Fuelling Britain's Future

A report for
the European Climate Foundation

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Authorisation and Version History

Version	Date	Authorised for release by	Description
3.0	6/3/2015	Philip Summerton	Final report.

Acknowledgments

This report builds on the analysis undertaken in 'Fuelling Europe's Future', developing the analysis to consider UK specific issues. In particular, the technology cost analysis presented in 'Fuelling Europe's Future' and developed by Ricardo-AEA and the core working group for that project, forms the starting point for this analysis.

Cambridge Econometrics provided the lead analytical work presented in this report, principally relating to the development and application of the passenger car stock model for the UK, the revision and updating of technology cost and infrastructure data and for the economic modelling undertaken in E3ME.

Element Energy, which previously contributed analysis on hydrogen and synergies between electric vehicle charging and the functioning of the electricity grid, updated the latter analysis for the UK context and this is presented in Chapter 7.

The report was funded by the European Climate Foundation who convened a core working group to advise and review the analysis and reporting. The authors would like to thank all members of the core working group for their respective inputs.

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Executive Summary

Overview

- This report assesses the economic costs and benefits of decarbonising passenger cars and vans in the UK. A scenario approach has been developed to assess a range of possible futures for vehicle technology in the UK, and then economic modelling has been applied to assess impacts. The study is based on a similar analysis undertaken for the EU as a whole, published in Fuelling Europe's Future[1].
- Five scenarios of the future UK passenger car and van fleet were developed:
  - a Reference (REF) scenario which includes no improvements to new vehicle efficiency after 2015
  - a Current Policies Initiative (CPI) scenario, based on the latest European Commission legislation which sets a standard for carbon emissions from new cars of 95 g/km by 2021
  - a low carbon technology scenario (TECH) which has a stronger penetration of advanced powertrains and more efficient internal combustion engines than the CPI by 2020, cutting new car emissions to 89 g/km. This falls further to 43 g/km by 2030 and 9 g/km by 2050
  - a variant of the TECH scenario which is dominated by sales of plug-in hybrid vehicles (PLUG-IN)
  - a second variant of the TECH scenario, FUEL CELL, in which fuel cell vehicles dominate the sales mix in place of plug-in hybrids

The impact on motorists

- The technologies required to improve the carbon efficiency of passenger cars and vans will add to the purchase cost. In the TECH scenario the average cost of a new car in 2020 is £21,800 compared to £20,500 in the REF; and by 2030 it is expected to cost £23,300 compared to £20,400 in the REF scenario (all in 2013 prices). However, the annual fuel bill savings are also significant. By 2030 the annual average fuel bill of all cars in the UK fleet (predominantly cars sold between 2020 and 2030) will have fallen from £1112 to £663 an annual saving of around £450 (again, all in 2013 prices).
- Overall, a transition to low carbon cars and vans will reduce the total cost of ownership. By 2020 a new Hybrid Electric Vehicle is expected to have a total cost of ownership lower than today's average car and a new Plug-in Hybrid would be even cheaper to own over the lifetime of the vehicle. By 2025, pure Battery Electric Vehicles could achieve cost parity with a traditional car and by 2030, Fuel Cell Electric Vehicles will also be competitive over the lifetime.

The economic impact

- The economic impact of reduced spending on petrol and diesel, the increase in spending on car purchase and the net reduction in the total cost of car ownership that are associated with the transition will be neutral to mildly positive for GDP and will lead to marginally higher levels of employment. By 2030, the transition to a low-carbon vehicle stock would

[1] Fuelling Europe's Future, Cambridge Econometrics (2012)

reduce the economy-wide annual cost of car ownership by around £8bn (2013 prices). Increasing the deployment of ultra-low emission vehicles further could lead to a £20bn economy-wide reduction in the annual cost of car ownership by 2050. These savings will be spent across the economy on consumer goods and services leading to a small increase in GDP and around 50,000 net additional jobs by 2050 (taking account of the impact of measures to recompense the government for the loss of fuel duty revenue).

- The competitiveness of UK car manufacturers and component suppliers is an important consideration for the economic results. If UK-based companies were able to manage the transition to a low-carbon vehicle fleet effectively and gain market share across Europe, the benefits of decarbonising the road transport sector could be more positive for the UK economy. A report published by the Low Carbon Vehicle Partnership[2] suggests that the UK automotive sector is well positioned to improve its competitive position and points to evidence of recent investment in low carbon innovations.

The economic benefits are reduced if oil prices remain low

- The scenarios were tested against an assumption of persistently low oil prices, in which the oil price gradually falls to 30% below the central IEA projections (published in November 2014) by 2050. This reduces the economic gains from switching to low-carbon vehicles (because a low-oil price future reduces the cost of conventional technologies), but there were still net positive results.
- By purchasing more fuel efficient vehicles, consumers reduce their exposure to volatile (and/or increasing) fuel prices. For the economy as a whole, this reduces the impact of volatile oil prices on economic growth.

The environmental impact

- We assume that electricity generation and hydrogen production are both largely decarbonised by 2030, and therefore are potentially more expensive than they would otherwise be. Electricity generation is expected to have a carbon intensity of around 50 g/kWh by 2030. We assumed hydrogen production methods that include centralised and decentralised electrolysis, with an implied carbon intensity lower than that of grid electricity.

Carbon emissions from passenger cars will be halved by 2030

- As a result of improved efficiency and a transition to advanced powertrains that are powered by electricity and hydrogen, carbon emissions from passenger cars are reduced substantially. Tail-pipe carbon emissions from passenger cars could be nearly halved by 2030 (compared to 2012) if efficiency measures and more advanced powertrains are taken up.
- Air quality would be improved by the penetration of advanced powertrains, particularly through the reduction of NO_X emissions. Emissions of particulate matter are likely to be reduced considerably from today's levels through the implementation of the Euro V and Euro VI new vehicle standards, but could be almost wholly eradicated by a transition to zero tailpipe emission cars and vans. The improvement in air quality will have most impact in densely populated urban areas, such as London and other major cities, where the concentration of air pollutants is highest.

[2] Investing in the low carbon journey. Low Carbon Vehicle Partnership (2014).

1 Background

1.1 Policy background

European policy context

Europe has set in place a policy roadmap to reduce GHG emissions by at least 80% by 2050. In transport, the European Commission's White Paper outlines an ambition to reduce transport emissions by 60% by 2050. To date this has principally relied on improving the efficiency of light-duty vehicles.

CO_2 emissions targets for light-duty vehicles in the EU were first introduced in 1998 under the voluntary ACEA agreement. The goal of this voluntary agreement was to reduce CO_2 from passenger cars to 25 per cent below 1995 levels (to 140g/km) by 2008/9.

Following under-performance of the voluntary agreement, the EU moved to mandatory CO_2 standards for light-duty vehicles. In 2009, the EU formally adopted Regulation 443/2009, which sets an average CO_2 target for new cars sold in the EU of 130 g/km by 2015 (tested on the NEDC Test Cycle), backed up by penalties for non-compliance.

After lengthy political negotiations, the European Parliament and the Council of the European Union reached agreement in November 2013 to introduce a Europe-wide passenger car emissions target of 95 g/km by 2021 and to impose penalties on car manufacturers who are not able to satisfy the required restrictions on emissions. This regulation has now been formally accepted as European law. Similar regulation exists for light commercial vehicles (Regulation No 510/2011), which aims to cut CO_2 emissions from vans to an average of 175g/km by 2017 and to 147g/km by 2020.

UK policy and supporting measures

The UK position is aligned with Europe. The UK has set a legally binding target to reduce GHG emissions by 80% by 2050 as part of the Climate Change Act. There are also four five-year carbon budgets covering the period 2008 to 2027 which, if met, will set the UK on course to reduce annual GHG emissions by 60% by 2030 compared to 1990 levels.

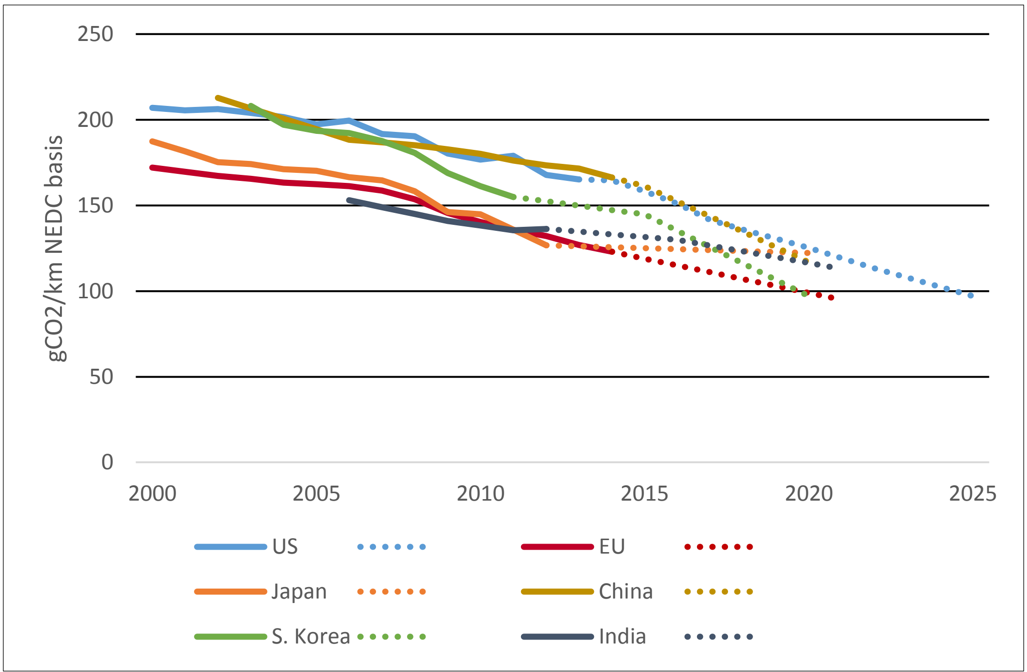
To support European vehicle emissions standards, the UK government has put in place a series of measures to support the deployment of Ultra-Low Emissions Vehicles (ULEVs)[3], including:

- a £5,000 subsidy to the consumer on the purchase price of ULEVs
- up to £35m has been made available to two to four cities that commit to supporting a step change in ULEV adoption in their areas through measures like access to bus lanes, ULEV car club support, infrastructure for residents, parking policy and changing their own fleets
- supporting the financing for the deployment of rapid charge points at every motorway service station by the end of 2014 and a network of over 500 rapid chargers across the country by March 2015
- vehicle excise duty exemption for low emissions vehicles

[3] Investing in ultra-low emission vehicles in the UK, 2015 to 2020, DECC.

Historically, Japan and the EU have led vehicle emission performance (see Figure 1.1: Global vehicle emissions performance and standards[4]). For the EU this is expected to continue, but Japan has recently set a standard for 2020 of just 122 g/km which is considerably less stringent than in the EU. South Korea, by comparison, has set fuel standards for 2020 that are in line with the EU. Canada and the US have recently introduced measures to reduce vehicle emissions between 2011 and 2016 by around 4 percent per annum. In 2012, the US agreed a 2025 standard of 107g/km (93g/km for cars alone). As a result, the emissions performance in various vehicle markets is expected to

Figure 1.1: Global vehicle emissions performance and standards



converge towards 2025.

1.2 Report layout

This report sets out an analytical approach to assessing the costs and benefits of a transition to low-carbon light-duty vehicles in the UK. The analysis presented in this report builds on the 'Fuelling Europe's Future'[5] study, which identified the economic effects of the transition to a low carbon vehicle fleet in Europe. Chapter 3 discusses the costs of vehicles and technologies required to improve the efficiency of vehicles as well as the impact on fuel costs and the total cost of owning a vehicle. Infrastructure will be required to support a transition to electric and fuel cell vehicles, this is discussed in Chapter 4. The net impact to the economy is discussed in Chapter 5, while Chapter 6 discusses the impact on emissions and local air pollution. All monetary values are expressed in pounds sterling, 2013 prices, unless otherwise stated.

[4] Sourced from the ICCT.

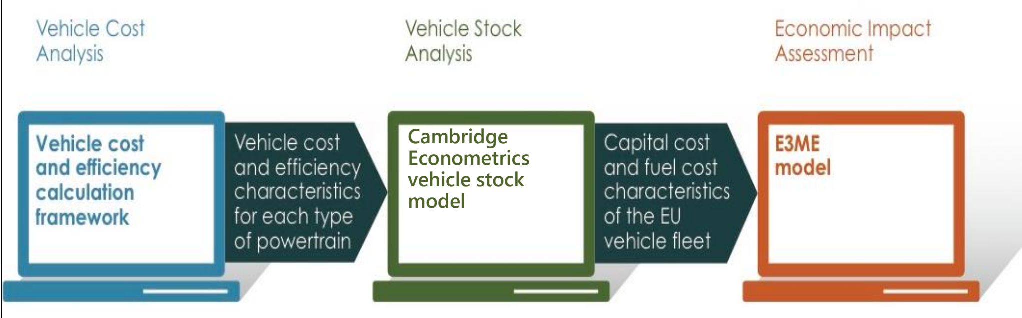
[5] Fuelling Europe's Future, Cambridge Econometrics (2012)

2 Approach

2.1 Analytical approach

The analytical approach taken follows that employed in the EU-wide study, 'Fuelling Europe's Future' (see Figure 2.1). To determine the economic impact of deploying low-carbon vehicles, the additional cost of vehicle technology was calculated based on the Road Vehicle Cost and Efficiency Calculation Framework used in 'Fuelling Europe's Future'. The per-unit cost was then applied to the vehicle fleet characteristics in each scenario, using Cambridge Econometrics' model of the UK vehicle stock, to arrive at annualized total capital costs for the whole UK vehicle fleet. This was combined with the calculated costs of supporting vehicle infrastructure and annualized fuel costs to provide the main inputs for the macroeconomic model E3ME[6].

Figure 2.1: Analytical Approach



For each scenario (discussed below) we developed assumptions on the uptake of technology and advanced powertrains, presented in Table 2.1.

The outputs of the vehicle stock modelling, and the assumptions highlighted, form the inputs to Cambridge Econometrics' model of the global economy, E3ME (see Appendix A for details), which includes the UK as an individual region. E3ME is a global macroeconomic model that covers the EU Member States' economies, with linkages between the economy to energy consumption and CO_2 emissions. Recently, the model has been used to contribute to several European Commission Impact Assessments, including reviews of the EU Emissions Trading System, Energy Taxation Directive and the Energy Efficiency Directive.

E3ME's historical database covers the period 1970-2010 and the model projects forward annually to 2050. The main data sources are Eurostat, the EC's AMECO database and the IEA. The E3ME model embodies two key strengths relevant to this analysis. The model's integrated treatment of the economy and the energy system enables it to capture two-way linkages and feedbacks between these components and its high level of disaggregation enables relatively detailed analysis of sectoral and national effects.

[6] More details about E3ME are available in the appendices and online at www.E3ME.com

Table 2.1: Assumptions, inputs and outputs associated with the vehicle stock modelling

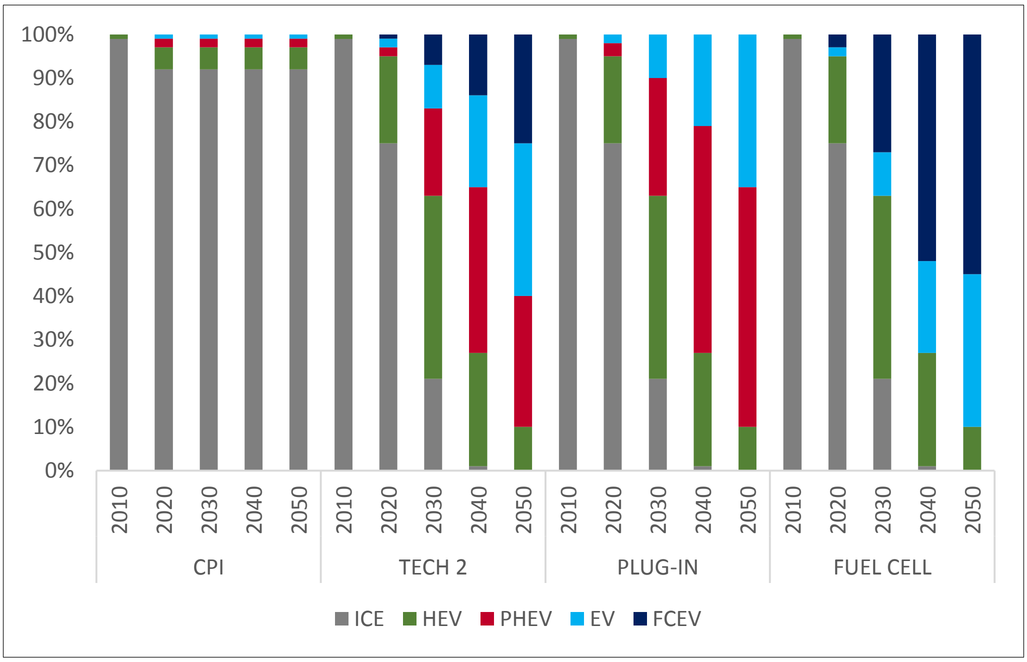
Key assumptions	Value/comments
Average distance travelled per year	Based on analysis by Ricardo AEA, we assume diesel cars are driven further than petrol cars and that mileage is higher in the first three years of a cars life and diminishes thereafter. The average vehicle distance is just over 12,500 km per year.
Average vehicle lifetime	We assume an average lifetime of 13.5 years (with a standard deviation of 4 years) in the projection period for all powertrain types. This assumption is based survival rate analysis from the Department for Transport.
Annual vehicle sales	We assume that total vehicle sales in the UK remain constant at 2.3m per annum over the projection period. This assumption is the same in all scenarios.
Characteristics of the current vehicle stock	Based on sales data for 1980- 2012 sourced from the ICCT (2013) and SMMT (2013).
Electricity price	The electricity price is taken from National Grid's Gone Green scenario. It is assumed that EV users will be charged the same price for electricity as households. Refer to Chapter 4.
Oil price	Oil prices are based on central projections from the IEA's World Energy Outlook (2014).
Average vehicle emissions in the rest of the EU	For each scenario, we assume that vehicle emissions in the rest of the EU follow a similar path to average vehicle emissions in the UK.
Technology costs	Refer to Chapter 3.
Test-cycle versus real-world performance	We assume that the real-world driving efficiencies are 24% higher than the reported test cycle performance and that this gap persists over the projection period. New vehicle efficiency is reported on the test-cycle basis, all other calculations are based on the real-world performance.
Inputs	
New vehicle sales mix by powertrain type	Scenario specific (refer to Section 2.2). Based on the scenarios used in the 'Fuelling Europe's Future' report.
The uptake of fuel-efficient technologies in new vehicle sales	Scenario specific (refer to Section 2.2). The uptake of various fuel-efficient technologies is based on uptakes in the equivalent scenarios from the 'Fuelling Europe's Future' report.
Outputs	
Average cost of new vehicles	Determined by: • the share of various powertrains in the sales mix and stock • the efficiency technologies installed across all powertrains
Fuel consumption of the vehicle stock, by fuel type	

2.2 Scenario design

In order to understand the economic impacts of a transition to low-carbon vehicles in the timeframe 2010-2050, five scenarios were developed:

- A Reference (REF) scenario which includes no improvements to new vehicle efficiency after 2015. Total energy use in the vehicle stock still falls, however, as today's new vehicles replace older (less efficient) vehicles in the stock.
- A Current Policies Initiative (CPI) scenario which is based on the latest European Commission legislation to regulate the new vehicle efficiency of cars to 95 g/km by 2021.
- A low carbon technology scenario (TECH) which is consistent with the TECH 2 scenario developed for Fuelling Europe's Future. The TECH scenario has a stronger penetration of advanced powertrains and more efficient ICE's than the CPI by 2020 leading to new vehicle emissions of 89 g/km. By 2030 this is reduced to 43 g/km as advanced powertrains account for 37% of sales and efficient hybrids 42% (see Figure 2.2). Advanced powertrains account for 90% of sales by 2050, with HEVs accounting for the remaining 10% resulting in new vehicle efficiency of 9 g/km. Vans achieve CO_2 performance of 139 g/km in 2020, 78 g/km in 2030 and 19 g/km in 2050.
- A variant of the TECH scenario which is dominated by sales of plug-in hybrid vehicles, PLUG-IN, which are taken up in place of fuel cell vehicles. In this scenario PHEVs account for 27% of new sales in 2030, increasing to 55% by 2050.
- A second variant of the TECH scenario, FUEL CELL, in which fuel cell vehicles dominate the sales mix in place of plug-in hybrids. In this scenario FCEVs account for 27% of sales in 2030, 52% in 2040 and 55% in 2050.

