacturers will perform just as well as conventional vehicles. In the longer term, EuroNCAP may evolve to measure and assess emerging crash avoidance technologies (EuroNCAP, 2009). By 2030, EuroNCAP may be very different from the largely crash safety-based programme of today.

6.2 Safety considerations for electric vehicles

6.2.1 Vehicle safety overview

Vehicle safety has three main elements: primary safety, secondary safety and tertiary safety. Over the next 20 years, it is likely that the vehicle safety legislation will be extended beyond the traditional assessment of secondary safety measures to incorporate advanced primary and tertiary systems.

Primary safety features are designed to help drivers (and their passengers) to avoid a collision, or at least to reduce its severity. For example, they can include systems for braking, handling, visibility and lighting. Increasingly, advanced primary safety features are being developed that include computers and sensors that can detect the state of a vehicle and predict the likelihood of a collision occurring. A warning system may then be activated to alert the driver to the hazard, or in some cases the vehicle itself may take action (e.g. to apply the brakes).

The benefits of advanced primary safety systems can be difficult to establish from casualty statistics. Many of the most advanced systems are not yet prevalent on British roads, but even if they are more common it is fundamentally difficult to identify from conventional sources where a particular system has successfully prevented a collision. Nevertheless, research carried out for the DfT showed that passenger cars fitted with one system, electronic stability control, are 25% less likely to be involved in fatal collisions (DfT, 2009d).

Secondary safety features are designed to prevent injuries (or reduce their severity) if a collision occurs. Good secondary safety performance can be achieved through a combination of structural features and advanced restraint systems. Improvements in secondary safety have played a key role in reducing road casualties over the last 15 years (Broughton, 2009). However, unlike primary safety features, which add little weight, secondary safety features have contributed to an increase in the mass of vehicles over this period.

Tertiary safety describes features that reduce the consequences of injury by making it easier and/or quicker for the casualty to receive medical treatment. For example, eCall is a system that automatically notifies the emergency services in the event of a collision and provides the location and driving direction of the vehicle. It has been estimated that
eCall has the potential to decrease the number of fatalities in road accidents by 5–10% in EU-15 countries, although the potential in the UK is probably significantly less than this (TRL et al., 2009).

6.2.2 Electric vehicle safety
EVs are not inherently unsafe nor will they necessarily expose the public to greater risks than ICE vehicles. Nevertheless, there is always the potential for unintended consequences whenever a new technology is introduced. This section describes some potential safety problems for EVs. It was not the intention to present a comprehensive review of the risks of electric propulsion. Instead, the focus was on certain characteristics of EVs that have the potential to influence British road casualty statistics, namely:

- the additional weight produced by the rechargeable energy storage system and the distribution of weight around the vehicle,
- the integrity of the rechargeable energy storage system in a collision, and
- the acoustic perception of an EV by other road users.

These topics were derived from various studies of EV safety, including Visvikis et al. (2010), Viladot et al. (1999) and Brown and Hall (1982). They represent the main differences between EVs and ICE vehicles relevant to vehicle safety and also take into account potential safety hazards that may not be regulated under the type-approval legislation (assuming that no major amendments above those discussed in the previous section take place).

6.2.2.1 Weight and weight distribution
EVs are typically heavier than equivalent ICE vehicles. The rechargeable energy storage system (i.e. batteries, capacitors, electromechanical flywheels, etc.) is the principal source of the additional weight. A vehicle may also require certain structural features to accommodate the weight of the rechargeable energy storage system and these features may add further weight themselves. In the longer term, efforts will be made to reduce weight elsewhere in the vehicle, through better design and by incorporating new technologies and alternative materials. However, since there is also significant interest in reducing the weight of conventional vehicles (to improve their fuel economy), EVs are likely to remain heavier in comparison.

There are numerous publications that discuss the potential effects of vehicle weight on safety. The basic physics is relatively straightforward: if two vehicles of different mass collide, the heavier vehicle will experience less deceleration than the lighter vehicle. On that basis, occupants of heavier vehicles are thought to face lower risks in collisions than occupants of lighter vehicles (Insurance Institute for Highway Safety, 2009). The reality is more complex and various factors can affect the secondary safety performance of a vehicle in a collision, such as the structural integrity of the passenger compartment, the “crush space” available to absorb energy, the performance of the restraint systems and even the age and other characteristics of the occupants. Nevertheless, Tolouei and Titheridge (2009) found that a 100 kg increase in mass decreases the risk of injury to the driver in a two-car injury accident by 3%. It could be argued, therefore, that an EV will offer secondary safety benefits to its occupants (in certain circumstances). However, a heavier vehicle will also be more “aggressive” and hence increasing the mass of a particular vehicle could increase the risks to occupants of other vehicles or vulnerable road users.

