FUELLING EUROPE'S FUTURE

JOBS

CO2

2030
2050

OIL

Acknowledgements

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1 Executive Summary

Europe could improve its growth prospects and increase overall employment by supporting auto sector innovation to curb its dependence on imported oil. There are currently concerns that the transition to a low-carbon economy will be too costly to embark upon during the economic crisis. But improving auto efficiency and switching to domestic energy sources for vehicles could contribute to Europe's key objectives of stimulating economic growth and mitigating climate change.

These are the main findings of this in-depth technical and macro-economic study, which has drawn on the advice of a broad range of stakeholders in the transport sector.

The innovations investigated would also cut direct CO_2 emissions from cars and vans by between 64 per cent and 93 per cent by 2050 in the three low carbon technology scenarios examined in this project, helping the EU achieve its goal of cutting overall transport emissions by 60 per cent. Tailpipe emissions of health-damaging pollutants, such as NOx would be cut by more than 85 per cent, with soot particles down by more than 70 per cent. And European motorists would benefit from lower costs of vehicle ownership.
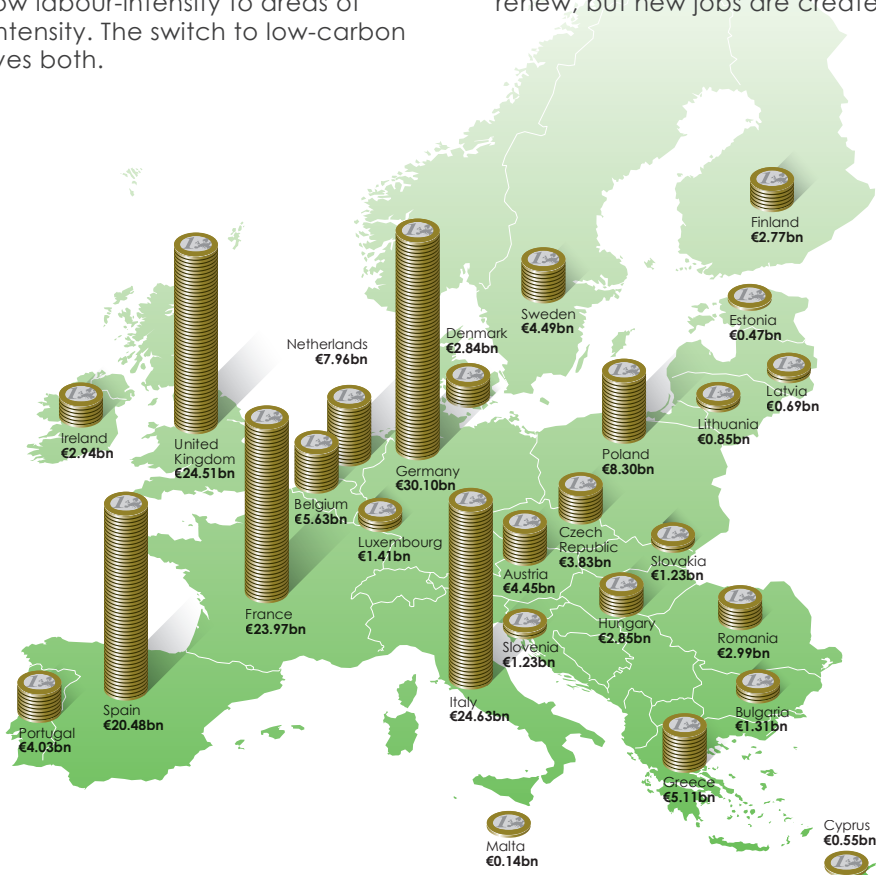
Job creation is a priority for policy makers across Europe. One way to boost growth in Europe would be to improve its trade balance, while another would be to shift the focus of spending from areas of low labour-intensity to areas of higher labour-intensity. The switch to low-carbon vehicles achieves both.

The fossil fuel supply-chain – including refining, distribution and retail of fuels – is one of the least labour-intensive value chains, and has most of its value-creation outside Europe. Therefore, reducing EU citizens' bills at the fuel pump and shifting spending towards other, more labour-intensive, areas of the economy induces net job creation. Furthermore, Europe excels in auto technology, and therefore increased spending on low-carbon vehicle components will create supply-chain jobs.