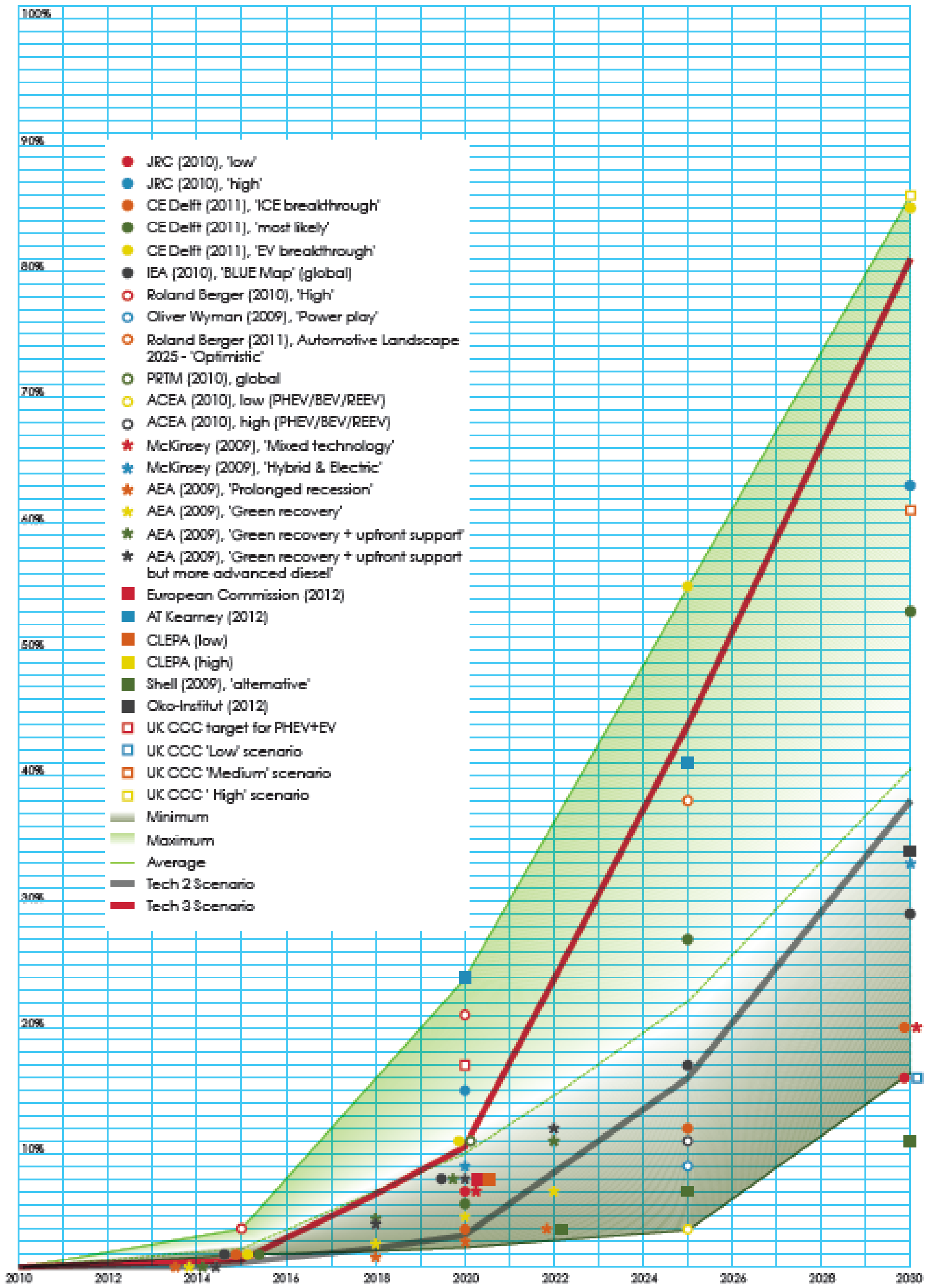
Figure 2.2: Sales mix in each scenario



The scenarios focus on technological improvements alone, on the assumption that vehicle technology becomes the main driver for decarbonizing road transport, rather than behavioural change or significant modal shift. The scenarios in this project are not an attempt to predict the evolution of future vehicles, but to examine a range of possible future outcomes.

The future deployment levels of advanced EVs in our TECH scenario (Tech 2 in Fuelling Europe's Future) is shown in Figure 2.3, where it is compared to a range of market forecasts and scenarios from the literature. This figure shows that our scenario falls comfortably within the range of other credible projections.

Figure 2.3: Scenario projections comparison



3 Vehicle Characteristics

3.1 Technology options and costs

In broad terms, five groups of technology deployment were considered in the Fuelling Europe's Future report and re-applied (and re-reported[7]) in this study:

- Improvements to the internal combustion engine
- Downsizing and hybridisation
- Light-weighting, aerodynamics and low rolling resistance tyres
- Batteries (deployed in PHEVs and EVs)
- Fuel cell vehicle systems

Improvements to the internal combustion engine

There remains much more that can be done to improve the efficiency of the internal combustion engine and transmission system, and many of the technologies that are already available on the marketplace can make a significant impact on fuel consumption in the 2015-2025 timeframe. Start-stop technology using advanced lead-based batteries is perhaps the most cost-effective way of achieving reductions of around 5 per cent in CO_2 emissions. Ricardo AEA has estimated that the cost per gram of CO_2 reduction is about half that of improving the fuel efficiency of the internal combustion engine, and less than a quarter of that for hybridisation.

Downsizing and hybridisation

Other options that are likely to be applied first include engine downsizing coupled with boost (e.g. combination of turbo- and super-charging) and direct injection for petrol engines. For example, there has already been a 31 per cent reduction in g/km of CO_2 between 2010 petrol Ford Focus variants (at 159 g/km) and 2012 EcoBoost branded variants (at 109 g/km), achieved mainly through the use of downsized engines (from 1.6 litres to 1.0 litres) with turbo-charging, direct injection and start-stop technologies. Systems combined also with increasing levels of hybridisation offer even greater potential benefits – e.g. 52 per cent reduction in CO_2 going from the 2010 petrol Toyota Yaris (at 164 g/km) to the 2012 Toyota Yaris hybrid (at 79 g/km). Additional improvements will also be possible in later years with more widespread use of further downsized engines, more sophisticated start-stop and direct-injection technologies, and their application in combination with other technologies like variable valve actuation and eventually the use of multi-port injection technologies and low temperature combustion technologies using "auto-ignition", like HCCI (homogenous charge compression ignition).

Light-weighting, aerodynamics and low rolling resistance tyres

All vehicles, regardless of powertrain type, can be made more efficient through reducing weight, aerodynamic drag and rolling resistance. However, weight reduction is the area with perhaps the greatest potential. In the short-term, weight reductions are likely to be achieved through a greater focus on minimising vehicle weight in the design process (e.g. in areas such as seating, glazing and interior components), in combination with further increases in the use of high strength steels and aluminium in the vehicle body structures.

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[7] Based on the analysis undertaken by Ricardo-AEA, reported in Fuelling Europe's Future Chapter 6.

Simplification of assemblies to reduce the number of components can also achieve weight reductions. Very significant gains are believed to be possible in the short term according to highly detailed analysis by Lotus (2010) and more recently FEV (2012). These studies demonstrated that achieving up to 20 per cent reduction in overall vehicle weight (i.e. across all vehicle subsystems) at minimal or even zero net cost was possible by 2020 while maintaining performance parity relative to the current vehicle. In the longer term more significant weight reduction (~40-50 per cent) may be possible (at higher cost) through more extensive use of lightweight materials such as carbon fibre.

Another technology which has potential to substantially reduce energy consumption by both conventional ICE's and advanced powertrains, is the installation of more energy-efficient tyres. Our assumptions on tyre efficiency are based on the European Commission's impact assessment on tyre labelling,[8] which suggests that a 1.5% efficiency improvement could be achieved for each 1kg/tonne of reduction in rolling resistance.

Not only are the potential energy savings associated with low-rolling resistance tyres substantial, but they can also be achieved at relatively low cost. According to the European Commission's impact assessment, replacing four Grade F tyres (with a rolling-resistance coefficient of 11-12kg/t) with Grade A tyres (with a rolling-resistance coefficient of under 7 kg/t) in a conventional passenger car, would cost an additional €56 (incl VAT) and lead to fuel savings of €280 over the lifetime of the tyres.

It is to be noted that whilst we have modelled the effect of more efficient tyres being installed in new vehicles, we have not considered the potential for more efficient tyres to be installed in the existing vehicle stock and, as a result, we have potentially underestimated the true potential impact of this technology in the short term.

Batteries

The principal factor determining the speed of progress for powertrain electrification is battery or energy storage technology. All four battery families (Lead, Nickel, Lithium and Sodium-based batteries) are used in the different levels of powertrain hybridization/electrification. Advanced lead-based batteries provide start-stop functionality (also named micro-hybrid) in almost all new ICE vehicles being placed on the market, while Nickel and Lithium-based batteries are a key determinant of the overall cost and performance of both current HEVs and more advanced plug-in vehicles (i.e. PHEVs, REEVs and BEVs). Improving battery technology and reducing cost is widely accepted as one of the most important, if not the most important factor that will affect the speed with which these vehicles gain market share.

There are four key areas where breakthroughs are needed, which include:

1. Reducing the cost
2. Increasing the specific energy (to improve vehicle range/performance for a given battery weight or reduce weight for a given battery kWh capacity)

[8] European Commission (2008) 'Directive of the European Parliament and of the council on labelling of tyres with respect to fuel efficiency and other essential parameters'

3 Improving usable operational lifetime

4 Reducing recharging times

In the short- to mid-term, lithium ion battery technology is expected to form the principal basis of batteries for use in full HEVs and more advanced plug-in vehicles (i.e. PHEVs, REEVs and BEVs). However, a number of new technologies are being researched. In the medium term lithium-sulphur holds perhaps the most promise (up to five times the energy density of lithium ion) with lithium-air having greater potential (up to ten times lithium ion energy density).

In 2010, the battery of a plug-in electric vehicle was estimated to cost between £4,800 and £13,100 (ACEA, 2011). The wide range of cost not only reflects uncertainty about the technology but is also dependent on the electric-only range of the battery. In 2013, the American Council for an Energy-Efficient Economy reported that costs were around $500/kWh in 2012, which would be broadly equivalent to $1,000 for a PHEV with an electric-only range of 10 miles and $5,000 for an electric-only range of 50 miles, suggesting that costs have fallen significantly. Detailed analysis for the UK Committee on Climate Change in 2012 estimated current costs at ~£460/kWh and predicted a reduction to £200/kWh by 2020 and £130/kWh by 2030 for a mid-size battery electric vehicle in the baseline scenario (CCC, 2012).

These figures have been used as a basis for the central case estimates used in the technology costs calculations of this study for BEVs, and can be viewed as more conservative estimates compared with other recent estimates from Roland Berger (~US$316-352 /kWh for the total pack by 2015) and McKinsey (US$200 by 2020 and US$160 by 2025 for the total pack), and the EUROBAT R&D roadmap target of reaching €200/kWh (US$260/kWh) by 2020.

PHEV batteries cost more than BEV batteries, per kWh. This is because the power requirements place a proportionally larger demand on the smaller battery pack in a PHEV, so batteries with higher power must be used at a somewhat higher cost.

Fuel cell vehicle systems

Next to pure EVs, renewably produced hydrogen used in fuel cell electric vehicles (FCEVs) offers one of the largest potential reductions in CO_2 in the longer term. FCEVs also offer the benefit of a range and refuelling time comparable to conventional vehicles. FCEVs are therefore particularly well-suited to long-distance driving. While many manufacturers have active R&D programmes developing fuel cell technology, there are still a number of barriers to bringing the technology to the marketplace, including:

- Fuel cell vehicles are currently substantially more expensive than conventional vehicles, or even BEVs, as a result of fuel cell costs.
- There are also very few locations where they can currently be refuelled. To encourage wide-scale uptake of FCEVs by consumers, a large network of hydrogen refuelling infrastructure is required to ensure convenience.
- The actual GHG savings are dependent on the source of the hydrogen. Since the combination of hydrogen production chain efficiency and vehicle efficiency is substantially less than for BEVs, significantly lower carbon

energy sources need to be used to achieve equivalent GHG savings (and greater amounts of primary energy).

- Innovation is also required in the fuel cell to reduce the required amount of platinum.

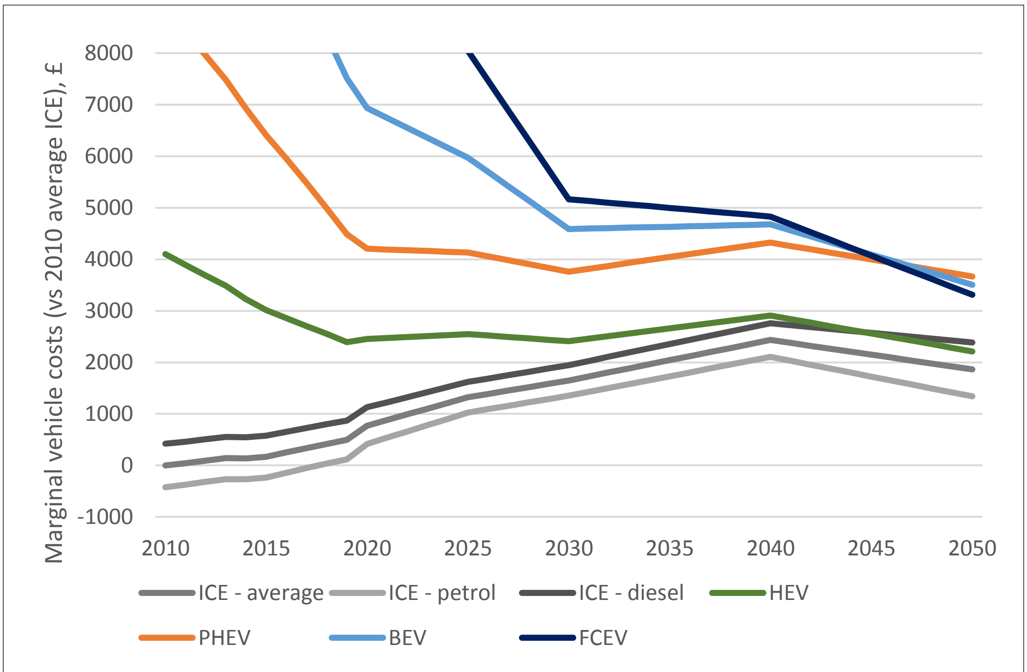
As a result of one or more of these issues, the focus over the last five years has been on battery technology and plug-in vehicles. However, in the summer of 2015 Toyota will launch its first hydrogen fuel cell vehicle in Europe, reportedly at a cost of around £40,000.

The Automotive Council UK's technology roadmap shows FCEVs moving from the demonstrator phase to production in the early 2020s. In addition, a recent study by the Carbon Trust predicts that FCEVs could achieve more than 30 per cent market share in the medium-sized car market by 2030. This is based on predictions for polymer fuel cell technology to achieve a step-change in cost reduction, with expected mass production costs coming down to around US$36/kW (current fuel cell system costs are around US$1,200/kW). Similar figures have also been cited in a recent study by MacKinsey, which suggested fuel cell stack costs could reach €43/kW as early as 2020. Our analysis has utilised slightly more conservative figures for the whole fuel cell system cost based on feedback from Daimler and ICCT.

Vehicle costs

Figure 3.1 shows the average cost of a car for each powertrain in the TECH scenario compared to the average cost of an internal combustion engine in 2010. Under this scenario petrol and diesel ICE's become more expensive as the technologies described above are adopted to improve the efficiency of the ICE. As new technologies are added, there is an upward pressure on vehicle costs, but as technologies reach mass deployment and learning effects take place we start to observe downward pressure on the cost of incremental technologies.

Figure 3.1: Additional capital cost of cars, by powertrain (TECH scenario)



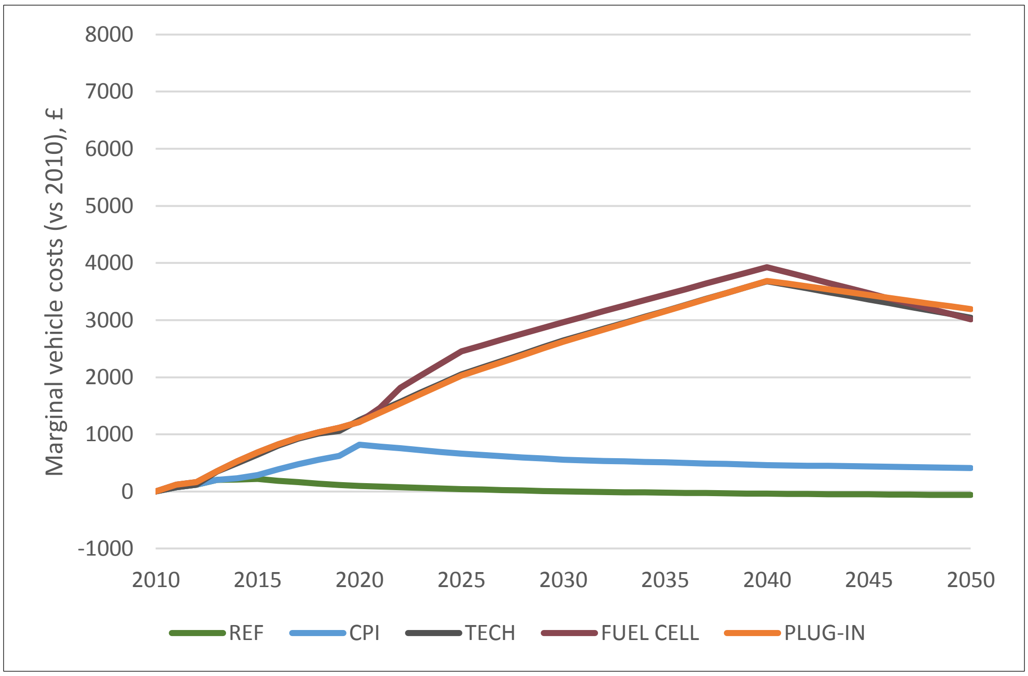
In 2015, hybrids cost around £2,800 more than the average ICE, but by 2025 this gap has fallen to around £1,200, before reaching near parity with ICE's post 2040.