The relationship between vehicle mass and occupant injury outcome is important. However, some of the benefits associated with mass may actually be related to size (Nusholtz et al., 2003). Clearly, mass and size are closely linked (at least in current vehicles), but they can have different effects. The size of a vehicle, especially its front end, is key to its performance in a frontal impact. A larger vehicle is more likely to have a longer crush space to absorb the collision. Broughton (2007) found that the mean risk of death for the driver of the smallest type of cars (minis and superminis) is four times the risk for the largest type (4x4s and people carriers).

Many of the first generation of pure EVs are smaller, lighter vehicles (minis and superminis). Some manufacturers have publicised their EV development programmes for larger vehicles (for example, Tesla and BYD), but it seems likely that this will remain the case through to 2030 and beyond (unless there is a significant energy storage breakthrough). The composition of the car fleet has already changed over the last ten years. New-car registration data published by the Society of Motor Manufacturers and Traders (SMMT) show that the market shares of smaller cars (minis and superminis) and larger cars (4x4 and multi-purpose vehicles) have increased relative to medium-sized cars (SMMT, 2010). However, Broughton and Buckle (2005) found that changes in the fleet (between 1997 and 2003) appear to have had only a minor contribution to the severity of car accidents. Nevertheless, if pure EVs penetrate the fleet in significant numbers, the market share of small cars may increase further relative to other vehicles. This may have an effect on casualty statistics, unless greater efforts are made to improve the “compatibility” of vehicles through both self and partner protection requirements in the legislative and/or consumer crash tests.

A final point to consider with regard to weight is the location of the rechargeable energy storage system within the vehicle and its effect on the overall weight distribution. In some EVs, the rechargeable energy storage system is installed in the rear at the expense of luggage compartment space. However, the current trend is to place the rechargeable energy storage system below the passenger compartment. This results in a relatively low centre of gravity for the vehicle and might be advantageous in terms of vehicle handling and stability. Furthermore, electronic stability control will be mandatory in all new cars in Europe from 2012, hence vehicle stability is likely to improve markedly irrespective of the type of energy source or its location.

6.2.2.2 Rechargeable energy storage systems
The rechargeable energy storage system is the key component of an EV. Any type of rechargeable energy storage system has the potential to be hazardous if it is not designed carefully, although concerns have been raised about batteries in particular (Visvikis et al., 2010). Hazards can emerge during the normal operation of the battery or during conditions or events outside its normal operating range. These include...
electrolyte/material spillage if the cell casing is damaged, the battery's reaction to high external temperatures and fire, and its electrical properties, e.g. under short-circuit, over-voltage and voltage-reversal conditions.

UNECE Regulation 100 deals with the safety of EVs “in use” and includes specifications that relate mainly to the protection of users against electric shock. The specifications for a rechargeable energy storage system focus on protection against excessive current by preventing overheating. UNECE Regulation 94 (frontal impact) and UNECE Regulation 95 (side impact) are being amended to include post-impact electrical safety requirements for EVs that will cover protection against electric shock, retention of the rechargeable energy storage system and electrolyte spillage following the impact test.

The integrity of the rechargeable energy storage system during a collision is very important when considering the potential effects of EVs on casualty statistics. For example, there are various damage mechanisms that might occur during a collision that could lead to short circuit (and hence the risk of high temperatures, smoke, fire, etc.). There is also the possibility of electric shock if an occupant makes contact with two live parts of different electrical potential. In a worst-case scenario, a person could survive a collision but receive a fatal shock. However, problems of this nature are not restricted to EVs. For example, ICE vehicles have the potential to catch fire and even explode, particularly following severe collisions. Fortunately, these events are very rare because adequate safety measures are designed into modern vehicles.

EV manufacturers know how to make their vehicles safe. There are various countermeasures that can be employed such as the use of inherently safer battery chemistries, fire-retardant additives or mechanical barriers. The structural integrity of the rechargeable energy storage system is not assessed for UNECE Regulations 94 and 95, but there are requirements to control its movement. There are also requirements relating to the protection against electric shock following the impact test.

The legislative crash tests comprise (perpendicular) 56 km/h frontal and 30 km/h side impacts only. It is possible that the vehicle countermeasures for retention of the rechargeable energy storage system or for protection against electric shock may perform differently in other impact angles or severities. Clearly, this is the approach with any system of type-approval and similar points could be made about the fuel system in ICE vehicles. However, a great deal is known about the performance of ICE vehicles in a wide range of scenarios; much less is known about EVs.