Between 660,000 and 1.1 million net additional jobs could be generated by 2030 in the three low-carbon technology scenarios examined in this research project, compared to a reference scenario in which cars continue to run on today's technology. In 2050, this rises to between 1.9 million and 2.3 million additional jobs, even when the jobs lost during this transition are taken into account. These benefits take time to achieve, because Europe's vehicle fleet takes 12 years to renew, but new jobs are created from day one.

Fig. 1.1

EU spending on petrol and diesel in 2012
Source: Eurostat, E3ME

Finland €2.77bn
Sweden €4.49bn
Estonia €0.47bn
Latvia €0.69bn
Lithuania €0.85bn
Denmark €2.84bn
Netherlands €7.96bn
Poland €8.30bn
Ireland €2.94bn
United Kingdom €24.51bn
Belgium €5.63bn
Germany €30.10bn
Czech Republic €3.83bn
Slovakia €1.23bn
Luxembourg €1.41bn
Austria €4.45bn
Hungary €2.85bn
Romania €2.99bn
France €23.97bn
Slovenia €1.23bn
Bulgaria €1.31bn
Spain €20.48bn
Italy €24.63bn
Greece €5.11bn
Portugal €4.03bn
Malta €0.14bn
Cyprus €0.55bn

Somewhat less than half of the additional jobs identified are direct jobs within the value chains for manufacturing vehicles and the supporting infrastructure. The prospect of these new jobs is set against a background in which Europe's auto industry is struggling with sluggish sales at home. Thus any new jobs arising from the manufacture of low-carbon vehicles would be offset by likely job losses as the industry in any case restructures to reduce over-capacity. The transition to low-carbon vehicles will also demand new skills from the workforce and that existing technologies are optimized. So, Europe must develop a pioneering environment to ensure it captures these opportunities.

Most of the new jobs are created outside the automotive value chain, in sectors such as services and construction, which benefit from the shift in spending away from the fossil fuel value chain and towards domestically-produced goods and services.

There are obvious uncertainties in assessing scenarios out to 2050, and the project has therefore taken care to use conservative assumptions throughout. Data on the cost of low-carbon vehicle technology have been largely sourced from the auto industry itself, including industry submissions for the European Commission's impact assessment on the proposed CO_2 standards for cars and vans in 2020. These have been supplemented with data from similar assessments for the UK and US governments, especially for the cost of zero-emissions vehicles.

Fuel price projections are based on the International Energy Agency's (IEA) World Energy Outlook.
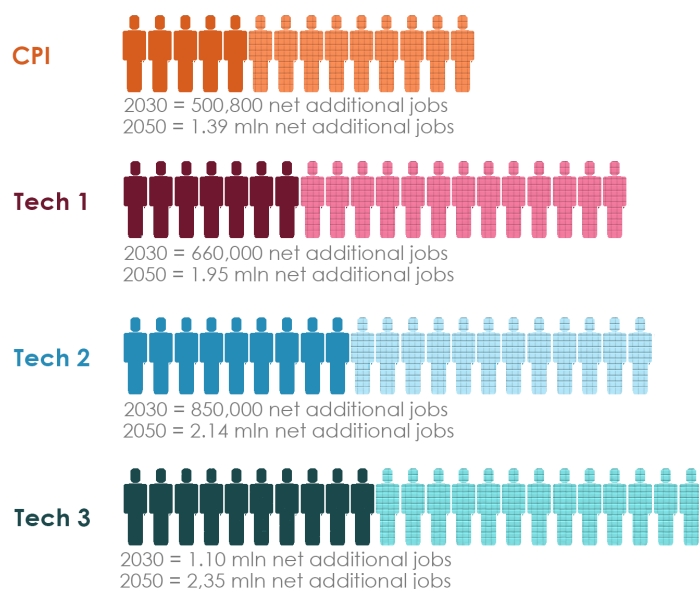
Despite the long-term uncertainty, much is already known about the vehicles that are being designed today for 2020, and these are the vehicles that will deliver most of the benefits in the timeframe to 2030. At an individual level, the cost of additional vehicle technology adds about €1,100 - €1,200 to the production cost of the average car in 2020 in the two scenarios that rely on conventional technologies, compared to the average 2010-manufactured vehicle. However, this is more than offset by the fuel savings realised by consumers.