More advanced powertrains remain significantly more expense that the typical petrol or diesel internal combustion engine. In 2015, Plug-in Hybrid electric vehicles have a manufactured cost around £5,700 more than an average ICE, which is reasonably close to parity to the consumer because In the UK there is currently a government grant in place, up to £5,000 on the purchase price of Ultra-Low Emissions Vehicles. Electric Vehicles and Fuel Cell Electric Vehicles are expected to cost considerably more until at least 2030, when they start fall to within around £3,000-£3,500 of 2030 ICE's.

The low-carbon scenarios envisage the take up of many technologies to improve engine efficiency, load, and aerodynamics. We assume that these technologies reach commercial costs when they are taken up in 10% of vehicles produced. At that point, we assume that each cumulative doubling of production of each technology option leads to a 10% reduction in unit costs. This is arguably a conservative estimate because, for example, it treats different degrees of light-weighting as independent options.

For each scenario Figure 3.2 shows the average vehicle cost in each scenario. To meet the 95 g/km standard in place for 2021, represented by the CPI scenario, the average car costs £870 more than the average 2010 car. Under the low carbon scenarios, the cost of the average car increases by nearly £1,400 by 2020, then rises to an increase of £4,000 by 2040 before falling slightly in the last decade of the projections as learning costs start to outweigh the persistent take-up of new technologies. The FUEL CELL scenario is marginally more expensive over the period 2020-2040 because of the additional cost of the fuel cell system relative to plug-in hybrids in this period.

Figure 3.2: Additional average vehicle costs, by scenario



Car buyers have been shown in some studies to undervalue future fuel savings, but a recent survey of 1,500 prospective car buyers found that over one third were willing to pay €1,000-2,000 extra for a hybrid car, and over a quarter were willing to pay a premium of more than €2,000 (PWC, 2014)

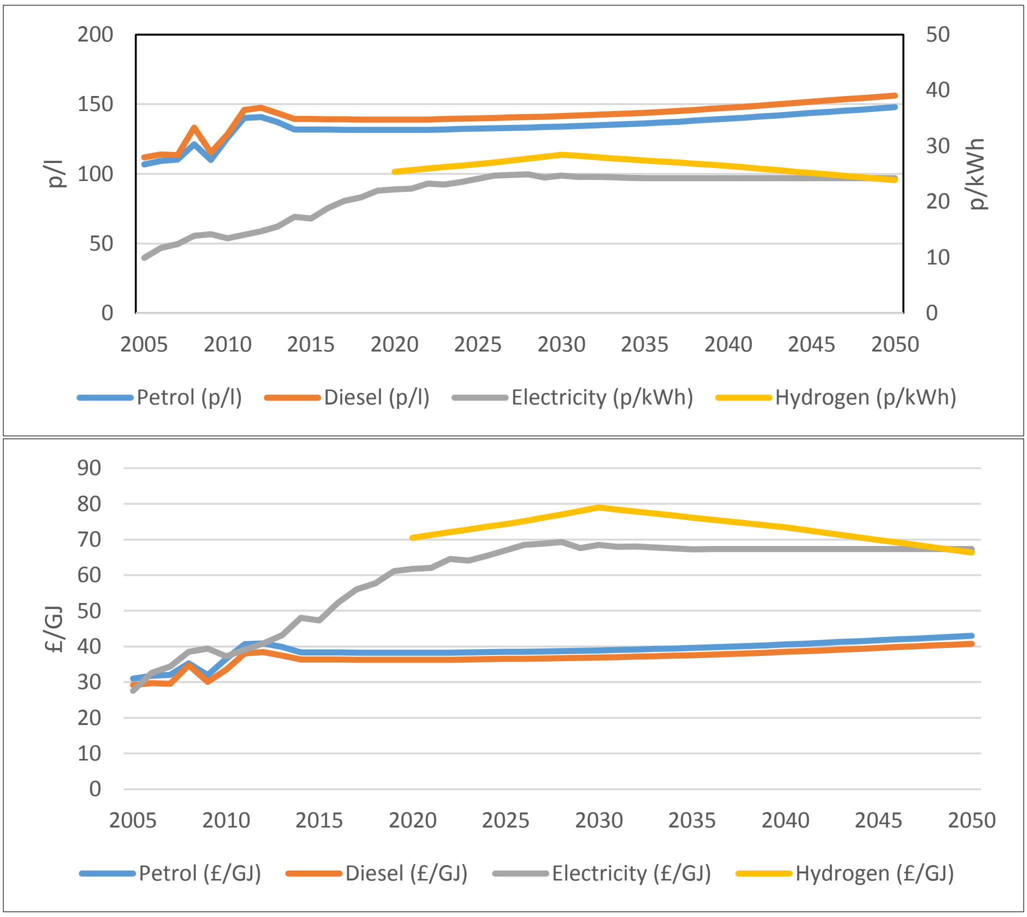
3.2 Fuel costs

Alongside the increase in vehicle costs come substantial improvements in energy efficiency, which drastically reduce the running costs of vehicles. However, this needs to be set against the impact of increasing energy prices and differences in the costs of alternative fuels.

The oil price projections assumed for this study has been updated to reflect the IEA's latest projections published in the November 2014 World Energy Outlook. The price of diesel is expected to stay modestly above the price of petrol and both are expected to grow in real terms, reaching an average of 150 p/l by 2050. In the short term the IEA's prices are above current market prices and so a low oil price sensitivity is explored in the economic analysis.

As the vehicle mix moves towards PHEVs, EVs and FCEVs it is important to consider the price of hydrogen and electricity. The National Grid's Gone Green scenario, from the publication "Future Energy Scenarios", has been used to construct wholesale and retail electricity prices faced by drivers of electric vehicles. Retail electricity prices are expected to increase significantly to 2025 and then level off at just under 25 p/kWh (in real terms) (see Figure 3.3).

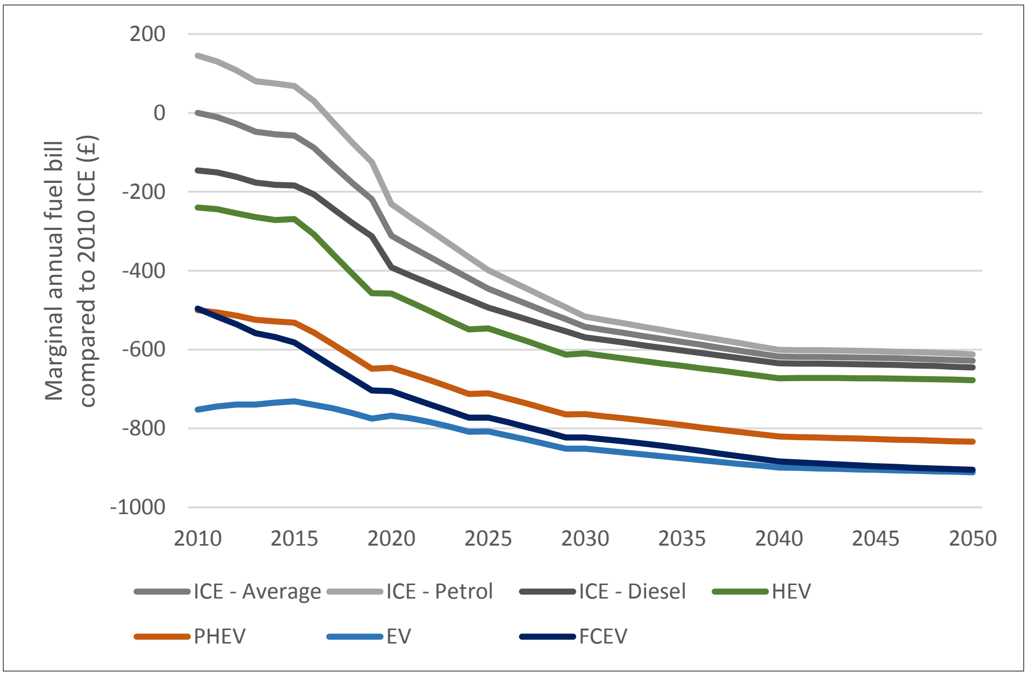
Figure 3.3: Fuel prices



Hydrogen prices are formed on the assumption that the hydrogen production is entirely delivered through a combination of centralised and decentralised electrolysis (see Section 4.3). To cover the cost of production, distribution and retail margins we estimate a price of hydrogen of around 28 p/kWh (just under £10/tonne) in 2030, falling to around 24 p/kWh (£8/tonne) by 2050 as production methods improve.

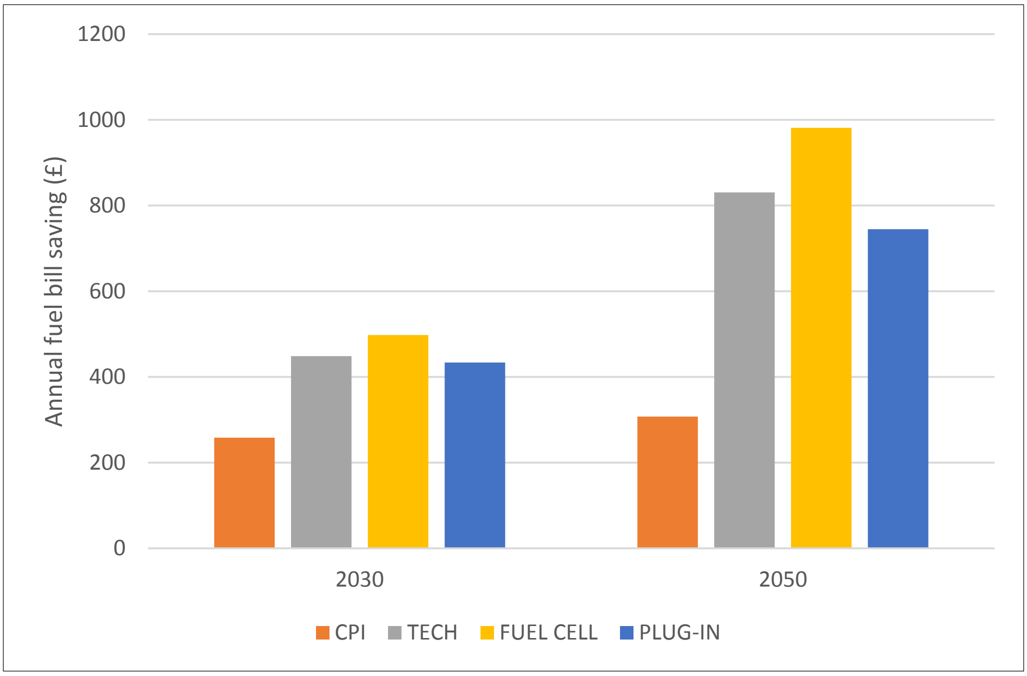
For each powertrain technology the annual running fuel costs are dramatically different. In 2010, the efficiency of an average new ICE implied average annual fuel cost is £975 over its 13 year lifetime, while the average hybrid is £217 cheaper (Figure 3.4). PHEVs, EVs and FCEVs are substantially cheaper to run. Fuel costs fall over the projection period in the TECH scenario as vehicle efficiency improves, by 2030, a FCEV is expected to cost just £230 to do the same mileage as today's ICE's; £215 for an EV and £295 for a PHEV (assuming typical trip patterns).

Figure 3.4: Annual fuel costs by powertrain



For the vehicle stock as a whole (and under real world driving conditions) the fuel savings associated with the efficiency savings outlined in the TECH scenario and its variants are also substantial. By 2030, the average annual fuel cost is £663, compared to £1,112 in the Reference scenario representing an annual average saving across the fleet of £449 (see Figure 3.5). By 2050, the annual average fuel bill in the TECH scenario could be reduced by nearly 70% compared to REF and by nearly 60% compared to the CPI.

Figure 3.5: Average annual fuel bill savings compared to REF



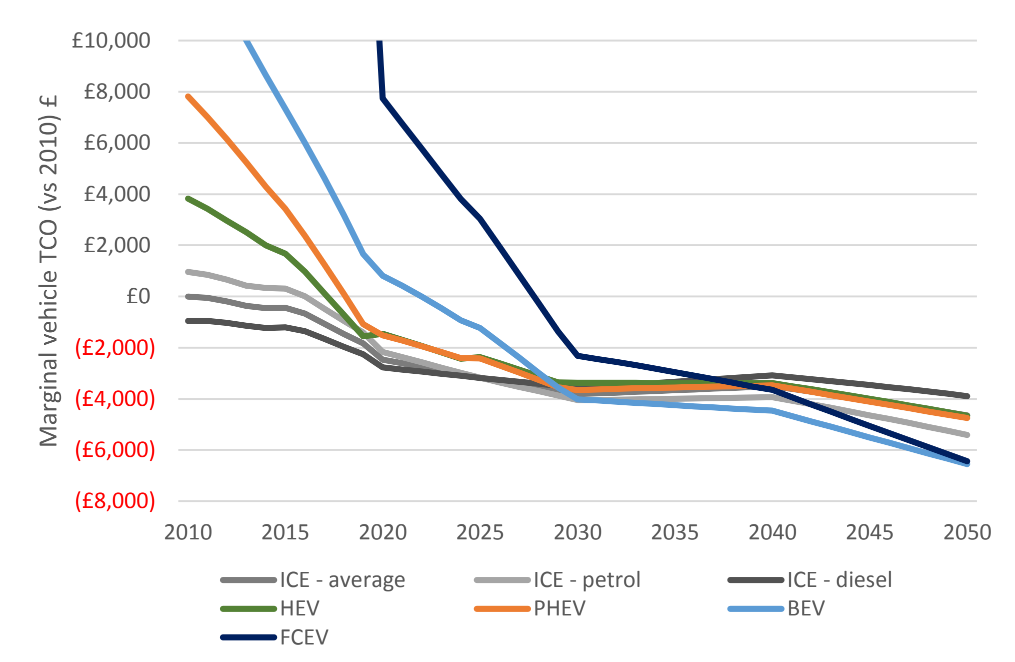
3.3 Total cost of ownership

Consumers select their vehicles on the basis of a wide range of factors, of which the up-front capital costs are just one element (though increasingly important in the current economic climate, particularly for business/fleet purchasers). In calculating the overall impact on motorists of improved vehicle efficiency, it is also useful to look at Total Cost of Ownership (TCO), which includes most other important factors in the overall running costs, such as fuel and maintenance costs

To reflect the fact that costs are faced in different years (the capital cost of the car is paid up-front or financed, while the fuel and maintenance costs are paid each year) it is necessary to discount future costs to reflect the borrowing costs faced by consumers.

Figure 3.6 shows the total cost of ownership (excluding insurance) for a new vehicle bought in each year, relative to the TCO of an average 2010 ICE under 10% discount rates. By 2020, HEVs and PHEVs are expected to be cheaper to own and run than a new ICE in 2010. By 2030, the TCO of all advanced powertrains are between £2,500 and £4,500 cheaper to own and drive than an average new 2010 ICE. FCEVs could reach parity before 2030, but there is still considerable uncertainty over both the expected cost of hydrogen and, more significantly, the capital cost of the FCEV's. In the TECH scenario to 2050, the TCO of FCEVs and EVs overtake that of all other cars as capital costs reach parity with PHEVs, but for much greater levels of fuel efficiency.

Figure 3.6: Marginal car total cost of ownership (10% discount rate)



Focus on light-weighting

Light-weighting plays an important role in improving the efficiency of passenger cars. In the vehicle stock model, five potential grades of weight reduction are available:

- mild light-weighting (10% of total weight)
- medium light-weighting (20% of total weight)
- strong light-weighting (30% of total weight)
- very strong light-weighting (35% of total weight)
- extreme light-weighting (40% of total weight)

The analysis suggests that as lighter materials for vehicles are developed and deployed, the total cost of ownership of a vehicle can be reduced. The TECH scenarios include a package of weight reduction options such that by 2030 the average car is between 25 and 30 per cent lighter than a car in the REF scenario. By 2050, new cars in the TECH scenario are around 35% lighter than in the REF scenario. A variant of the TECH scenario was developed that did not allow for weight reduction options beyond those in the REF scenario. Light-weighting reduces the total cost of petrol ICE ownership by just under £800 for a new car in 2020 and even as marginal energy savings on new light weighting technologies diminish for ICE's, total cost of ownership savings remain around £400 over the projection period (even at 10% discount rates).

Clearly, weight reduction options have an important role in cost effectively improving efficiency, but weight reduction also plays an important role in improving the performance of electric vehicles. Electric powertrains are highly efficient. As a result, weight, drag and rolling resistance account for a much larger proportion of the total efficiency losses. Reducing these losses may also allow the battery size to be reduced for a given range, further reducing vehicle weight and cost. Therefore, these options are seeing more significant and earlier introduction into such vehicles. For example, carbon fibre reinforced plastics (CFRP) are used for body components on BMW's i3 battery electric and i8 plug-in hybrid vehicles where it is reported to achieve a 50 per cent weight saving over steel and 30 per cent over aluminium.

3.4 Annual expenditure on purchasing and running cars

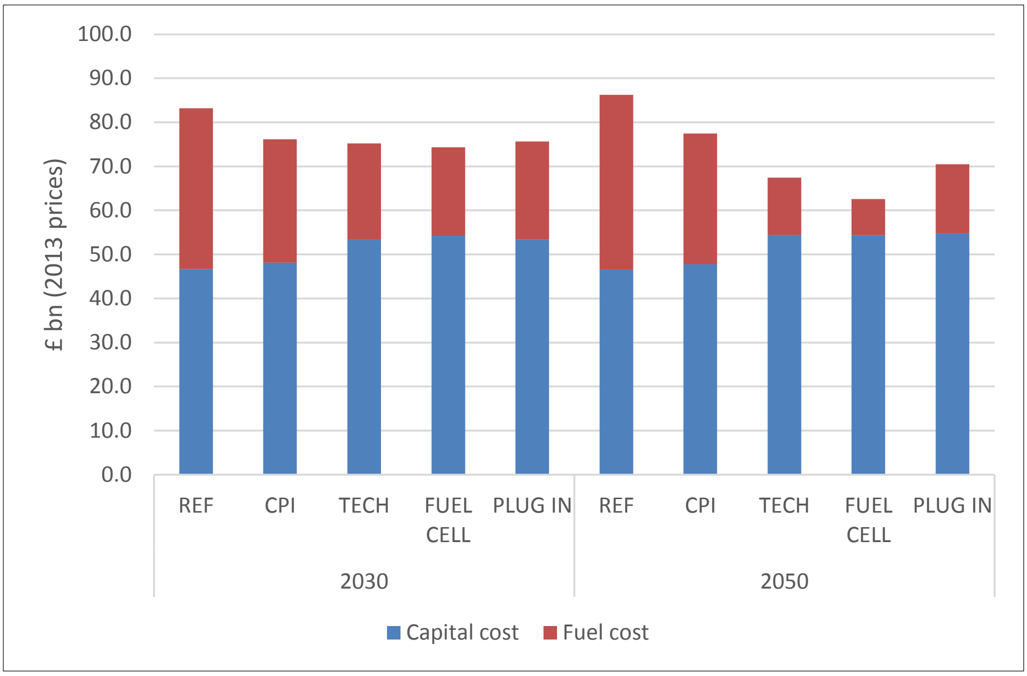
The macroeconomic impacts follow from the total annual expenditure on each of the three cost components across the entire vehicle fleet:

- capital cost: the cost of new sales of cars across the population
- fuel cost: the amount consumers spend on fuelling cars in a year
- maintenance cost: the amount consumers spend on maintaining their cars

In this analysis, the maintenance costs do not change substantially across vehicle types and, therefore, across scenarios. By contrast, the fuel and capital costs are quite divergent. By 2030 the total capital and fuel cost of cars in 2030 is around £83 bn in the REF scenario, but the net impact of the additional capital cost and the reduced fuel bill in the CPI scenario reduces the total cost to around £76 bn. This is further reduced in the TECH scenario variants to around £75bn.