One way of ensuring that an energy storage system performs in a greater range of scenarios than those specified in the frontal and side impact legislation is to specify certain component-level requirements and performance tests. This approach is taken for fuel tanks where there is a separate regulation. However, at the present time no component-level assessment is made of a rechargeable energy storage system in order to gain type-approval for the vehicle. There are various international standards for rechargeable energy storage systems that cover hazardous substance monitoring, mechanical abuse, thermal abuse and electrical abuse. There are also cell-level standards for batteries. A separate type-approval regulation for rechargeable energy storage systems is needed and may be developed in the future.

6.2.2.3 Acoustic perception

The acoustic emissions from a vehicle in motion comprise three main elements: noise from the engine and powertrain; noise from the interaction between the tyres and the road; and noise made by air as it flows around the vehicle. At low speeds (i.e. below 15–20 mph), the contributions of tyre/road noise and aerodynamic noise are relatively low and hence the powertrain noise is responsible for most of the acoustic emissions from the vehicle. Modern vehicles are quieter than ever, due largely to ever more stringent legislative requirements. Nevertheless, EVs typically generate less powertrain noise than ICE vehicles.

The lower levels of powertrain noise from EVs might have implications for the safety of other road users. For example, cyclists might use auditory cues to the presence of a vehicle when executing certain manoeuvres and pedestrians might use auditory cues when crossing the road. Visually-impaired pedestrians in particular may rely on auditory cues. In certain environments (i.e. where vehicles tend to travel at lower speeds), the rates of cyclist and pedestrian casualties might increase if EVs become more widespread. A study from the US found that HEVs engaged in certain low-speed manoeuvres were more likely to be involved in collisions with cyclists and pedestrians than ICE vehicles (Hanna, 2009). However, it was impossible to distinguish whether each collision was a result of the cyclist or pedestrian not seeing/hearing the car or vice versa. TRL is involved in a similar study for the UK DfT. The findings are expected to be published in late 2011.

The risks to cyclists and pedestrians from quieter vehicles have not been investigated fully. Nevertheless, audibility warning systems are starting to emerge (see www.gm.com and www.grouplotus.com). Recognising it might be necessary to regulate these systems in the future, the UNECE Working Party on Noise (GRB) set up an informal group on quiet road transport vehicles. The aim of GRB is to determine the feasibility of acoustic signalling techniques for quiet vehicles and the potential need for global harmonisation (GRB, 2010).
7 Conclusions

During Stage 1 of this project, a number of sources were analysed and various potential models for UK vehicle fleet composition by 2030 investigated. It was found that there is currently a lot of uncertainty regarding the direction of development for EVs and how quickly they will become adopted and accepted by the consumer. In part, this is due to the fact that battery technology is still being developed and improved. This makes it difficult to predict what the technical capabilities and costs of EVs will be by 2030 and, therefore, how prepared consumers will be to swap ICE vehicles for EVs.

The extent to which UK and European governments are willing to embrace and support the introduction of EVs is also unclear. Currently, it seems that the UK government is committing itself to becoming a world leader in the decarbonisation of transport; to what extent this will continue remains to be seen. In a similar manner, the EC appears to be supporting decarbonisation of transport and has introduced legislation to ensure that car manufacturers develop new technologies.

Other factors, such as price and availability of oil, scientific breakthroughs in ICE technology, consumer attitudes, land use and urban planning, and production of electricity from renewable sources, all have a role to play in affecting the likely development and adoption of EVs. It could be considered inevitable that at some point a switch to EVs will occur as oil is a finite resource; the difficulty lies in determining the extent of EV adoption by 2030.

In this report, scenarios adopted by BERR and the DfT (BERR and DfT, 2008) were considered to be a good representation of the possible development of the UK vehicle fleet by 2030. Out of those possible scenarios, the high-range scenario was considered to be the most probable based on the analysis of underlying factors carried out in Section 2 of this report. The scenario suggests that by 2030 there would be over 20 million EVs in the UK, which would be equivalent to over 27% of the UK vehicle fleet. This scenario appears to be in line with the recommendations made in the Committee’s report (Committee on Climate Change, 2009) to the government. The combination of this level of EV take-up and the probability of increases in fuel prices reported by ITPOES (Branson et al., 2010) and Beddington (Beddington, 2009) suggest that this could be a very possible scenario.