The owner of the average new car in 2020 will spend around €300 to €400 less on fuel each year than the owner of the average 2010-manufactured car. Given that the increased capital cost is less than the amount saved on fuel across the 12 year lifetime of a vehicle, this improves the budgets of households.

At the EU level, the two scenarios that rely on conventional technology add €22-45 billion to the yearly capital cost of the EU car and van fleet in 2030, but this is more than offset by avoided yearly spending on fuel worth €59-80 billion in 2030. This makes the total cost of running and renewing the EU car and van fleet in 2030 about €36 billion lower than if the fleet were to continue running on today's technology.

Fig. 1.2

EU job creation in the 4 scenarios
Source: E3ME

CPI

2030 = 500,800 net additional jobs
2050 = 1.39 mln net additional jobs

Tech 1

2030 = 660,000 net additional jobs
2050 = 1.95 mln net additional jobs

Tech 2

2030 = 850,000 net additional jobs
2050 = 2.14 mln net additional jobs

Tech 3

2030 = 1.10 mln net additional jobs
2050 = 2,35 mln net additional jobs

2 Summary for policymakers

A strong European auto industry with a technological lead in low-carbon vehicles

Europe faces daunting economic challenges: to rein in public debt, revitalize stagnant economies and create new opportunities for millions of jobless workers.

At the same time, the European Union is committed to playing a lead role in tackling climate change. Among the EU's headline climate initiatives, the European Commission's Transport White Paper[1] sets a goal of reducing transport CO_2 emissions by 60 per cent by 2050.

Political targets for climate action are coming under increasing scrutiny amid concerns that they might impose an excessive burden on industry at a time of economic hardship. It is therefore important to understand the economic impact of the transition to low-carbon vehicles.

And all the more so at a time when Europe's auto industry faces a sluggish domestic market, some over-capacity and growing competition from overseas rivals.
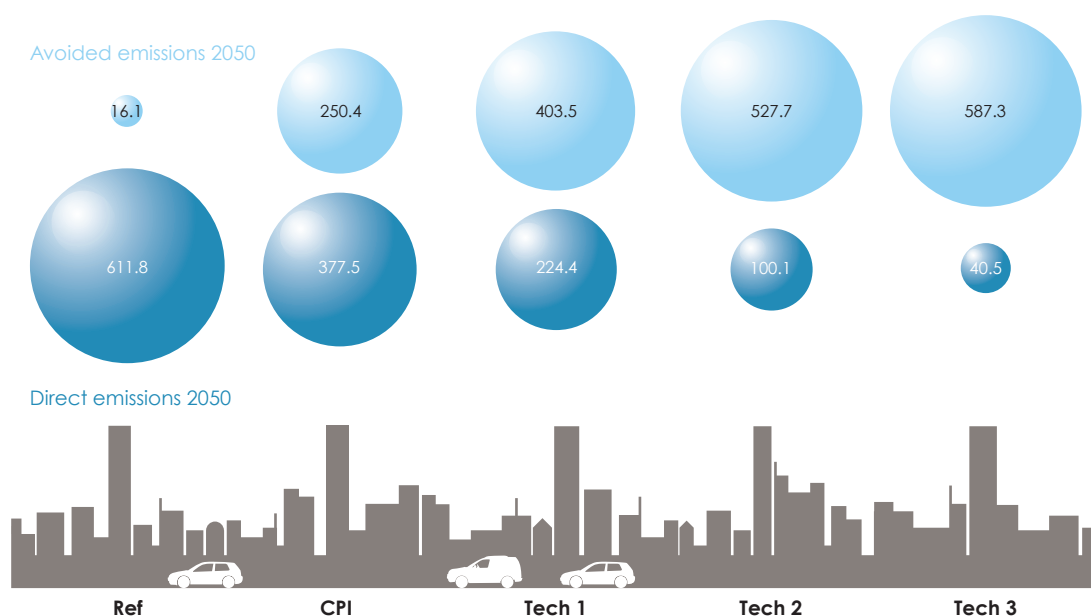
This study sets out to determine whether technologies to reduce CO_2 from light-duty vehicles – cars and vans – can strengthen Europe's economy by simultaneously stimulating innovation and improving the trade balance. The conclusion of more than one year of technical and macro-economic analysis is positive on both issues (Fig. 2.2)

Between 660,000 and 1.1 million net additional jobs could be generated by 2030 in the three low-carbon scenarios examined here. This rises to 1.9 million to 2.3 million net additional jobs in 2050. These numbers take full account of jobs lost during this transition, for example in the refining, distribution and sale of fossil fuels. Lost tax revenues from lower spending on petrol and diesel can be made up by raising the rate of VAT and the overall result is that European consumers are still better off on average. Somewhat less than half of the additional jobs identified are direct jobs within the value chains for manufacturing vehicles and supporting infrastructure.