By 2050, the impact is even larger. In the FUEL CELL scenario, the combination of very efficient and competitively priced FCEVs means that the total expenditure on cars is around £63bn compared to £78 bn in the CPI scenario. Allowing consumers to spend £15bn on other goods and services in the economy. For the PLUG IN scenario, the efficiency savings are not quite as stark and the total annual expenditure is reduced to £71bn, but this still represents a substantial saving over the CPI scenario (see Figure 3.7).

Figure 3.7: Capital and fuel costs of UK passenger car fleet



4 Infrastructure

4.1 Electricity generation

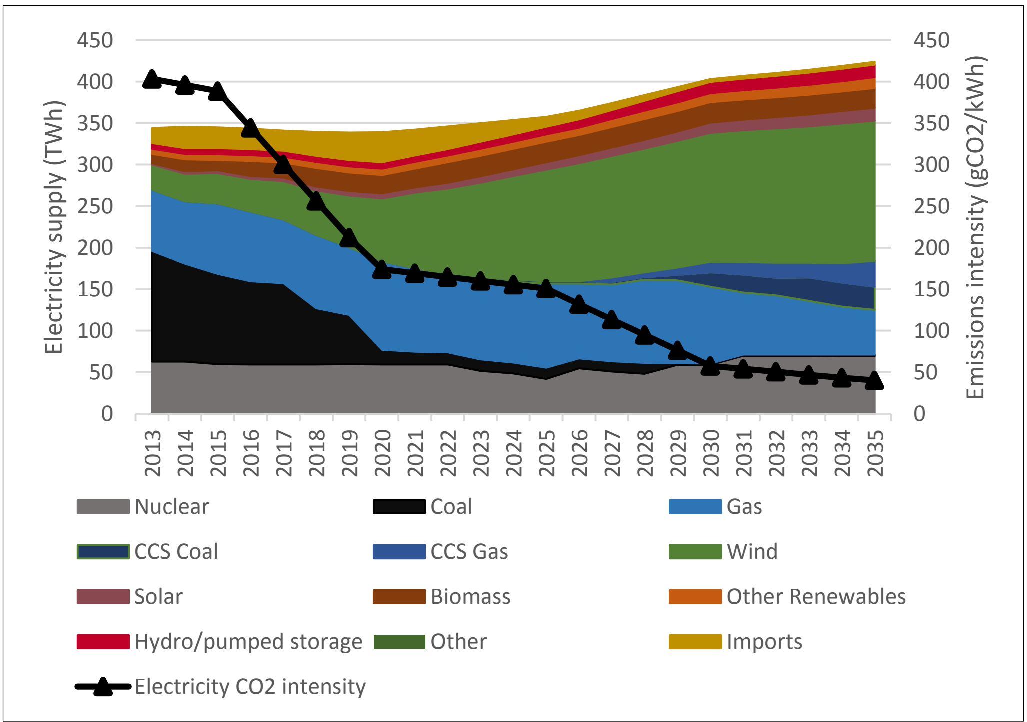
The transition to electric vehicles means that it is important to consider the future characteristics of the UK's electricity sector. For this analysis, the assumptions for the power sector follow the medium term projections developed by the National Grid in the scenario "Gone Green".

By 2030, Gone Green projects an electricity mix supplying just over 400 TWh to the grid. Nuclear stations that are expected to be decommissioned are replaced, as a result the total supply from nuclear in 2030 is similar to today at around 60 TWh. Coal-fired power is run-down to residual levels with nearly all coal-fired power stations closed before 2020. Gas-fired power and, more prominently, renewables fill the gap arising from falling coal-fired generation. By 2030 renewables account for over half of total generation (see Figure 4.1).

The carbon intensity of electricity falls to 174g/KWh by 2020 and to 57 g/kWh by 2030 - a considerable reduction from 2013 levels of around 400 g/KWh and broadly in line with the recommendations of the UK's Committee on Climate Change. By way of comparison, petrol has a carbon intensity of 239 g/KWh, but the energy efficiency of BEV powertrain is about four times that of a petrol ICE and so driving a BEV today would lead to lower carbon emissions even before accounting for the projected decarbonisation of the electricity sector.

By 2050, Gone Green envisages a near zero carbon electricity mix, dominated by nuclear (278 TWh), wind (166TWh) and CCS (112 TWh). Moreover, the UK becomes a net exporter of electricity to the rest of Europe, with net exports of around 50 TWh per annum.

Figure 4.1: Electricity generation and carbon intensity



Gone Green includes electricity demand from light duty vehicles. To make the analysis consistent, electricity supply has been adjusted to reflect the electricity demand from light duty vehicles in each scenario in this analysis.

Although the total demand for electricity anticipated by electric vehicles is fairly small relative to total electricity demand, there could be implications for peak electricity demand. With the deployment of more intermittent renewable technologies (such as onshore and offshore wind), as envisaged by the Gone Green scenario, the grid has less flexibility to deliver at times of peak demand. If EV's were charged at peak times (between 5pm and 7pm) it might be necessary to build additional 'peaking' electricity capacity to ensure that demand is met. However, this additional infrastructure cost could be avoided by Demand Side Response (DSR): for EV drivers, this could mean charging EVs through the night at times of low demand from other sources. This could have the double benefit of reducing curtailment of intermittent wind power that might occur through the night (see Chapter 7).

4.2 Electric charging infrastructure

The infrastructure for charging electric vehicles can be divided into two broad categories: private and public. Private infrastructure includes charging points installed in homes and at the workplace, while public infrastructure includes on-street charging points, charging points in supermarket and other public car parks, and rapid charging points at service stations.

The UK government has several initiatives in place to support the roll-out of charging infrastructure in the UK first outlined in "Making the Connection: The Plug-In vehicle Infrastructure Strategy" and supported by:

- The Electric Vehicle Homecharge Scheme: To help private plug-in vehicle owners offset some of the upfront cost of the purchase and installation of a dedicated domestic recharging unit, householders who own, lease or have primary use of an eligible electric vehicle may receive up to 75% (capped at £900) off the total capital costs of the charge point and associated installation costs.
- Plugged-in Places: The Plugged-in Places programme offers match-funding to consortia of businesses and public sector partners to install electric vehicle charging points.
- The National Infrastructure Plan: In November 2014, the UK government pledged £15m between 2015-16 and 2020-21 for a national network of charge points for Ultra Low Emissions Vehicles (ULEVs) on the strategic road network.

According to the Office for Low Emission Vehicles "By the end of March 2013, over 4,000 charge points had been provided through the eight Plugged-in Places projects. About 65% of these Plugged-in Places charge points are publicly accessible. Using data provided by charge point manufacturers, it is estimated that non Plugged-in Places organisations may have also installed about 5,000 charge points nationwide"

The evidence to date from the Plugged-In Places programme suggests that the majority of charging is done at home between 5pm and 9am the following day, and this is expected to continue. However, some charging is still expected within the working day at work charging points or public car parks.

To align with the analysis of Plugged-In Places data, the charging infrastructure assumptions in this study follow that of the *Grazing* scenario outlined in Fuelling Europe's Future:

- Home charging is the main mode of charging
- Convenience public infrastructure plays an important role, with heavy starting investment to develop critical mass and consumer confidence
- Significant up-front investment in rapid charging points on the major road network

The costs of charging infrastructure have been adapted from Ricardo AEA's analysis in Fuelling Europe's Future, such that a 3 kW one plug domestic charging point has a capital and installation cost of around £1,150. Workplace charging points are included as two plug 7 kW, ground mounted at an installed cost of around £1,470 (see Table 4.1). Rapid chargepoints that would be expected at motorway service stations are estimated to cost £38,400 to manufacture and install, but provide full battery charges in 30 minutes.

Table 4.1: Charging point cost assumptions

Main application	Charging point features	Power (kW)	Charge time	Production cost (£)	Installation cost (£)
Residential	Wall box One plug User protection during charging Options for metering	3 kW	4-8 hours	330	820
Workplace	Ground mounted Two plugs Choice of access control systems	7 kW	4-8 hours	650	820
Parking (on-street and shopping centres)	Ground mounted Two plugs High resilience Different access options	22 kW	1-2 hours	4,900	2,450
Stations on motorways	Rapid charging 2 plugs High resilience	43 kW	30 minutes	17,960	20,410

4.3 Hydrogen production and distribution

Hydrogen can be produced on both small and large scale, and from a variety of sources and processes. As part of the UK H2 mobility study, eleven possible sources for hydrogen production were assessed, including those deriving from fossil resources, such as natural gas and coal, as well as renewable sources such as solar, wind, biomass and water. Processes included chemical, biological, electrolytic, photolytic and thermo-chemical techniques.

The diversity of energy sources and processes makes hydrogen a promising energy carrier and important to energy security. However, it results in a wide range of production facilities, from large, central facilities, through smaller semi-central ones to on-site production from steam reforming of natural gas or electrolysis.

The H2 mobility study suggests that hydrogen in the UK would most likely be a mix of Steam Methane Reforming, in the near term, and a gradually increasing share of electrolysis. The members of the UK H2 Mobility project consider Carbon Capture and Storage technologies for hydrogen production to be unlikely before 2030. This is broadly consistent with National Grid's Gone Green scenario for the power sector, which has only 30 TWh of CCS based electricity generation by 2030.

The Low Carbon Innovation Coordination Group's "Technology Infrastructure Needs Assessment of Hydrogen for Transport" suggests a similar mix of hydrogen production technologies to the UK H2 Mobility study. It envisages a mix of decentralised electrolysis with coal based Steam Methane Reforming that is gradually replaced by centralised electrolysis. An alternative scenario envisages a mix of decentralised electrolysis and central SMR without CCS that is gradually replaced by SMR with CCS and syngas production (predominantly) from coal.

For this study, we assume the same production mix for hydrogen production as in Fuelling Europe's Future: an even mix of decentralised (50%) and centralised (50%) electrolysis supply chains (see Table 4.2). The decentralised chain takes electricity from the grid, while the centralised chain is expected to be located by major wind farms. The costs of delivered hydrogen in these chains are generally higher than in Steam Methane Reforming but SMR without CCS has a carbon intensity that is not consistent with this study's objective so this energy chain was not included.

Table 4.2: Hydrogen production chains

	Centralised chain	Decentralised chain
Primary energy source	Wind	Grid electricity
Electrolysis	Alkaline, capacity up to 10,000kg/day Lifetime 20 years Stack life 40,000 hours H2 delivered at 30 bar Load factor 90%	PEM, capacity up to 100kg/day Lifetime 20 years Stack life 40,000 hours H2 delivered at 30 bar Load factor 90%
Compression	Two stage compression: Stage 1: 30-170 bar Stage 2: 170: 480 bar	Stage 1: 30-170 bar (refuelling compressor at station)
Transmission and distribution	500 bar tanker; 900kg day Round trip of 200km	Not required.

Decentralised electrolysis stations can use either grid power or a dedicated renewable electricity source (or combination of the two) to produce hydrogen via electrolysis using water as a feedstock.

When it is not produced on-site, hydrogen needs to be transported to the stations. This can be done in gaseous or liquid form in trucks or via pipelines from a nearby hydrogen plant or refinery.

Currently, one of the most economic ways to provide hydrogen for fuelling stations is by truck, with hydrogen as liquid or gas. Liquid hydrogen has a relatively high density so that it is possible to transport approximately five to ten times more hydrogen on a truck than when using compressed gas. This can significantly lower the delivered cost of hydrogen, especially when transport distances are moderate or long.

This method of distribution takes advantage of large central hydrogen production facilities that make hydrogen for other purposes, such as oil refining or food processing. This pathway also has the benefit that increases in demand can often be met simply by scheduling more frequent truck deliveries without needing to change the footprint of the original equipment.

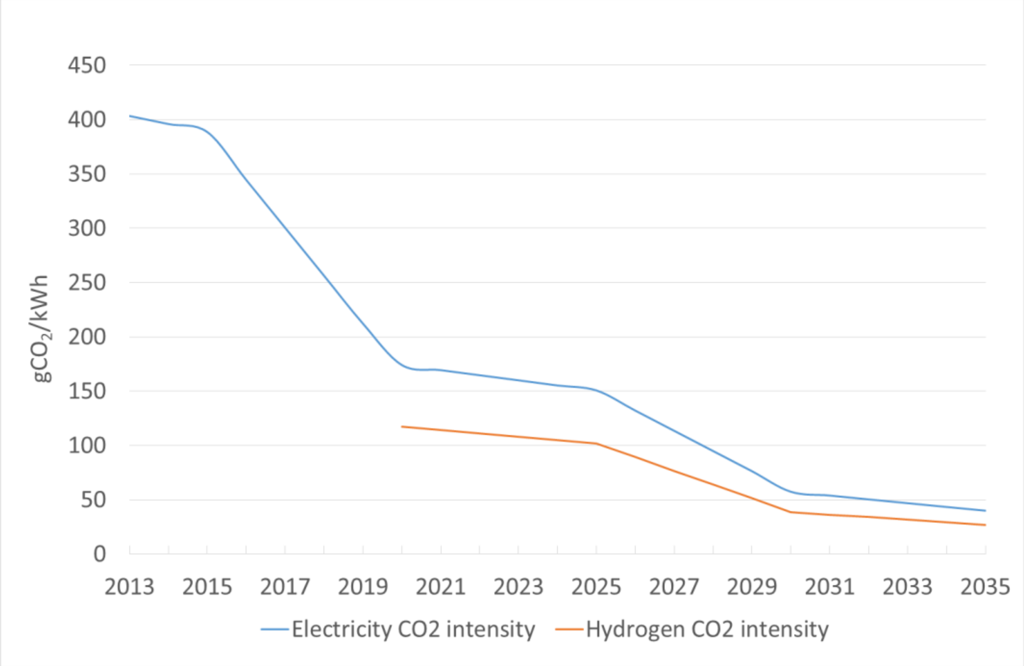
In the longer term, despite higher initial capital costs, pipelines could provide one of the most cost effective options by achieving economies of scale if large volumes (associated with supplying hundreds or thousands of stations) are needed.

A wide variety of distribution infrastructures may therefore be considered, with important implications for costs at EU level. Overall, studies which model distribution pathways (e.g. McKinsey) assume that gaseous trucks are initially the most important method, with liquid trucks bridging the gap to pipelines.

Ultimately, the investment in distribution infrastructure depends on the projected approach to production. The hydrogen production and distribution "energy chains" for use in vehicles used in this study are based on the assumptions in Fuelling Europe's Future. The costs have been updated to reflect the cost of electricity assumptions in the National Grid's Gone Green scenario. The CO_2 intensity of hydrogen production falls in line with the changes in the carbon intensity of electricity (see Figure 4.2[9]).

[9] The carbon intensity for hydrogen is lower than for electricity because it is assumed that half of the supply is sourced from grid electricity and half from wind power directly. The energy conversion loss associated with producing hydrogen from electricity is accounted for.

Figure 4.2: Carbon intensity of electricity and hydrogen



4.4 Hydrogen refuelling

The refuelling network for hydrogen is expected to follow a similar model to petrol and diesel refuelling. Hydrogen refuelling stations will need to be built across the UK to support the fleet of hydrogen vehicles projected in the scenarios.

The recent research "UK H2 Mobility: Phase 1 results" suggests that in the period 2015-20 around 65 hydrogen refuelling stations will be needed in and around major population centres to encourage take-up. Over the following five years to 2025 a five-fold increase in refuelling stations is required enabling close-to-home refuelling for about half of the population. By 2030, the study estimates around 1150 stations, extending close-to-home refuelling to the whole population.

Following the approach applied in Fuelling Europe's Future gives similar projections to the UK H2 Mobility study. We assume that in 2020, the stock of FCEVs will require one refuelling station for every 2,500 FCEVs increasing to one refuelling station for every 3,300 FCEVs by 2030, which is just over 1,000 stations in the FUEL CELL scenario.

By 2050, the number of hydrogen refuelling stations is assumed to increase to around 4,600 supporting 15m FCEVs. By way of comparison, there were around 8,700 petrol and diesel refuelling stations in 2011 in the UK, supporting around 29m cars.

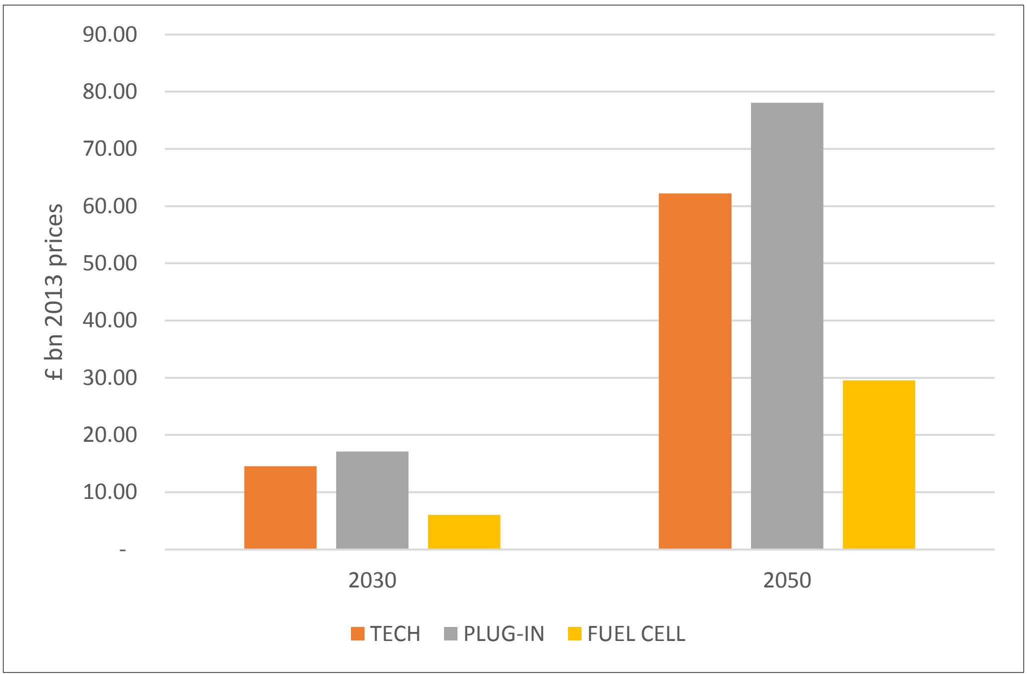
In line with the assumption applied in Fuelling Europe's Future, the assumed cost of a hydrogen refuelling station is €1.5m, falling over time as a result of learning.