A model was developed using the selected scenario as a way to calibrate a base case, which then enabled the assessment of the sensitivities of the various factors on the overall EV and PHEV adoption rates by 2030. It was found that, according to the TRL model, the period 2020–2030 is likely to be influential in how widespread EVs and PHEVs become in the UK. A number of different scenarios were modelled and it was found that even small changes in parities of key parameters such as cost and infrastructure could lead to significant changes in overall proportions of EVs and PHEVs. In particular, the percentage of PHEVs could vary considerable between 2020 and 2030 due to small changes in parities leading to mass-market penetration, or not.

Based on the selected base-case scenario for 2030, impacts on traffic, transportation and safety were identified and discussed. It is considered that impacts based on vehicle performance parameters, such as top speed and acceleration, are likely to be limited due to most EVs and PHEVs at or near to market attempting to resemble existing ICE vehicles as closely as possible. An area where a potential change could be seen is development of ITS for navigation and location, and reservation of available charging points and availability of those charging points in urban and interurban environments.

In terms of safety, a number of issues were identified that need further research and investigation. Topics such as the presence of high-voltage components in the vehicle, the behaviour of EVs and PHEVs in collisions and charging safety all need further investigation, and are not likely to be answered fully until agreements are reached on standardisation of EVs and charging infrastructure.
8 Future work

The model developed in this project can be continuously updated to reflect ongoing developments in the EV marketplace. This could be ongoing work that leads to the creation of an increasingly accurate model that could be used to inform decision making and identify future potential work areas.

Further research could be undertaken in the EV safety area that would inform future standardisation of EuroNCAP testing for EVs and PHEVs and type-approval. Standardisation of charging infrastructure, batteries used in vehicles and connections between the charging infrastructure and the vehicle will also be affected by safety aspects.

Although it is not expected that by 2030 there will be a considerable impact on traffic management due to an increased number of EVs, additional modelling could be carried out to simulate what this potential impact may be. On interurban roads, the impact of an increased number of EVs may be slower average speeds, while in urban environments it could be the need for changing UTC systems to accommodate potentially faster EV acceleration. Possible congestion around popular charging points in urban environments could be another potential result of the increased number of EVs that could be modelled.

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## Glossary of terms and abbreviations

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<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ACEA</td>
<td>European Automobile Manufacturers' Association</td>
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<td>AFV</td>
<td>Alternative-fuel vehicles</td>
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<td>BERR</td>
<td>Department for Business, Enterprise and Regulatory Reform (disbanded in June 2009 and replaced by the Department for Business, Innovation and Skills)</td>
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<td>CLEPA</td>
<td>European Association of Automotive Suppliers</td>
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<td>CO₂</td>
<td>Carbon dioxide gas</td>
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<td>DfT</td>
<td>Department for Transport</td>
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<td>EC</td>
<td>European Commission</td>
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<td>eCall</td>
<td>European in-vehicle emergency call service that automatically contacts emergency services if the vehicle is involved in an accident</td>
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<td>ECSSTA</td>
<td>European Community Small Series Type-Approval</td>
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<td>ECWVTA</td>
<td>European Community Whole Vehicle Type-Approval</td>
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<td>EEA</td>
<td>European Environment Agency</td>
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<td>EU</td>
<td>European Union</td>
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<td>EUCAR</td>
<td>European Council for Automotive Research and Development</td>
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<td>EuroNCAP</td>
<td>European New Car Assessment Programme</td>
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<td>EV</td>
<td>Electric vehicle</td>
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<td>FPE</td>
<td>Fuel price escalator</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<td>GRB</td>
<td>UNECE Working Party on Noise</td>
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<td>HEV</td>
<td>Hybrid electric vehicle</td>
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<td>ICE</td>
<td>Internal combustion engine</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>ITPOES</td>
<td>UK Industry Task-Force on Peak Oil and Energy Security</td>
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<td>ITS</td>
<td>Intelligent transport systems</td>
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<tr>
<td>IVA</td>
<td>Individual Vehicle Approval</td>
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<tr>
<td>kWh</td>
<td>Kilowatt hours</td>
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<td>LCV</td>
<td>Light commercial vehicles</td>
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<td>NAIGT</td>
<td>New Automotive Innovation and Growth Team</td>
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<tr>
<td>NSSTA</td>
<td>National Small Series Type-Approval (UK)</td>
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<tr>
<td>OECD</td>
<td>Organisation for Economic Cooperation and Development</td>
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<tr>
<td>PHEV</td>
<td>Plug-in hybrid electric vehicle</td>
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<tr>
<td>R&amp;D</td>
<td>Research and development</td>
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<tr>
<td>SMMT</td>
<td>Society of Motor Manufacturers and Traders</td>
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<tr>
<td>TRL</td>
<td>Transport Research Laboratory</td>
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<tr>
<td>UNECE</td>
<td>United Nations Economic Commission for Europe</td>
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<td>UTC</td>
<td>Urban traffic control</td>
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Appendix A: Explanation of electric vehicle adoption model