The prospect of these new jobs is set against a background in which Europe's auto industry is struggling with slow sales at home.

Fig. 2.1

Direct tailpipe GHG emissions from cars and vans
Source: SULTAN

Avoided emissions 2050

16.1   250.4   403.5   527.7   587.3

611.8   377.5   224.4   100.1   40.5

Direct emissions 2050

Ref   CPI   Tech 1   Tech 2   Tech 3

Thus any new jobs arising from the manufacture of low-carbon vehicles would be offset by likely job losses as the industry in any case restructures to reduce over-capacity. This raises the question of whether such a shift is feasible and attractive for EU manufacturers in an increasingly global automotive market. More and more countries are enacting tighter fuel-efficiency standards to cut rising fuel bills and tackle climate change (Fig. 3.1).

Europe and Japan have world-leading fuel-efficiency targets, and the boost that this gives to innovation for their domestic auto manufacturers could contribute to their competitive position in international markets.

The EU auto sector stakeholder group CARS21 has concluded that the industry's competitiveness depends on success in maintaining its technology lead. This lead will be increasingly challenged. China is trying to move ahead on the development of electric vehicles. The United States has set ambitious efficiency standards for 2025. Japan has made a robust start on hybrid technology. The global automotive marketplace is becoming increasingly competitive.

## Projecting the costs of low-carbon cars

The project has benefited from the advice of a broad range of stakeholders in the transport sector, including auto producers, technology suppliers, workers' groups, energy providers and environmental groups. The data generated by the study will serve as a reference point for discussions about the low-carbon transition.

Understanding the economic impact has required detailed technical research to forecast the implied costs of technology, both for vehicles and for the supporting infrastructure for charging or refuelling. These projections of technology costs, combined with forecasts of future energy costs from the IEA, provide the key inputs to the macro-economic modelling of impacts on GDP and jobs.

The Working Group benefited from detailed data on the cost of improving the fuel efficiency of Internal Combustion Engine (ICE) vehicles, which were submitted in 2011 to the European Commission by the car manufacturers' association ACEA and the automotive parts suppliers group CLEPA.

Fig. 2.2

Impacts on CO_2, employment and vehicle fleet costs in the four scenarios in 2050, versus the Reference scenario Source: SULTAN, E3ME
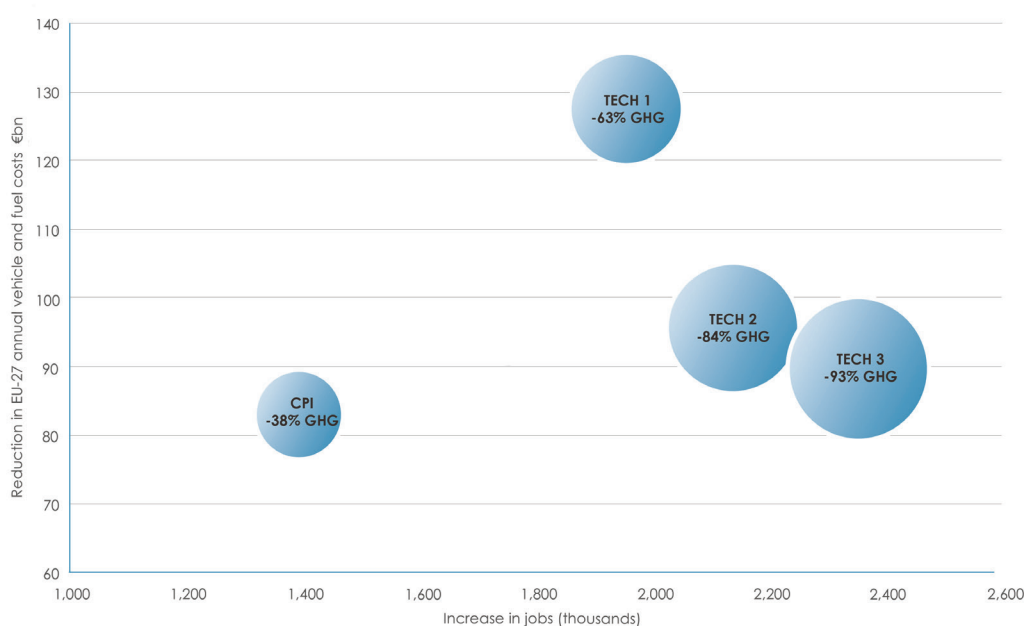
These were supplemented with data from research conducted for the US Environmental Protection Agency (EPA). The starting point for analyzing the cost of advanced technologies, such as fuel-cells and batteries, was research for the UK government's Committee on Climate Change.