4.5 Total infrastructure requirement and funding

Across the three low-carbon scenarios, the investment requirements for the charging infrastructure and hydrogen refuelling stations are quite different[10]. The FUEL CELL scenario requires less investment in infrastructure as the distribution of hydrogen is relatively more centralised than the distribution of electricity in the PLUG-IN scenario which requires home or work charging for all electric vehicles in addition to the (more modest) requirements for public infrastructure (see Figure 4.3).

The investment in infrastructure needs to be paid for. We assume that households and businesses pay for private charging points upfront when purchasing a PHEV or BEV, while public infrastructure, which is installed in shopping centres, supermarkets and by motorways, is financed by the operating businesses who pass on the costs to consumers in the form of higher prices.

Figure 4.3: Cumulative infrastructure investment



[10] The investment required to produce and distribute electricity and hydrogen are included in the economic analysis but are not reported in this comparison which only includes charging points and refuelling stations.

5 Macroeconomic impact

5.1 Economic impacts

The stock model analysis described in Chapter 3 shows that UK consumers would benefit from the lower costs of ownership associated with low-carbon vehicles. This section of the report builds on the results from the vehicle stock model analysis to assess the wider macroeconomic implications of a low-carbon vehicle fleet in the UK. A macroeconomic model of the global economy, namely E3ME, is used to model the effects on UK GDP, consumption, investment, the balance of trade and employment resulting from the changes in vehicle costs, fuel consumption and charging infrastructure, as outlined in Chapter 3 and Chapter 4.

This section begins by defining the key drivers of the macroeconomic results and, within this context, the relevant characteristics of the UK economy. Then it explains the key assumptions applied in the macroeconomic modelling. Finally, it describes the different macroeconomic results in the four scenarios, as modelled in E3ME.

Factors affecting the macroeconomic results

The key macroeconomic flows resulting from an increase in purchases of low carbon vehicles and a change in the vehicle fuel mix are shown in Figure 5.1 and Figure 5.2 below.

Figure 5.1: Effects of an increase in deployment of EVs on the vehicle supply chain, consumers and the economy

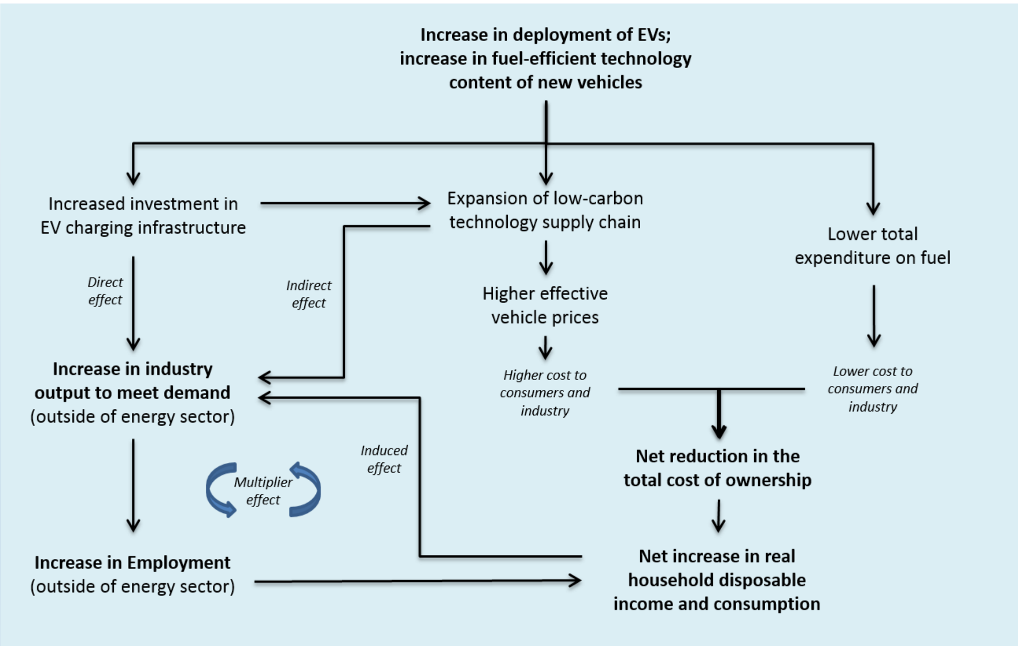
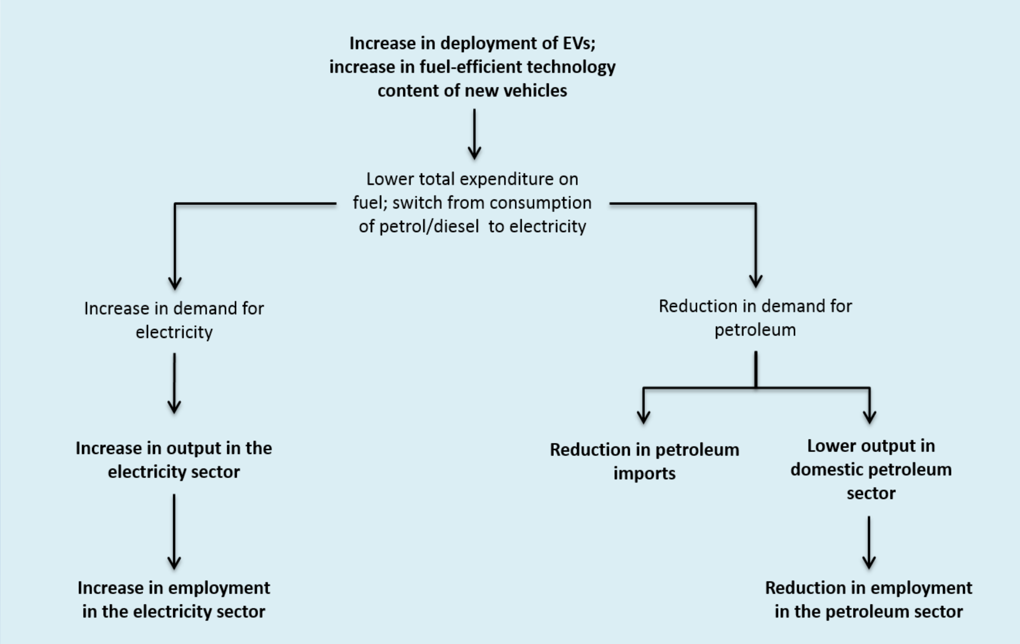


Figure 5.2: Effects of increased deployment of EVs on the energy sector



The macroeconomic effects depicted in the diagrams above relate to four key drivers:

1) The effects on consumers and businesses of higher upfront vehicle costs counteracted by fuel cost savings, which lead to a net reduction in the total cost of vehicle ownership by 2050
2) The effect of reductions in demand for petrol and diesel and increases in demand for electricity and hydrogen
3) The effect on the motor vehicle supply chain due to an increase in demand for energy-efficient component parts
4) The effect of investment in electric vehicle and hydrogen charging infrastructure

Each of these factors also has associated indirect and induced effects and together, they explain the expected net economic outcome of a more fuel-efficient vehicle fleet in the UK. The macroeconomic effects associated with each of these factors are described below.

The effects on consumers and businesses of higher upfront vehicle costs counteracted by fuel cost savings, which lead to a net reduction in the total cost of vehicle ownership

The technologies contained in advanced powertrains are expensive relative to the technologies in conventional ICE vehicles: the results from the vehicle stock model show that, by 2030, the average car in the TECH, PLUG-IN and FUEL CELL scenarios costs around 14% more than in the REF scenario and by 2050 (when there is a higher share of advanced powertrains in the vehicle sales mix) they cost around 17% more than in the REF scenario. By 2050, the effect on consumers of this increase in upfront vehicle costs is more than offset by savings in the cost of fuel due to more efficient vehicles and the switch from petrol and diesel fuel to hydrogen and electricity. As a result, in the TECH, FUEL CELL and PLUG-IN scenarios, the total cost of ownership of BEVs and PHEVs converges to the total cost of ownership of ICEs by 2030 and the cost of owning a BEV or FCEV falls below the cost of a conventional

ICE by 2050. The lower lifetime ownership costs associated with BEVs and FCEVs would lead to an increase in real household incomes, which would lead to increased consumer purchasing power and increased demand for other consumer goods and services, leading to an increase in GDP and gross output.

It is worth noting that UK vehicle owners, on average, drive slightly less distance than drivers in the rest of the EU, with an average distance travelled of 12,500 km per annum. As a result, the relative benefit of the reductions in fuel consumption associated with advanced powertrains (BEVs, PHEVs, FCEVs) would be slightly lower for the average UK driver than that for the average driver in the EU.

The effect of reductions in demand for petrol and diesel and increases in demand for electricity and hydrogen

Another key factor driving the macroeconomic result is the effect of changes in vehicle fuel consumption patterns on imports and domestic output in the oil and petroleum sectors. Whilst domestic production of primary oils in the UK reached 40.6 mt in 2013[11], the UK is still heavily dependent on imports of oil and petroleum, which has accounted for over 50% of total supply to the UK market in recent years. In 2013, the UK imported 59.1 mt of crude oil, at a cost of £30.1bn[12].

Although oil and petroleum products are also used by industry, households and other modes of transport, energy demand from cars and vans currently accounts for around 55% of final energy demand for oil in the UK. Reductions in vehicle demand for petrol and diesel could therefore reduce the UK's dependence on oil imports and reduce exposure to potential oil price shocks. Reduced demand for petrol and diesel would also reduce output in the domestic petroleum sector, however, as the petroleum refining sector has a low labour intensity and a relatively short supply chain, the macroeconomic effects of a reduction in demand for domestically produced petroleum would be limited.

By contrast, electricity and hydrogen are predominantly produced domestically. Increases in consumption of these fuels would therefore have a marginal benefit for the UK supply chain and for the UK economy, relative to the consumption of oil and petroleum products, such as petrol and diesel.

The effect on the motor vehicle supply chain due to an increase in demand for energy-efficient vehicle component parts

The transition towards more efficient vehicles will lead to increases in demand for more sophisticated technologies and on-board computer systems and will stimulate investment and innovation in energy efficient products for vehicles. This increase in demand for more expensive, complex and sophisticated technologies will lead to an expansion of the vehicle supply chain. The vehicle supply chain in the UK is labour-intensive and has a slightly lower import content relative to the supply chain for petrol and diesel fuels. Taking this effect in isolation, the transition to a low-carbon vehicle fleet (which requires consumers to spend more on the capital cost of vehicles and less on fuel) is likely to lead to net benefits for the UK economy, as well as increases in output and employment in the manufacturing and engineering sectors.

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[11] DECC, 'Digest of UK Energy Statistics 2014'.

[12] DECC, 'Digest of UK Energy Statistics 2014'.

The extent to which the low carbon vehicle transition benefits the UK economy is heavily dependent on the import content in the motor vehicles supply chain. Historical data for the UK suggests that the supply chain for vehicles manufactured in the UK has a relatively high import content (around 30%-40%) which limits the extent to which the domestic economy would benefit from the transition to more efficient vehicles (see Table 5.1). However, most of the non-domestic supply chain for motor vehicles is located in Europe and so the increases in demand for energy-efficient technologies could also lead to increases in output and employment in the manufacturing sectors in other European countries, the benefits of which might partially spill-over to the UK economy.

Despite a moderately high import content in the UK motor vehicles supply chain relative to many other European countries, the import content in the supply chain for motor vehicles is lower than in the petroleum refining sector. The supply chain for motor vehicles also has a higher labour intensity and therefore increases in the value of output in the motor vehicles sector due to the transition to more fuel-efficient vehicles has the potential to create many more new jobs in higher-tier supply sectors than those lost in domestic industries related to petroleum refining.

Table 5.1: Import content and labour intensity in the supply chain for the motor vehicles and petroleum refining sectors

	Import content (imports as a percentage of total supply in the UK, 2013)	Labour intensity (jobs per million pounds of gross output, 2013)
Motor vehicles supply chain sectors		
Fabricated Metal products	22%	11.4
Rubber and plastics	38%	8.7
Basic metals	46%	3.9
Petroleum refining supply chain		
Oil extraction	59%	0.9

Source(s): ONS, DECC, own calculations.

The effect of investment in electric vehicle and hydrogen charging infrastructure

An increase in advanced powertrains in the vehicle fleet will require substantial investment in charging infrastructure. This includes both privately installed infrastructure in people's homes and in workplaces and public infrastructure in shopping centres, cinemas and fast charging points on motorways. The annual investment in charging infrastructure amounts to £2.5bn in TECH, £3.8bn in PLUG-IN and £1.7bn in FUEL CELL by 2050. This investment stimulus would boost gross output in the construction sector and its supply chain.

However, the charging infrastructure investment must have a means of financing and, in these scenarios, we assume that households and businesses pay for the charging points upfront when purchasing a PHEV or

BEV, which diverts their spending away from other goods and services. We assume that the public infrastructure, which is installed in shopping centres, cinemas and by motorways, is financed by higher prices in retail sectors. The effect of the investment stimulus on GDP will therefore be dampened slightly by the higher prices faced by consumers in order to finance this investment cost.

Macroeconomic modelling assumptions

In addition to the technical assumptions in the vehicle stock model (as presented in Chapter 2), there are a number of additional simplifying assumptions that were applied for the economic modelling.

Firstly it is assumed that vehicle manufacturers in other EU countries achieve the same vehicle emissions targets as those achieved by the UK in each scenario. This assumption was chosen because it is most likely that future emissions standards will be set at the European level. The effect of this assumption is that learning in technology manufacturing will be quicker, leading to a lower price of advanced technologies in 2050. Furthermore, the balance of trade in the UK could be affected depending upon the extent to which other European economies are affected by the low-carbon vehicle transition.

The cost of technology was represented in the E3ME model by adding the changes in manufacturing costs to the unit costs of production in the motor vehicles sector to represent the additional capital cost for the UK of more efficient technology. It was assumed that all of these higher costs were passed on to final consumers (both in domestic production and imported vehicles) through higher vehicle purchase prices.

In reality, it is possible that pricing strategies will result in European manufacturers selling early vehicles at a loss to gain a standing in the market, but as soon as a particular model is manufactured at large volume it is simply not commercially viable to sell a car for less than cost. In the scenarios, it is assumed that both domestic and imported vehicles are subject to the same increase in costs. It is also assumed that motor vehicle export and import volumes and domestic gross output volumes in the motor vehicles sector remain the same between scenarios.

For the electric vehicle and hydrogen charging infrastructure, we assume that private EV charging points in homes and workplaces will be paid for by consumers when they purchase a BEV or PHEV. We assume that public charging points will be financed by higher prices in the retail sector and that the taxes and margins paid by electric vehicle owners will be the same as those paid by household electricity users in the UK.

In addition, we have assumed that government balances remain neutral between scenarios. The loss of fuel duty revenue in the low-carbon vehicle scenarios is assumed to be directly compensated by an equivalent increase in VAT revenue, which is achieved by increasing the rate of VAT in the low-carbon vehicle scenarios. The rationale for this assumption was to ensure that government balances were not affected by the transition to more fuel-efficient vehicles in order to present a neutral set of scenarios.

Macroeconomic results

Table 5.2 and Table 5.3 shows the macroeconomic results for each scenario in 2030 and 2050 respectively.

Table 5.2: Macroeconomic results in 2030 (percentage difference from REF)

	REF	CPI	TECH	FUEL CELL	PLUG-IN
GDP (£ million, 2013)	2,597,290	0.0%	0.1%	0.1%	0.1%
Consumption (£ million, 2013)	1,575,908	0.0%	0.0%	-0.1%	0.0%
Investment (£ million, 2013)	457,111	0.0%	0.5%	0.3%	0.6%
Exports (£ million, 2013)	450,413	0.0%	0.0%	0.0%	0.0%
Imports (£ million, 2013)	448,044	0.0%	0.1%	0.0%	0.1%
Real income (£ million, 2013)	1,629,147	-0.1%	0.0%	0.0%	0.0%
Consumer prices 2013=1	2.076	0.2%	0.4%	0.5%	0.4%
Employment (000s)	33,786	0.0%	0.0%	0.0%	0.0%

Source(s): Cambridge Econometrics, E3ME.

Table 5.3: Macroeconomic results in 2050 (percentage difference from REF)

	REF	CPI	TECH	FUEL CELL	PLUG-IN
GDP (£ million, 2013)	3,811,637	0.0%	0.1%	0.2%	0.1%
Consumption (£ million, 2013)	2,368,499	0.0%	0.0%	0.0%	0.0%
Investment (£ million, 2013)	613,769	0.1%	0.7%	0.6%	0.8%
Exports (£ million, 2013)	730,604	0.0%	0.0%	0.0%	0.0%
Imports (£ million, 2013)	697,655	0.0%	0.4%	0.4%	0.4%
Real income (£ million, 2013)	2,338,946	0.0%	0.0%	0.1%	0.0%
Consumer prices 2013=1	2.978	0.1%	0.4%	0.5%	0.4%
Employment (000s)	36,214	0.0%	0.1%	0.1%	0.1%

Source(s): Cambridge Econometrics, E3ME.

E3ME shows that the transition to a low-carbon vehicle fleet would lead to a small positive impact for the UK economy. There is a very small increase in real incomes and consumption in the TECH, FUEL CELL and PLUG-IN scenarios[13] as consumers save money on the cost of owning and running a vehicle and have more money available to spend on other goods and services. By 2050, there is a 0.6-0.8% increase in investment in the TECH, PLUG-IN and FUEL CELL scenarios, primarily because of the charging infrastructure investment, but also due to secondary effects, as increases in output and GDP create a more positive environment to stimulate more business investment. There is a modest increase in imports (0.4% in 2050) as increases in real consumption drives an increase in demand for imported products and due partly to an increase in imports of energy-efficient products for vehicles. However, the net effect on imports is reduced somewhat due to reductions in imports of crude oil and refined petroleum in the low-carbon vehicle scenarios.

The E3ME results show that the loss of fuel duty revenue would be partially offset by an increase in other tax revenues. The economic stimulus in the low-carbon vehicle scenarios leads to a small increase in income tax revenue (as a result of higher employment and real incomes) and an increase in VAT revenues (due to higher levels of consumption). However, these increases in tax revenues are not sufficient for government revenue neutrality between scenarios. Therefore, to maintain consistent government balances between scenarios, we have assumed an increase in the VAT rate in the CPI, TECH, FUEL CELL and PLUG-IN scenarios to compensate for the reduction in fuel duty revenues in each of these scenarios. This increase in the rate of VAT to maintain government revenue neutrality is the main explanation for the small increase in consumer prices of around 0.4% by 2050.

5.2 Jobs

The net effect on jobs resulting from the transition to a low-carbon vehicle fleet, as modelled in E3ME, incorporates sector-specific direct effects, indirect effects in the motor vehicle, petroleum refining and electricity sector supply chains, and induced effects due to changes in average incomes (which affect economic demand) and changes in prices and wages. The jobs figures in the low-carbon vehicles scenarios incorporate the following:

- An increase in jobs in the motor vehicles supply chain due to increases in demand for fuel-efficient vehicle components
- A reduction in employment in the petroleum refining sector and its supply chain following the reduction in vehicles' demand for petroleum
- Positive induced effects (as real incomes rise due to the lower cost of vehicle ownership, consumption rises, leading to further increases in demand for goods and services and, as a result, increases in the demand for labour)
- Negative induced effects (as prices rise, employees request higher wages which increases the cost of labour relative to capital and leads to a substitution effect, in which firms reduce the share of labour inputs to production)

[13] This increase is <0.1% and hence does not show up in the tables presented.