Although government and industry initiatives/targets for improving the technological, environmental and economic outlook for EVs are known, the effectiveness of these measures is difficult to quantify. Expected improvements in ICE and hydrogen fuel cell technology are likely to counteract (to an unknown extent) the appeal of EVs in the market. In addition, the availability of infrastructure to charge and operate EVs will be a significant factor in their adoption. The range of EVs, which averages about 90 miles, is considerably less than that of ICE vehicles and presents another potential barrier to adoption. According to estimates so far (Table 3.5), EVs are likely to remain a small part of the total vehicle fleet by 2030.

The parameters affecting EV fleet scenarios discussed in Section 2.2.1 of this report, and their areas of influence, can be organised as shown in Table 4.1.

It is expected that the composition of EVs in the market will ultimately depend on their competitiveness in the areas of performance (emissions, durability, speed, etc.), range, cost (fixed and running), availability of infrastructure (e.g. charging stations) and general consumer attitude. As EVs develop to attain greater overall parity, which is determined by the individual parities of areas of influence with the dominant vehicle type in the market, they can be expected to form a greater part of the vehicle fleet.

In addition, each of the areas of influence will not have equal weight in overall parity. If, for example, infrastructure is weak but range is high, then infrastructure can be given a lower weight in the model and range can be given a lower value. Conversely, good infrastructure may reduce the importance of range (since people can travel without the fear that they may not be able to charge their vehicles), assuming other factors remain the same.

Parities are modelled by the logistic function, which by default assumes an initial parity of 0.5. This choice also means that we expect EVs to at least stay “equal” in relation to other technologies. For each parameter, two variables determine the shape that parity takes over the period under consideration:

1) Swiftness – This determines how quickly a parameter attains parity with the dominant standard (or becomes the dominant standard). Complete parity is achieved when the value is equal to 1.

2) Lag – This determines the initial value of a parameter parity.

An example of a parameter with varying levels of swiftness but a lag of zero is shown in Figure A1.

If a parameter is expected to start with a lower level of parity and then progress during the period, lag can be modified, and parity profiles could look like those in Figure A2.

Adjustments for fuel price are made in line with a long-term price elasticity of demand of -0.58 (Espey, 1996). A variable amount for the substitution effect on EVs of an increase in the price of fuel is used to determine how much it might affect demand. According to the oil price projections of the Department for Energy and Climate Change (2010), as shown in Road Transport Forecasts 2009 (DfT, 2009e), the base case (i.e. most likely case) used in the model would present a scenario as shown in Figure A3.

Once overall parity – which is the weighted sum of the parities of areas of influence – has been determined, consumer attitudes and reaction determine the position of EVs in the overall fleet. Vehicle fleet is expected to increase with parity, and how fast that will happen depends on parameters for consumers’ response to parity and the lag associated with that response. We expect that the EV fleet will increase faster as it attains a position that is dominant in terms of the areas of influence in the market. It is expected that the EV fleet will increase quickly once parity exceeds a certain point and EVs get closer to a dominant position.
IMPLICATIONS OF THE WIDESPREAD USE OF ELECTRIC VEHICLES

Figure A1 Parity for a parameter showing varying levels of swiftness

Figure A2 Parity for a parameter showing varying levels of lag

Figure A3 Change in electric vehicle demand based on a substitution parameter of 50%
Implications of the widespread use of electric vehicles

Electrification of personal transport is anticipated to be a natural progression in the process of the decarbonisation of transport. This Insight Report aims to evaluate possible scenarios that already exist, in order to determine the most likely scenario for the introduction and adoption of electric vehicles in the UK by 2030. A number of scenarios have been assessed based on a selection of key factors that could influence a possible 2030 scenario. Based on assumptions of how key factors, such as oil price and government policy, are likely to develop in the years leading up to 2030, the most probable scenario is selected for the composition of the UK vehicle fleet by that time.

This Insight Report was written as part of an internal reinvestment project for the TRL Academy, *The implication of the widespread use of electric vehicles for TRL*. Its main purpose is to identify the most probable scenario for the composition of the UK vehicle fleet by 2030, in order to gain an understanding of how widely electric vehicles will be adopted. Based on that scenario, an examination of the possible characteristics of electric vehicles in the UK vehicle fleet by 2030 is described and the implications that this may have on traffic, transportation and safety are discussed.

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