These data were reviewed by automotive experts at Ricardo-AEA and the International Council on Clean Transportation (ICCT), both of which have a substantial track record in automotive analysis. The data were also reviewed by members of the Working Group with direct experience in the automotive industry, for example Nissan, CLEPA, members of the battery-makers' association EUROBAT, and the trade union body IndustriAll Europe. Expert input on specific technologies was also contributed by other auto manufacturers.

The study found that reducing car emissions to the range of 90-95 g/km in 2020 would add €1,056 - €1,154 to the cost of manufacturing a car. For comparison, analysis of the same data for the European Commission in 2011, but by a different method, arrived at a similar figure of €1,159. In another study, the ICCT concluded that improving the efficiency of the internal combustion engine to meet a target of 95 g/km in 2020 would add less than €1,000 to the cost of a car. This would be lower if full use was made of weight reduction measures.

Our analysis showed that in 2010, Hybrid Electric Vehicles (HEVs) were almost €3,000 more expensive to manufacture than the average ICE vehicle.

However, this cost differential narrows to around €1,000 in 2020 as HEVs become more widely deployed to meet proposed CO_2 standards and as a result of learning effects and scale economies.
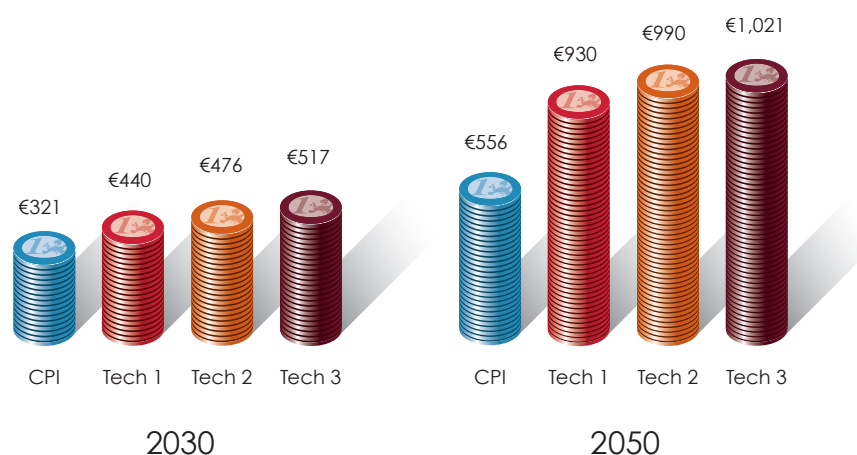
The additional manufacturing costs for Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) are likely to remain considerably higher than ICE or HEV technologies until after 2030.

The projections for reductions in the cost of batteries used in this analysis are more conservative than some recent estimates, for example by McKinsey[2] and Roland Berger[3]. When account is taken of fuel and other running costs, the Total Cost of Ownership of all key technologies converges quite quickly under a range of different assumptions.

Indeed, in all cases examined in this study, the additional capital cost to the motorist is more than offset by avoided spending on fuel. So, revisiting the example given above, hitting a target of 95 g/km in 2020 might add an extra €1,056 euros to the cost of manufacturing the average vehicle, compared to 2010, but the owner of the average new car in 2020 will spend between €300 and €400 less on fuel each year (Fig. 2.3).

	2030				2050		
€321	€440	€476	€517	€556	€930	€990	€1,021
CPI	Tech 1	Tech 2	Tech 3	CPI	Tech 1	Tech 2	Tech 3

Economic impacts of a shift to more fuel-efficient vehicles

While additional vehicle technology is an added cost to the motorist, it is equally an added source of revenues for auto component suppliers and companies in their downstream supply chains. Vehicle technology is an area in which Europe excels. Thus, from a macro-economic perspective, much of the money spent on additional vehicle technology remains within the European economy. There are over 3,000 auto parts companies in Europe, accounting for about 75 per cent of the vehicle industry's final product value.