- Increases in productivity as economic sectors expand and take advantage of economies of scale and learning effects, which reduces the labour intensity in some sectors

Figure 5.3 presents the E3ME model results for the net impact on employment in each scenario. The results show that the transition to a low-carbon vehicle fleet would lead to a 0.1% increase in employment by 2050. The employment results do not vary greatly between the TECH, FUEL CELL and PLUG-IN scenarios. The reason why employment in these scenarios is higher than in the REF scenario is partly due to direct and indirect effects (i.e. an increase in employment in the motor vehicles supply chain and in the installation of EV chagrining points), and partly due to induced effects, as the total cost of ownership of an EV falls below that of a conventional ICE resulting in an increase in real household incomes, an increase in demand for consumer goods and services and, in order to meet this increase in demand, an increase in output and employment.

Figure 5.3: Net additional jobs in 2030 and 2050 (relative to the REF scenario)

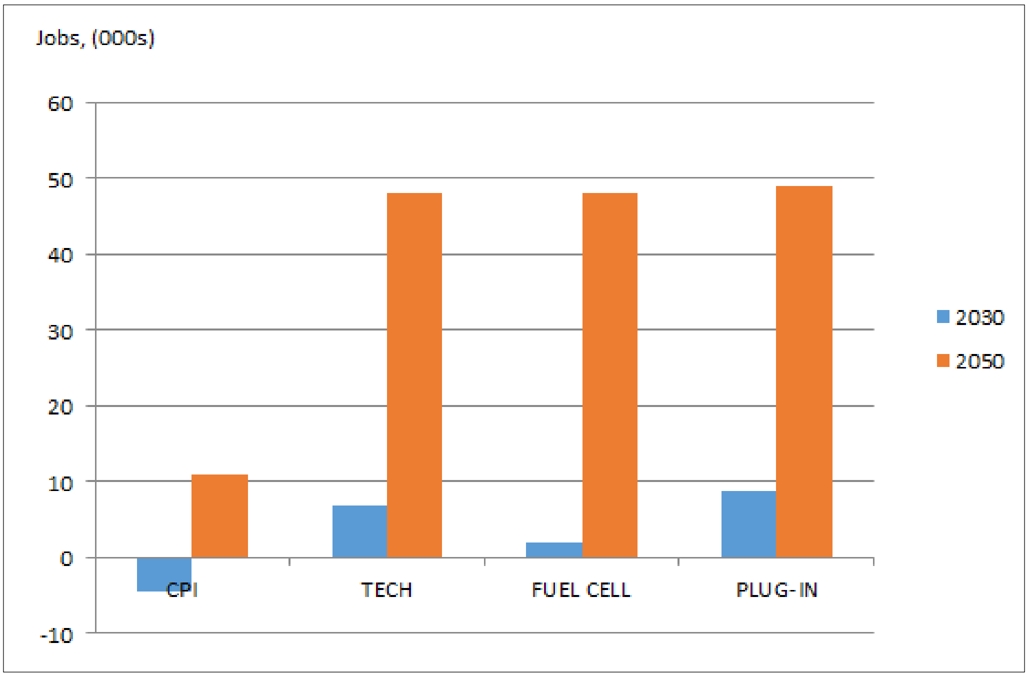
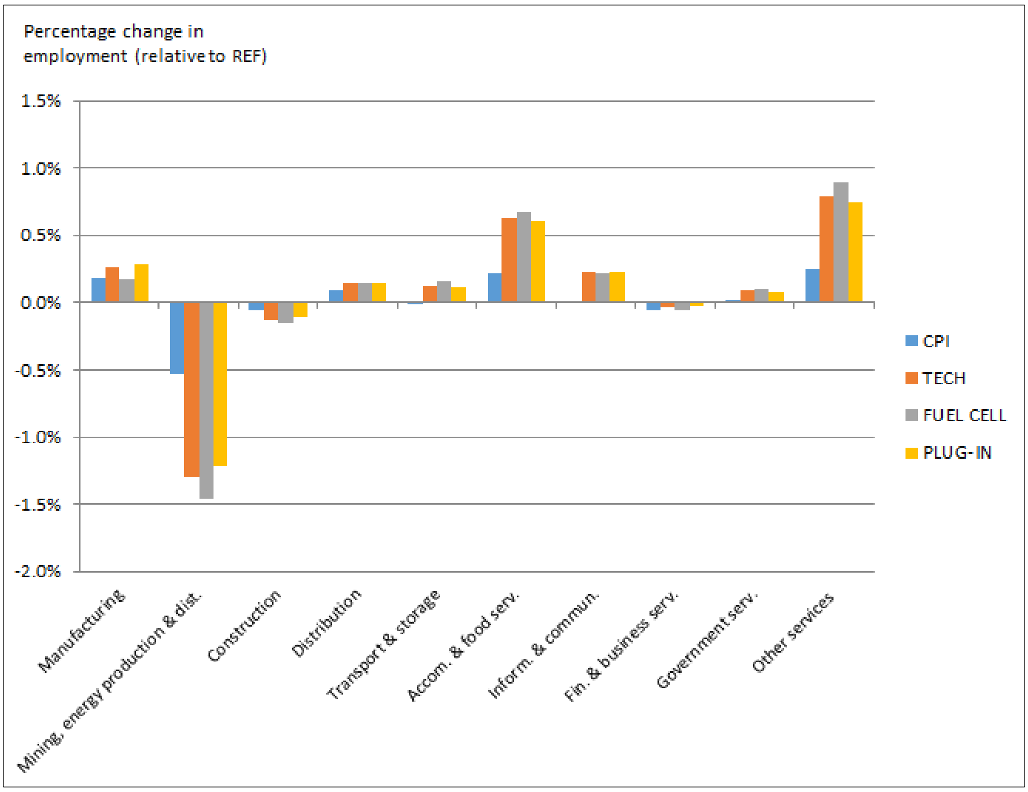


Figure 5.3 shows the net effects of the low-carbon vehicle transition on employment by sector in the UK in 2050. There is an increase in employment in the manufacturing sector, reflecting the effects of an expansion of the motor vehicle supply chain, and there is a reduction in employment in manufactured fuels (refining), reflecting the reduction in the road transport sector's demand for petroleum. The net increase in jobs is highest in the service sectors due to a strong induced effect resulting from the rise in real incomes and consumer purchasing power brought about by the lower cost of vehicle ownership and direct employment effects.

The estimated employment equations in E3ME also take account of labour productivity improvements and the effect of changes in real wages which can lead to a change in the ratio of capital/labour inputs selected by firms. In the low-carbon vehicle scenarios, there is an increase in the general price level, which leads to an increase in wages due to wage-bargaining effects (facing higher prices and higher costs of living, employees demand higher wages from their employers). The repercussion of this increase in real wages is an increase in the cost of labour relative to the cost of capital. Historically, some firms respond to this change in relative costs by reducing labour inputs to production, and this effect is evident in the E3ME results. The size of this effect varies across sectors and depends upon the extent to which labour can be substituted for other factors of production (capital, energy etc), as well as the level of unemployment in the economy, as high levels of unemployment would limit real wage growth. The results for the UK show that this real wage effect is particularly strong in the construction, business services and manufacturing sectors. In construction, there is a sizeable increase in real wages, which is the primary explanation for the reduction in employment in this sector despite increases in demand for construction services and increases in output in this sector. In the manufacturing sector, the employment results are also diminished somewhat due to increases in real wages.

There is a reduction in employment in the mining, energy production and distribution sector due to the reduction in demand for petrol and diesel. However, although this sector sees a 1-1.5% reduction in employment by 2050, this only translates to around 2,500 jobs due to the low labour intensity of the sector (Figure 5.4).

Figure 5.4: Percentage increase in employment in 2050 (relative to the REF scenario)



In E3ME the labour market is not assumed to be in equilibrium and there is no restriction of full employment in the long run. There is some spare capacity in the baseline labour market and so an economic stimulus (such as that provided by the investment in low-carbon vehicles), leads to real economic effects, as well as potential wage effects. The extent to which the real employment effects dominate is partially dependent on the level of unemployment in the baseline. If the unemployment rate is high i.e. labour supply is much greater than labour demand, then an increase in demand will have little impact on real wages, but will draw a number of people out of unemployment. By contrast, an increase in economic demand and gross output in a country with low rates of unemployment will lead to greater wage effects, as a shortage in the supply of labour will drive up the price of labour.

In the UK, the level of unemployment reached 6.0% in August-October 2014 and, in the long-run, the level of unemployment in the baseline for the UK is low relative to that in most other countries in the EU. This partially explains why the employment effects associated with the low-carbon vehicles scenarios in the UK are slightly lower than the findings for similar scenarios at the EU level (as detailed in the 'Fuelling Europe's Future' study).

5.3 Energy dependence and resilience

In 2013, the UK imported around 50.3 m tonnes of crude oil and extracted 38.5 m tonnes. Of this total supply, 30.4 m tonnes were exported while around 34.6 m tonnes are used for road transport.

UK Continental Shelf extraction of crude oil is in decline and as a result imports of crude oil look set to increase, putting further pressure the UK's dependency on oil producing countries. In 2013, oil imports were predominantly sourced from Norway, with Algeria, Nigeria, Russia and Equatorial Guinea making up the top five crude oil import sources in 2013.

The UK's energy independence could be improved by sourcing and extracting more crude oil, or by reducing demand as the CPI and TECH scenarios envisage.

The effects on energy resilience in each scenario

To test the effects of the low-carbon vehicle scenarios on energy resilience, in each scenario, we tested the economic responsiveness to oil price shocks. In each of the scenarios, a one-off increase (shock) to the oil price of 50% of the baseline oil price was applied in 2030 to quantify the extent to which decarbonising light duty vehicles reduces the effects of the price increase on consumer bills and the economy more generally.

The annual cost of fuel for the average vehicle in 2030 is £1112 in the Reference scenario and a 50% oil price shock increases the annual cost by £322 to £1,434 (a 29% increase). The 50% oil price shock only leads to a 29% increase in the cost of fuel to the consumer in the Reference scenario because fuel duty accounts for around half the cost of vehicle fuel and this does not increase with the oil price shock (although VAT does).

The effect of the oil price shock on consumer bills is reduced incrementally in each scenario relative to the reduction in oil consumption. Of course, oil prices could fall and then drivers of the least efficient vehicles would gain most (relatively). However, it is clear that consumers can reduce their exposure to oil price volatility by purchasing more efficient cars and vans.

The effect that light duty vehicle efficiency has on macroeconomic resilience to the oil price shock is more limited. The more that vehicle owners are protected from shocks in fossil fuel prices, the more they are able to spend on other goods and services in real terms. However, oil is used throughout the economy in industrial processes, aviation, shipping, domestic heating and road freight. The scenarios assume the same use of oil in these sectors and so the effects of an oil price shock on the economy remains reasonably similar across the scenarios.

In 2030, the oil price shock in the REF scenario reduces GDP by 0.11%. As a result of the increased fuel efficiency and reduced exposure of consumers to oil in the CPI, TECH and FUEL CELL and PLUG-IN scenarios, the impact on GDP is reduced to 0.08%, 0.05%, 0.04% and 0.05% respectively. UK economic resilience to oil price volatility would be further improved if steps were taken to improve the efficiency with which oil is used in industrial processes, aviation, shipping, domestic heating and road freight.

The macroeconomic effects under a low oil price scenario

The scenarios were tested against an assumption of persistently low oil prices, whereby the oil price gradually fell to 30% below the central IEA projections (Nov. 2014) by 2050. Although this slightly reduced the relative benefits of the low-carbon scenarios, we found that there were still net positive results in the low-carbon scenarios. This is mainly because the efficiency savings still lead to a net reduction in the total cost of owning a car. Additionally it is also partly because under a low oil price, although the relative running cost of conventional ICEs will fall, the VAT revenues on fuel in the baseline REF scenario will also fall, and so the required increase in the VAT rate to compensate the loss of VAT revenue on fuel is not as large. The results from the low oil price sensitivity analysis are shown in Table 5.4 below.

Table 5.4: Macroeconomic results in 2050 (percentage difference from REF)

	REF	TECH (central scenario)	TECH (low oil price sensitivity)
GDP (£ million, 2013)	3,811,637	0.1%	0.1%
Consumption (£ million, 2013)	2,368,499	0.0%	-0.0%
Investment (£ million, 2013)	613,769	0.7%	0.7%
Exports (£ million, 2013)	730,604	0.0%	0.1%
Imports (£ million, 2013)	697,655	0.4%	0.4%
Real income (£ million, 2013)	2,338,946	0.0%	-0.0%
Consumer prices 2013=1	2.98	0.4%	0.5%
Employment (000s)	36,214	0.1%	0.1%

Source(s): Cambridge Econometrics, E3ME.

The reduction in oil demand that results in the scenarios, if matched across the major oil consuming countries could itself cause a reduction in the oil price. In doing so, the economies of oil importing countries could be boosted further as a direct result of the efficiency improvements. For the UK, the case is mixed. On the one hand, lower oil prices benefit consumers and businesses through lower costs; but on the other hand the oil exploration and extraction industry would be likely to face a downturn. As the UK now imports more oil than it produces, overall it is reasonable to expect that a fall in the global oil price could be an additional source of economic benefit associated with improved vehicle efficiency, but since the analysis focusses predominantly in Europe we have not sought to quantify this impact.

5.4 Competitiveness

The economic modelling reported in Section 5.1 does not consider the competitiveness impact on different manufacturers, instead it captures the impact on the entire manufacturing sectors that are affected. The motor vehicles (and component supplier) manufacturing sector is boosted because consumers spend more on the vehicle and less on fuel, and so the demand for manufacturing (refining) petrol and diesel is reduced.

However, the transition towards low carbon vehicles could affect different manufacturers operating in the market in different ways and this could have implications for the manufacturing sectors as a whole and therefore for the economic modelling results.

Recent analysis by for the European Commission by TNO[14] outlines three concepts for assessing competitiveness:

- microeconomic: competitiveness is reflected in the costs to EU manufacturers in reducing the tailpipe emissions of vehicles
- innovation: competitiveness is reflected in the ability of EU manufacturers to innovate in response to the low carbon transition and develop products that increase market share (higher value products)
- macroeconomic: competitiveness is reflected in the volumes of production for the manufacturing sector in a given economy

For an individual manufacturer, it is the trade-off between the impacts of cost competitiveness for relative to the innovation (value/quality) of the new products developed. At a macroeconomic level it is the aggregate performance of the manufacturers in the sector that determines the impact on competitiveness.

In Europe, imports from non-EU countries make up a relatively small share of supply. Trade data suggests that total imports of motor vehicles (NACE sector 29.1) were around €30 bn in 2013. By comparison, European exports of motor vehicles were around €144 bn. Overall, the European car market in the same year had a value of €302 bn representing 11.8m new car sales at an average price of €25,561[15]. Of the imported vehicles to the EU market, around 75%

[14] Assessment of competitiveness impacts of post-2020 LDV CO2 regulation, TNO.

[15] Pocketbook 2014, ICCT.

come from just four countries (Turkey, Japan, US and South Korea). The implication of the relatively small share of imported vehicles in the European market is that while individual manufacturers might see changes in market share, the overall competitiveness impact on European motor vehicles (and component) manufacturing is not likely to be affected.

The UK market and manufacturing sector is starkly different. According to the ICCT, the UK car market was worth €57 bn in 2013, but economic trade data shows that imports of motor vehicles to the UK were around €36 bn in the same year while exports from the UK were around €32 bn. Imports to the UK are sourced predominantly from Europe, with Germany alone accounting for over 40% of all imports. While over half of UK exports are destined for non-European markets.

Put plainly, UK based manufacturers are not only operating in the UK market but also in European and global markets. In all markets they are competing against European and non-European based manufacturing with the implication that the relative performance of UK manufacturers to increase market share will have an impact on the economic results.

The separation of ownership and production is another important factor when considering the impact of changes in markets. Most of the value-added generated by car manufacturers accrues to the employees through the supply-chain and not to the owners of the business. As a result, it is more important to the macroeconomic results to consider where the production of the vehicles and their components takes place, rather than where the owners of a particular company are located.

There is some recent evidence to suggest that the UK facilitates an attractive business environment for developing new vehicle technologies to meet the low carbon agenda. This would imply that the economic results for the UK could be more positive if component and vehicle manufacturers in the UK outperform European and global competitors. A report for the Low Carbon Vehicle Partnership[16] suggests that over the last ten years we have seen:

- 291 unique low carbon investments by 85 different companies with a confirmed total value of £17.6 billion in low carbon investments (approximately £40 billion by extrapolation).
- average new car tailpipe CO_2 emissions have fallen by 25% to below the threshold of 130g/km, ahead of the EU-mandated timetable

The report suggests that these achievements are the result of improved cooperation between government and industry, in addition to the opportunities brought about by the low carbon vehicle legislation and the low carbon transition more generally. Specifically the authors cite the following organisations as playing an important role in developing low carbon vehicle manufacturing and investment in the UK:

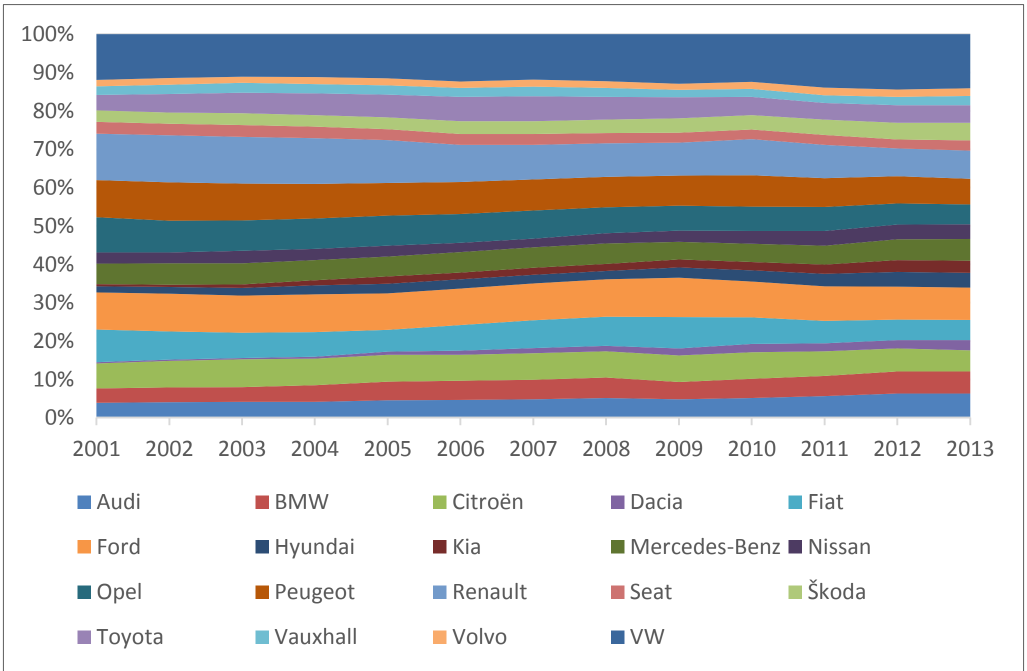
- the creation of the Automotive Innovation and Growth Team (2002), which challenged the view of the auto sector as a sunset industry

[16] Investing in the low carbon journey. Low Carbon Vehicle Partnership (2014).

- the creation of the LowCVP (2003) to provide a focal point for stakeholder engagement, including NGOs, academics, road users and others, as well as industry and government, on low carbon vehicle policy issues and wider stakeholder engagement.
- the creation of the Technology Strategy Board (TSB) (2007) and Advanced Propulsion Centre (2013) which provide consistent support for innovation.
- the development of a New Automotive Innovation and Growth Team (2009) which defined the industry's way forward.
- the Automotive Council (2009) which became the focal point for industry and government dialogue.
- the setup of the Office for Low Emission Vehicles (OLEV) (2009) as an office in DECC and the Green Bus Fund (2009) which helped to create market conditions for low carbon vehicle uptake
- the support of Regional Development Agencies and, latterly, Local Enterprise Partnerships towards automotive innovation and manufacturing at local level.

However, there is also evidence to suggest that changes in market share in the European market are gradual and modest. Figure 5.5 shows the changes in European market share of the 19 leading vehicle manufacturers. It therefore remains an open question as to whether the low carbon transition in cars and vans will improve the competitiveness position of UK-based manufacturers and therefore UK manufacturing.

Figure 5.5: European market share by brand



For refining, there is a question as to whether the capacity for refining in the UK will decline even in the absence of falling demand from road transport that occurs in the TECH scenario, instead brought about by ageing capacity, European regulations (such as the REACH legislation) and fast-evolving markets in the US and elsewhere.

The central economic modelling reflects conservative assumptions on competitiveness:

- UK based manufacturers' share of component supply to OEMs follows historical trends
- UK based manufacturers' share of the car market follows historical trends
- UK based refining products in the UK market decline proportionately with imports as demand for petrol and diesel is reduced

To test the range of the economic impact, a set of low import sensitivities were developed. These sensitivities reflect the potential gains to the UK economy if domestic industries were able to adapt to a change in the structure of demand within the road transport sector. The low import sensitivity combines:

- A reduction in imports in the vehicle supply chain (if industries adapt quickly following an increase in demand for low-carbon vehicle component parts, UK industries could benefit from first-mover advantage; furthermore, as car manufacturers begin to locate their manufacturing facilities in the UK e.g. Nissan leaf in Sunderland, it could be argued that the low-carbon vehicle supply chain will follow)
- an assumption that the reduction in demand for petrol and diesel affects petroleum imports, but that the domestic refining industry will adapt and maintain baseline levels of production of petroleum products in order to meet demand from other sectors e.g. the chemicals and plastics sector and demand from outside of the EU

Table 5.5 outlines the differences in the assumptions on competitiveness between scenarios.

Table 5.5: Description of competitiveness scenarios

	Core scenarios	Enhanced competitiveness
Refining sector	The domestic share of petroleum production in total supply is estimated based on historical trends (domestic content ~ 60%)	The domestic refining sector is assumed to be unaffected by changes in domestic vehicle demand for petrol and diesel, which is instead assumed to only affect imports of petroleum
Motor vehicle supply chain	The share of motor-vehicle component parts manufactured within the UK is estimated based on historical trends. domestic content ~ 35%)	Following the transition to low carbon vehicles, the UK captures a larger market share in the motor vehicle supply chain (equivalent to the EU average of 40%)

The results of the low import sensitivities are shown in Table 5.6.

Table 5.6: Impact of low import sensitivity on macroeconomic indicators

	REF	TECH (central scenario)	TECH (low import sensitivity)
GDP (£ million, 2013)	3,811,637	0.1%	0.2%
Consumption (£ million, 2013)	2,368,499	0.0%	0.0%
Investment (£ million, 2013)	613,769	0.5%	0.6%
Exports (£ million, 2013)	730,604	0.0%	0.0%
Imports (£ million, 2013)	697,655	0.1%	-0.4%
Real income (£ million, 2013)	2,338,946	0.0%	0.1%
Consumer prices 2013=1	2.978	0.4%	0.4%
Employment (000s)	36,214	0.0%	0.1%

If UK-based companies were able to manage the transition to a low-carbon vehicle fleet effectively, then the potential benefits of decarbonising the UK road transport sector could be more positive. If more businesses that produce energy-efficient vehicle components located in the UK (compared to the historical share of UK-based vehicle technology companies) and if the domestic petroleum refining sector was able to diversify in such a way that it was not adversely impacted by the reduction in vehicle demand for petrol and diesel, then the GDP impacts could be greater, and up to 18,000 net additional jobs would be created by 2030.

6 Environmental impact

6.1 Greenhouse gas emissions

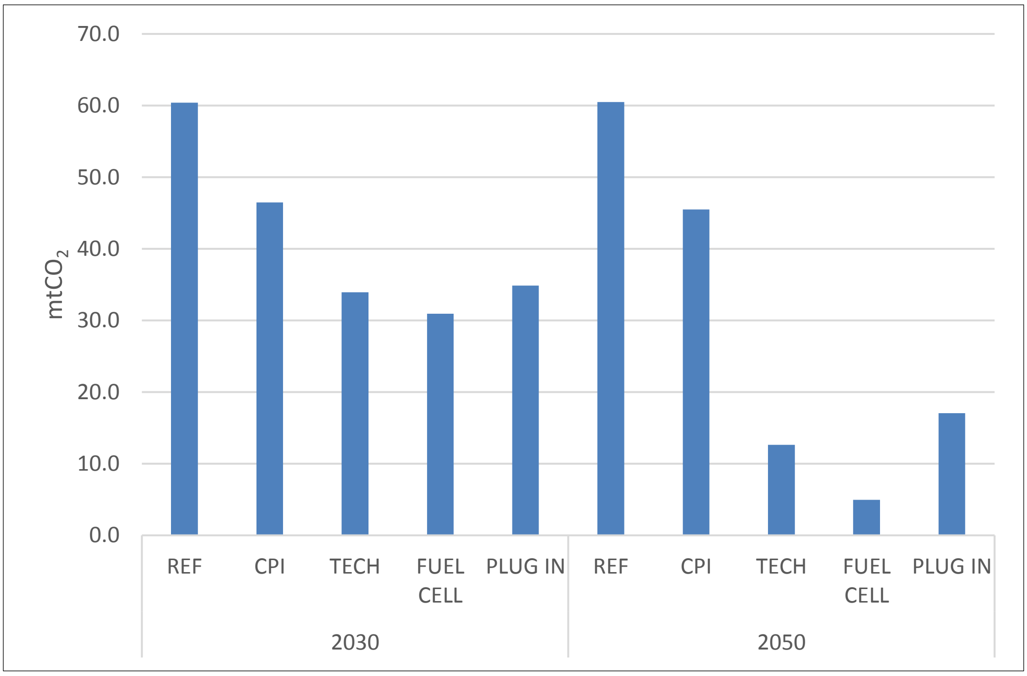
In 2012, UK greenhouse gas emissions were around 580 $mtCO_2e$, of which 474 $mtCO_2$ came from carbon emissions. Of this, 117 $mtCO_2$ were from transport and two-thirds of transport emissions were from passenger cars (64 $mtCO_2$) and vans (15$mtCO_2$).

By 2030, tail-pipe emissions from passenger cars could be reduced to around 46 $mtCO_2$ under the CPI scenario, and even fall as low as 33 $mtCO_2$ if the uptake of ultra-low emission vehicles envisaged in the TECH scenario is realised (see Figure 6.1).

In 2030 a new BEV is expected to have four times the fuel efficiency of a new petrol ICE, moreover, electricity is expected to have a carbon intensity more than four times lower than petrol. The combination of these factors suggests that the 'in use' emissions of a BEV will be over 16 times lower than that of a petrol ICE in 2030.

The transition to an ultra-low carbon vehicle stock envisaged by the TECH scenario (and variants) would all but eliminate tail-pipe emissions from passenger cars and light-duty vehicles by 2050. For the FUEL CELL scenario, tailpipe CO_2 emissions from passenger cars could fall to 5 $mtCO_2$. Moreover, electricity and hydrogen production are both expected to become almost entirely zero-carbon.

Figure 6.1: Annual CO_2 emissions from passenger cars



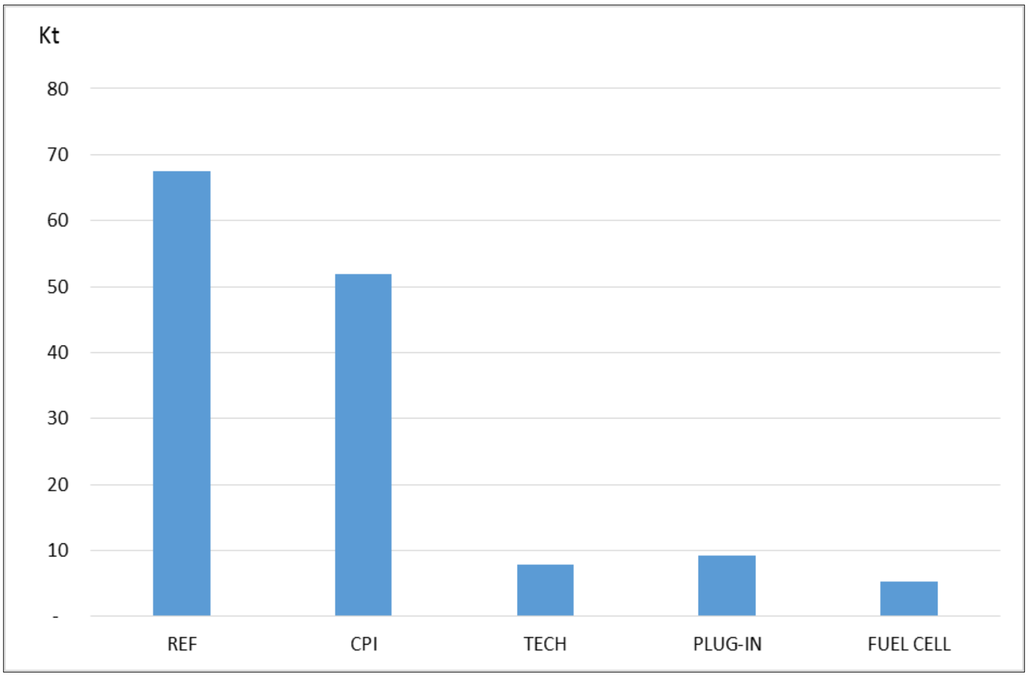
6.2 Local air pollutants

Cars and vans also produce NO_x and particulates: local air pollutants with harmful consequences for human health. In 2012, the National Air Emissions Inventory estimates are that around 220 kilo tonnes of NO_x were emitted by cars and vans in the UK, and around 7,400 tonnes of particulate matter from the combustion of petrol and (predominantly) diesel[17][18].

The potentially harmful effects of NO_x include its reaction with ammonia to form nitric acid, which can damage lungs and worsen respiratory diseases, and its reaction with volatile organic compounds to form ozone, which can also affect the tissue and functioning of the lungs.

Since NO_x is produced in the combustion of fossil fuels, the TECH scenario projects a substantial reduction in tailpipe emissions of NO_x as a result of the reduced use of these fuels (Figure 6.2). By 2050, the TECH scenario results in a 95% reduction in direct NO_x emissions from cars and vans compared to 2012, since so little fossil fuel is consumed in this scenario. In short, decarbonisation would have the additional benefit of effectively eradicating direct NO_x emissions from the vehicle tailpipe. Under the REF scenario, NO_x emissions might fall by as much as 54% (by 2050) as a result of implementing the existing Euro V and Euro VI air pollutant standards. However, these reductions are much less certain than the reductions in the TECH scenario and its variants, which include high levels of vehicles using hydrogen and electricity with zero tailpipe emissions.

Figure 6.2 NOx emissions from cars in 2050



[17] Includes all PM10 (Particulate Matter < 10µm) arising from the fuel burned by cars and vans.

[18] Additional particulate matter is also produced in breaking and through general tyre wear.

Particulate emissions are expected to be reduced in all scenarios, including the REF, as a result of the implementation of Euro 5 and Euro 6 standards which dramatically limit the particulate emissions on new diesel passenger cars and vans (see Table 6.1).

Table 6.1: EU emissions standards for passenger cars

Legislation	Test cycle	NOx limit value (g/km)	PM limit value (g/km)
Diesel			
Euro 1		-	0.140
Euro 2 IDI	ECE+EUDC	-	0.080
Euro 2 DI		-	0.100
Euro 3		0.50	0.050
Euro 4	NEDC	0.25	0.025
Euro 5		0.18	0.005
Euro 6	WLTP	0.08	0.005
Petrol			
Euro 1		-	-
Euro 2	ECE+EUDC	-	-
Euro 3		0.15	-
Euro 4	NEDC	0.08	-
Euro 5		0.06	0.005
Euro 6	WLTP	0.06	0.005

Source(s): ICCT, "The impact of stringent fuel and vehicle standards on premature mortality and emissions".

6.3 Air quality in London

London (Greater London) is home to around 8,400,000 people and is the largest city in the UK. The city has the highest population density in the UK of around 4,761 people per square kilometre. The implication of such a high population density is that roads are congested and air pollution is relatively concentrated.

To improve air quality in London, the Mayor of London's Air Quality Strategy sets out four significant policies to reduce NO_x and particulates from cars and vans:

- *Congestion Charging Zone*: The London congestion charge is a fee charged on most motor vehicles operating within the Congestion Charge Zone (CCZ) in central London between 07:00 and 18:00 Monday to Friday. The charge aims to reduce congestion, and to raise investment funds for London's transport system

- *Low Emissions Zone*: The London Low Emission Zone (LEZ) is a traffic pollution charge scheme with the aim of reducing the tailpipe emissions of diesel-powered commercial vehicles in London. The LEZ emissions standards are based on European emission standards relating to particulate matter (PM), which are emitted by vehicles, which have an effect on health.
- *Electric Vehicle Delivery Plan*: *The Mayor launched his Electric Vehicle Delivery Plan in May 2009. It set out the aim for London to have a network of publicly accessible charge points, with 100,000 EVs on London's roads by 2020.*
- London Hydrogen Action Plan: The action plan sets out the strategic framework and timeline for an action plan addressing vehicles and infrastructure, production and storage, stationary and early market applications.

Moreover, to support the uptake of low carbon vehicles, London is part of the Plugged in Places Programme. The London scheme is run by SourceLondon who currently operate 1,300+ charge points with another 4,500 expected before 2018.

The uptake of ultra-low emission cars and vans in London would yield significant benefits to air quality in London. Air quality monitoring of NO_x and particulates in London, shows that limits are typically exceeded at kerbside and roadside monitoring locations. This suggests that although emissions from road transport do not account for all local air pollution (46% of NOx emissions and 80% of particulate emissions), it is road transport emissions that lead to the concentration of pollutants breaching the regulated air quality limits in many of London's boroughs. By reducing tail-pipe emissions, air quality in London could therefore be brought within guideline concentrations.

7 Potential synergies between electric vehicles and the electricity grid

It is often assumed that the electricity requirements of EVs will put additional stress on the electricity grid, particularly if EV charging takes place at times of peak electricity demand. Recent studies of EV use (such as those funded under the OFGEM LCNF programme) do show that the presence of an electric vehicle can result in a near doubling of evening peak load for a household. Assuming EVs are used for commuting purposes, arrival times at home at the end of the evening commute do correlate with the increase in electricity consumption in the evening, and with widespread uptake, this would be challenging for the grid to accommodate.

However, usage patterns also show that EVs only need a small portion of the evening/overnight charging "window" to become fully charged[19]. This presents an opportunity to move the charging time away from periods of peak demand, and avoid the generation of new peaks and associated infrastructure investments.

Furthermore, there is also the potential for a fleet of electric vehicles to contribute useful services in the form of electricity grid stabilisation, or "balancing services". A distributed battery resource in EVs could also be charged at times when output from renewable generators is high, thus reducing curtailment on these generators and improving the economics of the system.

The analysis presented in this chapter identifies the potential value of grid support services provided by the future stock of EVs. It uses EV deployment assumptions from the TECH scenario, where it is assumed that there are over 6 million EVs in the stock by 2030, growing to around 23 million by 2050. It is also assumed that there is moderately high deployment of renewable sources of electricity (RES), with around 30% of generation from wind and a further 5% from other renewable sources by 2050.

7.1 Analysis summary

The methodology used for this analysis is identical to that developed for the "Fuelling Europe's Future" report, and so is not repeated here. All relevant input data in this report is UK specific. In summary the analysis:

a) Identifies the set of services that the Grid "System Operator" requires to maintain grid stability, which could be provided by a fleet of EVs

b) Identifies the growth in demand for these services over time

c) Using EV utilisation data, calculates the volume of service each vehicle could be expected to provide.

[19] For example: Electric Vehicle reports for the Customer Led Network Revolution project, available at : www.networkrevoliution.co.uk/resources/learning-outcomes

d) Using the "Tech" scenario EV deployment figures, projects the aggregated volume of services that could be provided by an EV fleet.

e) Determines the capability of an EV fleet to provide these services, their value (both aggregated and in terms of potential revenue for each customer)

The key services included in the scope are[20]:

- Frequency response – typically these are very fast reacting devices that help to stabilise system frequency after an unplanned event (such as a large Nuclear plant going off line) and are maintained for up to 30 minutes.
- Reserve services – these are services maintained over a longer time period which support the grid as system frequency is brought back to operational conditions.
- Reduced curtailment – in a high renewables future, this is the amount of RES energy that can be absorbed by an EV fleet, which otherwise would be have to be limited, or "curtailed" in order to balance supply and demand.

Data for this analysis was taken from a number of sources. Vehicle utilisation profiles were taken from a number of Element Energy studies and published reports on EVs. Data on System Operator service demands were taken from National Grid reports. RES penetration levels are from the National Grid "Gone Green" scenario. Estimation of reduced curtailment was based on a report on the value of energy storage by Prof. Goran Strbac et al, commissioned by the Carbon Trust[21].

7.2 Key results

Figure 7.1 and 7.2 show the revenues that could be generated by a fleet of EVs providing the above services, over the period to 2050. Figure 7.1 shows the overall revenues generated by the EV fleet, while Figure 7.2 shows the annual revenue per EV in the fleet. Note that in both cases, the revenues flowing to the EV owner would be less than the figures shown.

The EV fleet could generate nearly £1 bn worth of system benefits by 2050, with the equivalent value per vehicle of around £100/annum. Most of this is from reduced RES curtailment, with around 40% coming from response and reserve services. The volumes grow with the size of the EV fleet. The potential maximum revenue per EV reaches a maximum around 2030 but reduces therafter due to the stabilisation of balancing costs and the dilution of value amongst a larger fleet.

[20] Note that for item (a) above we exclude the storage of and subsequent export to the grid of electricity. This is based on the adverse economics associated with battery degradation and very poor equipment utilisation.

[21] https://www.carbontrust.com/media/129310/energy-storage-systems-role-value-strategic-assessment.pdf

An indicative figure of ca. £100/annum per EV would represent a significant fraction of the annual EV charging cost. If they could be efficiently monetised, the provision of these services would reduce EV ownership costs and provide beneficial services to the grid without significant additional infrastructure. However, it should be noted that the commercial model supporting the provision of services from a distributed EV fleet is not clear, and any aggregation would result in additional transaction costs that would dilute the value flowing towards the EV owner.