At the macro-economic level, the two efficiency scenarios examined here add €22-45 billion to the yearly capital cost of the EU car and van fleet in 2030, but this is more than offset by avoided yearly spending on fuel, worth €59-80 billion in 2030.

This makes the total cost of running and renewing the EU car fleet in 2030 about €36 billion lower than if the fleet were to continue running on today's technology.
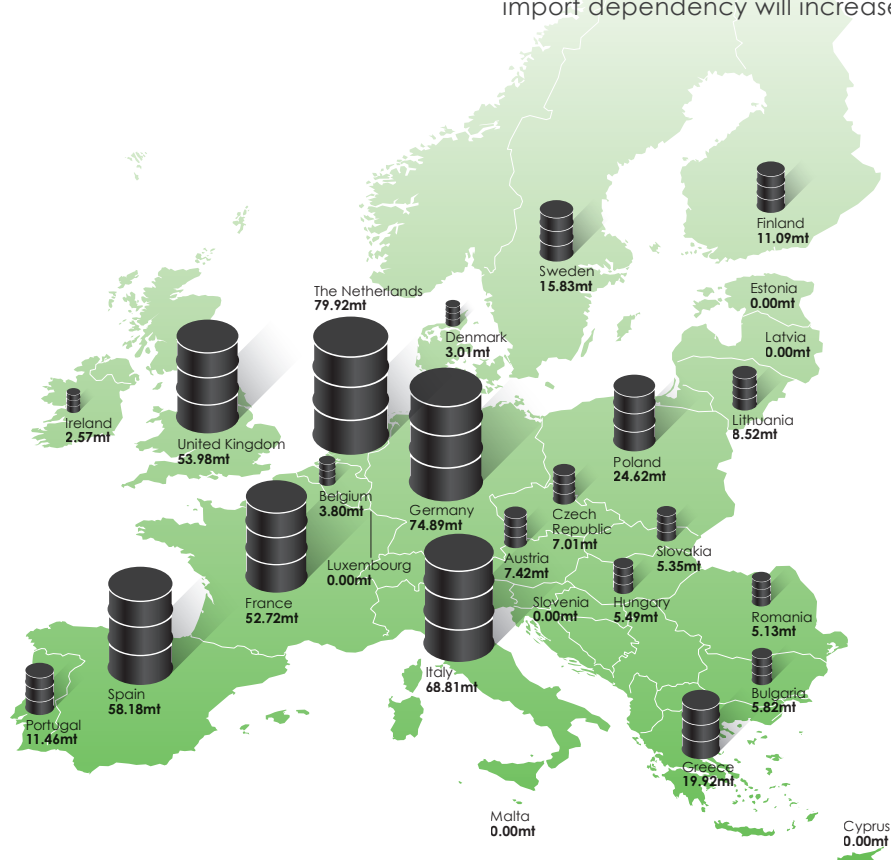
Europe is a major oil importer. Nearly 4 billion barrels of oil were imported into the European Union in 2012 at a value of €385 billion (See Fig. 2.4). Compared to most other sectors of the European economy, the value chain associated with petrol and diesel has two main features: it has a low intensity of labour, meaning that for every million euros of value added, relatively few direct jobs are created (Fig. 2.5); and most of the value chain is outside Europe, meaning that much of the money spent on diesel or petrol leaves the economy.

Some of the oil revenue that accrues to petro-states is recycled back into the European economy through purchases of EU exports, but an analysis of EU trade with petro-states shows that this represents a very small percentage of total EU trade. Therefore, the reduction in EU trade that might result from a reduction in spending on oil imports by Europe is negligible.

The future cost of oil is also expected to increase. In its central case, the IEA projects that crude oil prices will increase from €59 per barrel in 2010, to €105 per barrel by 2030. Furthermore, if steps are not taken to reduce EU demand for oil, then domestic reserves will be steadily consumed and import dependency will increase further.