Figure 7.1 Total revenue generated by EV services to the electricity grid

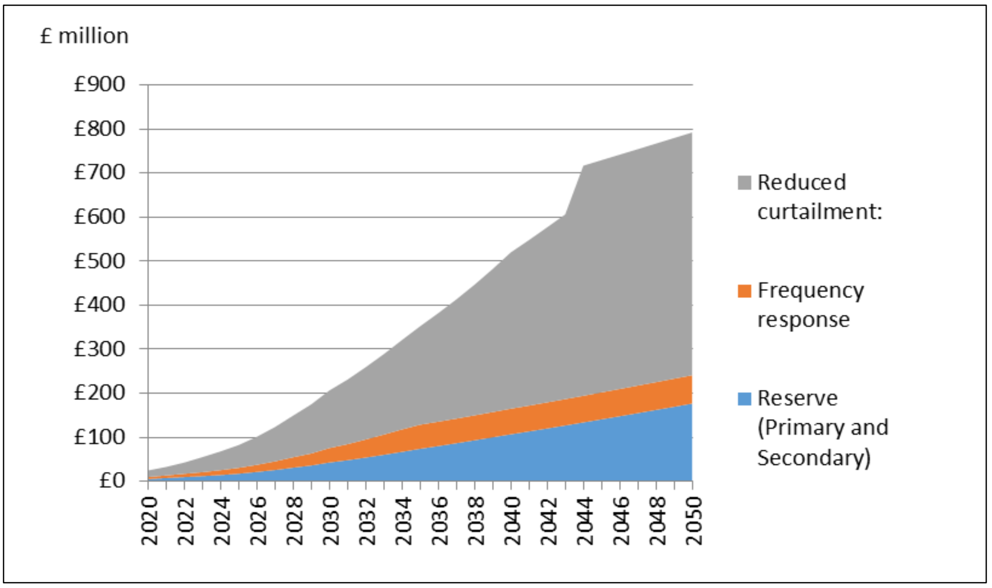
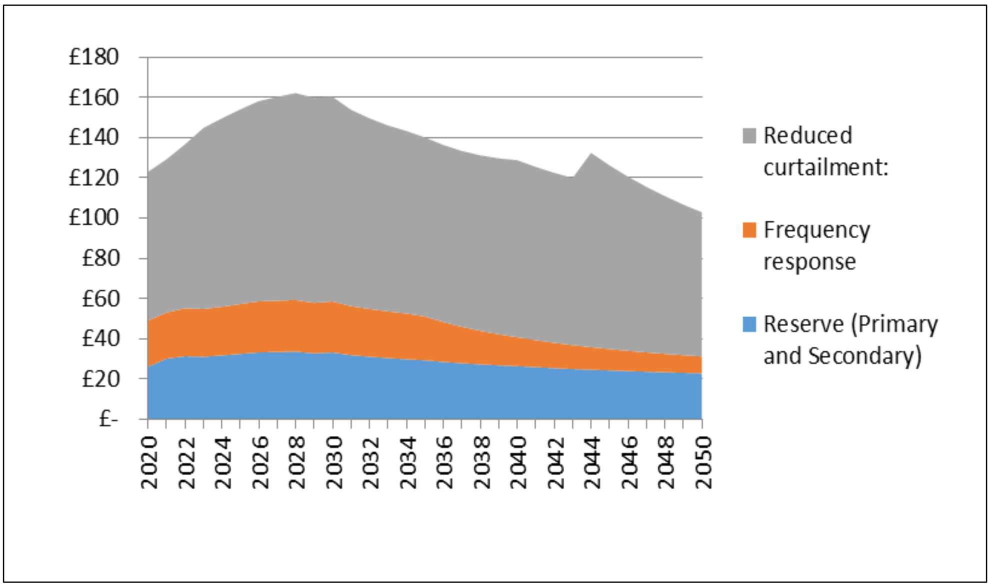


Figure 7.2 Revenue generated per EV



8 Conclusions

The analysis described in this report explores the requirements and the impact of substantially decarbonising cars and vans in the UK. Building on the analysis presented in Fuelling Europe's Future, it assesses the technology costs, fuel costs, and supporting infrastructure required in the UK for advanced powertrains and efficiency technologies. The impact such a transition would have on consumers, the economy, greenhouse gas emissions, air quality and the energy system is then also assessed.

The analysis required the development of a vehicle stock model for the UK which allows for analysis of the cost and energy consuming characteristics of UK cars. It has been developed to inform this analysis and is based on UK vehicle data, as well as technology cost data developed and published in Fuelling Europe's Future. Scenarios of future technology take-up were developed with a group of industry experts and assessed in the vehicle stock model, the outputs of which were then assessed in the economic model, E3ME.

For consumers, we find that a low carbon transition in light-duty vehicles would bring about considerable financial benefit to car owners as lifetime fuel savings outweigh the additional capital cost of cars. Moreover, the evidence suggests that European vehicle standards for 2015 and 2020 are already yielding (and will continue to yield) financial savings for consumers over the lifetime of the car. This finding held across the range of low carbon technology scenarios that were assessed, despite considerably different characteristics across the different vehicle types of plug-in hybrids, battery electric vehicles and fuel cell electric vehicles.

Perhaps the most important consideration across the various technology scenarios is the uncertainty they encompass. There remains considerable uncertainty around the required supporting infrastructure and technological development. For battery electric vehicles (and, arguably, to a lesser extent for plug-in hybrid vehicles), the main uncertainties regard the scale and pace of vehicle cost reduction, consumer confidence in the technology (specifically range anxiety), the cost and scale of supporting charging infrastructure, the potential impact on the electricity distribution network and the potential for integration with the energy system that maximises the value of the battery. For fuel cell vehicles, the main uncertainties are similar (the scale and pace of cost reduction, the cost and scale of the challenge to produce and distribute hydrogen, and the potential to use hydrogen for energy storage to improve efficiency in the energy system) but arguably greater since the technology is more nascent.

Despite some differences between the low carbon technology scenarios, all of these scenarios share the key results of this analysis:

- It is expected that all of the advanced vehicle types will yield lower cost of ownership than traditional ICEs by 2030 leading to direct financial benefits to motorists.

- All of the scenarios are likely to yield a neutral to positive impact on the economy and on jobs across the period assessed. As the UK is a net oil importer there is value to be gained by reducing oil imports and effectively reallocating that value into the motor vehicle supply chain and the value chain associated with the provision of supporting infrastructure.
- The transition away from oil that results in each of the low carbon technology scenarios will also improve the UK economy's resilience to the impact of oil price volatility.
- There is additional energy storage value associated with the deployment of batteries although there remain questions as to how that value can be realised and by whom, and the extent to which hydrogen also offers an energy storage option to the UK energy system.
- The positive economic impact, while modest, accounts for the steady erosion of fuel duty revenues to government by maintaining neutrality in government balances across society (which is modelled by marginally increasing taxes elsewhere to compensate government) despite the relatively high tax rates on petrol and diesel.
- By design, all of the low carbon scenarios lead to substantial cuts in carbon emissions, broadly in line with cars and vans expected share of the total reduction in emissions required by UK legislation.
- There are likely to be substantial co-benefits arising from the low carbon transitions modelled as they will lead to reduced concentrations of particulates and NOx in urban environments.

The estimated range of the impact of the transition on the UK economy depends partly on the share of the new low carbon vehicle market in Europe and globally (and its supply chain) that is captured by UK based manufacturers. That overall share will be dependent on the aggregate performance of individual companies in the UK relative to European and global competitors operating in the same emerging markets for new technology components and vehicles.

We acknowledge that the research presented in this report could be improved and/or supplemented with additional research. In our view, the most important of these are:

- an analysis of the consumer response to a change in the total cost of ownership, the changing ratio between capital costs and operating costs in the total cost of ownership, and the perception of the residual value of higher capital cost vehicles in second hand markets
- a more detailed understanding of the interaction between energy storage possibilities (batteries and hydrogen) that extends to understanding the scope, costs and limits of hydrogen storage and conversion back to electricity; and, separately, the impact of the mass distribution of battery storage through electric vehicles on the electricity distribution system and facilitation of this in electricity market policy
- the economic and social impact on other European economies that have different economic characteristics to the UK, for example with radically

different electricity/energy systems, vehicle manufacturing supply chains and consumer spending patterns to better understand the characteristics of economies that gain more than others

- an analysis of how potential future value chains might evolve, particularly concerning the development and commercial deployment of alternative battery, fuel cell and light-weighting technologies
- the potential impact on the global oil price that global adoption of more efficient and advanced power train vehicles could have, and the potential impact of that on global economic growth
- a continuous appraisal of the current and future technology costs and efficiency savings of the various technologies in light of ongoing technological research and development
- behavioural studies that provide insight as to whether technology will directly influence the types of cars that are bought in different market segments and the extent to which usage might evolve and the implications of behavioural changes on the supporting infrastructure requirements

Overall however, based on the current body of evidence, we conclude that a transition to low carbon cars and vans would yield benefits for UK consumers and for the environment (both in terms of reduced greenhouse gas emissions and reductions in local air pollution), and have a neutral to positive impact on the wider economy.

Appendices

Appendix A The E3ME Model

A.1 Introduction

Overview

E3ME is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes. The global edition is a new version of E3ME which expands the model's geographical coverage from 33 European countries to 53 global regions. It thus incorporates the global capabilities of the previous E3MG model.

Compared to previous model versions, version 6 of E3ME provides:

- better geographical coverage
- better feedbacks between individual European countries and other world economies
- better treatment of international trade with bilateral trade between regions
- a new model of the power sector

This is the most comprehensive model version of E3ME to date and it includes all the features of the previous E3MG model.

Recent applications

Recent applications of E3ME include:

- an assessment of the economic and labour market effects of the EU's Energy Roadmap 2050
- contribution to the EU's Impact Assessment of its 2030 environmental targets
- evaluations of the economic impact of removing fossil fuel subsidies
- an assessment of the potential for green jobs in Europe
- an economic evaluation for the EU Impact Assessment of the Energy Efficiency Directive

This model description provides a short summary of the E3ME model. For further details, the reader is referred to the full model manual available online from www.e3me.com.

A.2 E3ME's basic structure and data

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970-2012 and the model projects forward annually to 2050. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other sources where appropriate. For regions outside Europe, additional sources for data include the UN, OECD, World Bank, IMF, ILO and national statistics. Gaps in the data are estimated using customised software algorithms.

A.4 The main dimensions of the model

The main dimensions of E3ME are:

- 53 countries – all major world economies, the EU28 and candidate countries plus other countries' economies grouped
- 69 industry sectors, based on standard international classifications
- 43 categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of air-borne emission (where data are available) including the six greenhouse gases monitored under the Kyoto protocol

The countries and sectors covered by the model are listed at the end of this document.

A.5 Standard outputs from the model

As a general model of the economy, based on the full structure of the national accounts, E3ME is capable of producing a broad range of economic indicators. In addition there is range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)
- sectoral output and GVA, prices, trade and competitiveness effects
- international trade by sector, origin and destination
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices
- CO_2 emissions by sector and by fuel
- other air-borne emissions
- material demands (Europe only at present)

This list is by no means exhaustive and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2050.

A.6 E3ME as an E3 model

The E3 interactions

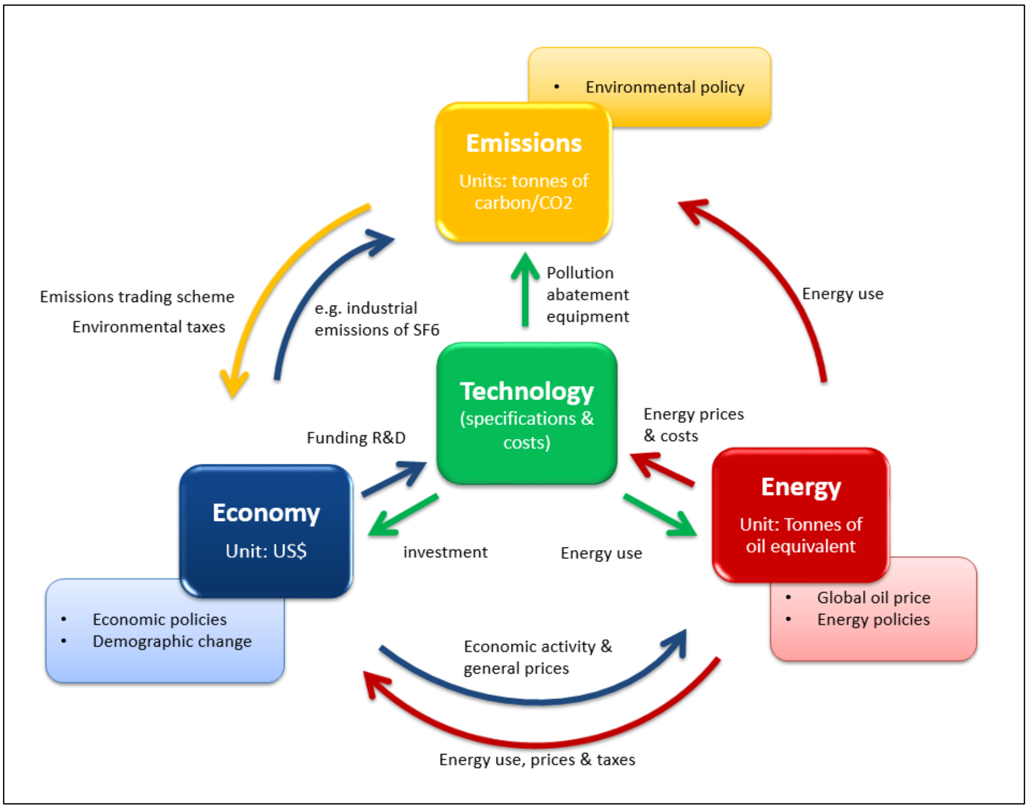
Figure A.1 shows how the three components (modules) of the model - energy, environment and economy - fit together. Each component is shown in its own box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For each region's economy the exogenous factors are economic policies (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of the energy industries). For the environment component, exogenous factors include policies such as reduction in SO_2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides measures of emissions of the main air pollutants to the environment module, which in turn can give measures of damage to health and buildings. The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

The role of technology

Technological progress plays an important role in the E3ME model, affecting all three Es: economy, energy and environment. The model's endogenous technical progress indicators (TPIs), a function of R&D and gross investment, appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in the E3ME's energy and material demand equations to capture energy/resource savings technologies as well as pollution abatement equipment. In addition, E3ME also captures low carbon technologies in the power sector through the FTT power sector model[22].

Figure A.1: CO_2 emissions in the road transport sector



[22] See Mercure, J-F (2012), 'FTT:Power A global model of the power sector with induced technological change and natural resource depletion', Energy Policy, 48, 799–811.

A.7 Treatment of international trade

An important part of the modelling concerns international trade. E3ME solves for detailed bilateral trade between regions (similar to a two-tier Armington model). Trade is modelled in three stages:

- econometric estimation of regions' sectoral import demand
- econometric estimation of regions' bilateral imports from each partner
- forming exports from other regions' import demands

Trade volumes are determined by a combination of economic activity indicators, relative prices and technology.

A.8 The labour market

Treatment of the labour market is an area that distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment, average working hours, wage rates and participation rates. The first three of these are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age band.

The labour force is determined by multiplying labour market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labour force and employment. This is typically a key variable of interest for policy makers.

A.9 Comparison with CGE models and econometric specification

E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, underlying this there are important theoretical differences between the modelling approaches.

In a typical CGE framework, optimal behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from a post-Keynesian framework and it is possible to have spare capacity. The model is more demand-driven and it is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3ME regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2020) and rebound effects[23], which are included as standard in the model's results.

A.10 Key strengths of E3ME

In summary the key strengths of E3ME are:

- the close integration of the economy, energy systems and the environment, with two-way linkages between each component
- the detailed sectoral disaggregation in the model's classifications, allowing for the analysis of similarly detailed scenarios
- its global coverage, while still allowing for analysis at the national level for large economies
- the econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to CGE models
- the econometric specification of the model, making it suitable for short and medium-term assessment, as well as longer-term trends

[23] Where an initial increase in efficiency reduces demand, but this is negated in the long run as greater efficiency lowers the relative cost and increases consumption. Barker, T., Dagoumas, A. and Rubin, J. (2008) 'The macroeconomic rebound effect and the world economy', Energy Efficiency.

Table 1: Main dimensions of the E3ME model

	Regions	Industries (Europe)	Fuel Users
1	Belgium	Crops, animals, etc	Power use and transformation
2	Denmark	Forestry & logging	Own use and transformation
3	Germany	Fishing	Iron and steel
4	Greece	Coal	Non-ferrous metals
5	Spain	Oil and Gas	Chemicals
6	France	Other mining	Non-metallic minerals
7	Ireland	Food, drink & tobacco	Ore-extraction (non-energy)
8	Italy	Textiles & leather	Food, drink and tobacco
9	Luxembourg	Wood & wood prods	Textiles, clothing & footwear
10	Netherlands	Paper & paper prods	Paper and pulp
11	Austria	Printing & reproduction	Engineering etc
12	Portugal	Coke & ref petroleum	Other industry
13	Finland	Other chemicals	Construction
14	Sweden	Pharmaceuticals	Rail transport
15	UK	Rubber & plastic products	Road transport
16	Czech Rep.	Non-metallic mineral prods	Air transport
17	Estonia	Basic metals	Other transport services
18	Cyprus	Fabricated metal prods	Households
19	Latvia	Computers etc	Agriculture, forestry, etc
20	Lithuania	Electrical equipment	Fishing
21	Hungary	Other machinery/equipment	Other final use
22	Malta	Motor vehicles	Non-energy use
23	Poland	Other transport equip	
24	Slovenia	Furniture; other manufacture	
25	Slovakia	Machinery repair/installation	
26	Bulgaria	Electricity	
27	Romania	Gas, steam & air cond.	
28	Norway	Water, treatment & supply	
29	Switzerland	Sewerage & waste	
30	Iceland	Construction	
31	Croatia	Wholesale & retail MV	
32	Turkey	Wholesale excl MV	
33	Macedonia	Retail excl MV	
34	USA	Land transport, pipelines	
35	Japan	Water transport	
36	Canada	Air transport	
37	Australia	Warehousing	
38	New Zealand	Postal & courier activities	
39	Russian Fed.	Accommodation & food serv	
40	Rest of Annex I	Publishing activities	
41	China	Motion pic, video, television	
42	India	Telecommunications	
43	Mexico	Computer programming etc.	
44	Brazil	Financial services	
45	Argentina	Insurance	

46	Colombia	Aux to financial services
47	Rest Latin Am.	Real estate
48	Korea	Imputed rents
49	Taiwan	Legal, account, consult
50	Rest ASEAN	Architectural & engineering
51	OPEC	R&D
52	Indonesia	Advertising
53	Rest of world	Other professional
54		Rental & leasing
55		Employment activities
56		Travel agency
57		Security & investigation, etc
58		Public admin & defence
59		Education
60		Human health activities
61		Residential care
62		Creative, arts, recreational
63		Sports activities
64		Membership orgs
65		Repair comp. & pers. goods
66		Other personal serv.
67		Hholds as employers
68		Extraterritorial orgs
69		Unallocated/Dwellings

Source(s): Cambridge Econometrics.