Fig. 2.4

Annual crude oil imports to the EU (includes imports for refining)
Source: COMEXT, Eurostat

Finland 11.09mt
Sweden 15.83mt
Estonia 0.00mt
Latvia 0.00mt
The Netherlands 79.92mt
Denmark 3.01mt
Lithuania 8.52mt
Ireland 2.57mt
United Kingdom 53.98mt
Poland 24.62mt
Belgium 3.80mt
Germany 74.89mt
Czech Republic 7.01mt
Slovakia 5.35mt
Luxembourg 0.00mt
Austria 7.42mt
France 52.72mt
Slovenia 0.00mt
Hungary 5.49mt
Romania 5.13mt
Italy 68.81mt
Bulgaria 5.82mt
Spain 58.18mt
Portugal 11.46mt
Greece 19.92mt
Malta 0.00mt
Cyprus 0.00mt

In contrast to the production of petrol and diesel, the European auto sector has a long supply chain dominated by European suppliers; the value chain has many more jobs associated with it than the oil supply chain; and Europe exports vehicles (and vehicle designs) to other world regions.

Europeans spend around €269 billion each year on cars and vans, with most of that value accruing to European manufacturers and their suppliers. Even when Europeans buy non-European brands, the majority of those cars are manufactured in Europe. Thus, the transition to low-carbon vehicles represents a shift in spending away from the fossil fuel supply-chain, which creates low value for Europe, and towards the vehicle supply-chain, which creates high value for Europe. By using the macro-economic model E3ME, we have made estimates of the change in economic flows.

In a scenario in which the Internal Combustion Engine is either optimized or hybridized, the annualised capital cost of Europe's fleet of cars and vans increases by €64 billion by 2050 (excluding taxes), compared to a future in which the fleet continues running on today's

technology. The total fuel costs, including tax, for running Europe's fleet of cars and vans are reduced by €323 billion in 2050 compared to a future dependent on today's ICE.
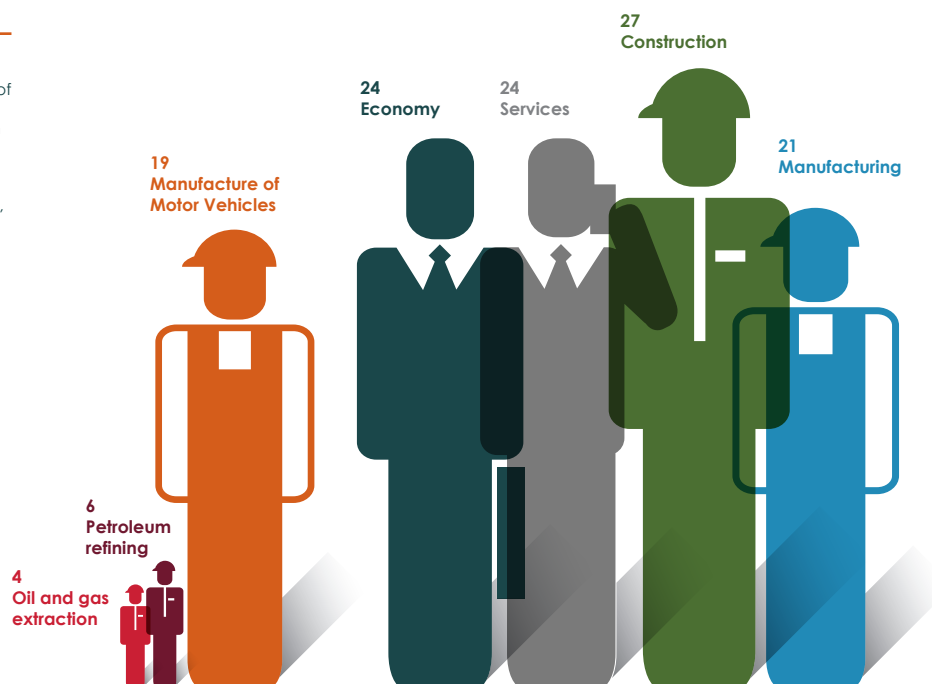
This is split between €191 billion of avoided spending on fuel and a €132 billion reduction in government receipts from fuel taxes, fuel duties and VAT. Of the €191 billion of avoided spending on fuel, part of the reduction falls on the refining, distribution and retail sectors, leaving approximately €140 billion of avoided spending on imported crude oil or oil products.

The net effect of reduced expenditure on petrol and diesel and increased expenditure on vehicles translates to €222 billion of additional GDP in Europe after second order multiplier effects are taken into account.

The transition to spending more on vehicles, less on fuel, and more in other areas of the economy, also changes the sectoral composition of the economy, leading to a substantial increase in European employment of 1.95 million net additional jobs in 2050 (Fig. 2.2).

27 Construction

24 Economy

24 Services

21 Manufacturing

19 Manufacture of Motor Vehicles

6 Petroleum refining

4 Oil and gas extraction

Impacts of a shift to alternative fuels

The impact of switching to alternative fuels, such as electricity and hydrogen, requires consideration of three new factors – the impact of replacing spending on imported oil with spending on domestically produced hydrogen or electricity; the impact of deploying the charging or refuelling infrastructure; and the impact of interactions that are created between the transport system and the power system.

The requirement for additional infrastructure was modeled both for charging plug-in Electric Vehicles (EV) and for providing hydrogen to Fuel Cell Electric Vehicles. Three different EV-charging network densities were examined to capture the range of uncertainty around motorists' charging preferences. These included differing amounts of home-charging, workplace-charging and public-charging.

The annualized costs of EV infrastructure were large – 26 billion to 80 billion in 2050 in the two scenarios that include advanced vehicles.

Even so, the combined annualized cost of the vehicle technology and the infrastructure technology remains less than, or broadly similar to, the avoided costs of fossil fuels (Fig.2.6). In other words, the money saved by burning less fossil fuel is enough to pay for both the additional vehicle technology and the new energy infrastructure that is needed. In the process, substantial numbers of jobs are created.

Switching fuels to electricity and hydrogen is likely to have a positive impact on the European economy. Firstly, it leads to greater vehicle efficiency because fuel cells and electric vehicles are inherently more energy-efficient than combustion engines. More importantly, the production of electricity and hydrogen is predominantly a domestic supply chain by 2050; so the fuel-switching represents substitution of domestic production for imported fuels. Infrastructure investment also has a positive impact on GDP because infrastructure projects stimulate domestic activity and require relatively high labour input in the supply chain.

Fig. 2.6

Total cost of ownership in 2030 and 2050 for each of the five scenarios
Source: SULTAN
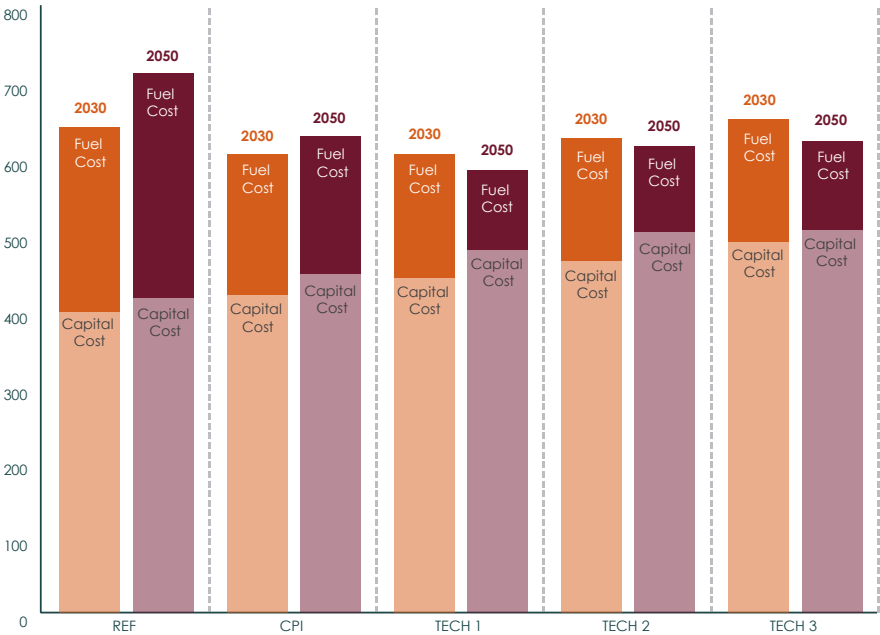
Impacts on government revenues

A major concern to national governments is the prospect of lower revenues as the petrol and diesel tax base is reduced. The scenarios in this study are government-revenue-neutral and VAT has been increased (on a country-by-country basis) to meet the lost receipts from excise duties. The analysis also suggests that taxation of the increased economic activity that results from a switch to low-carbon vehicles largely compensates for the lost tax revenues from fuel.
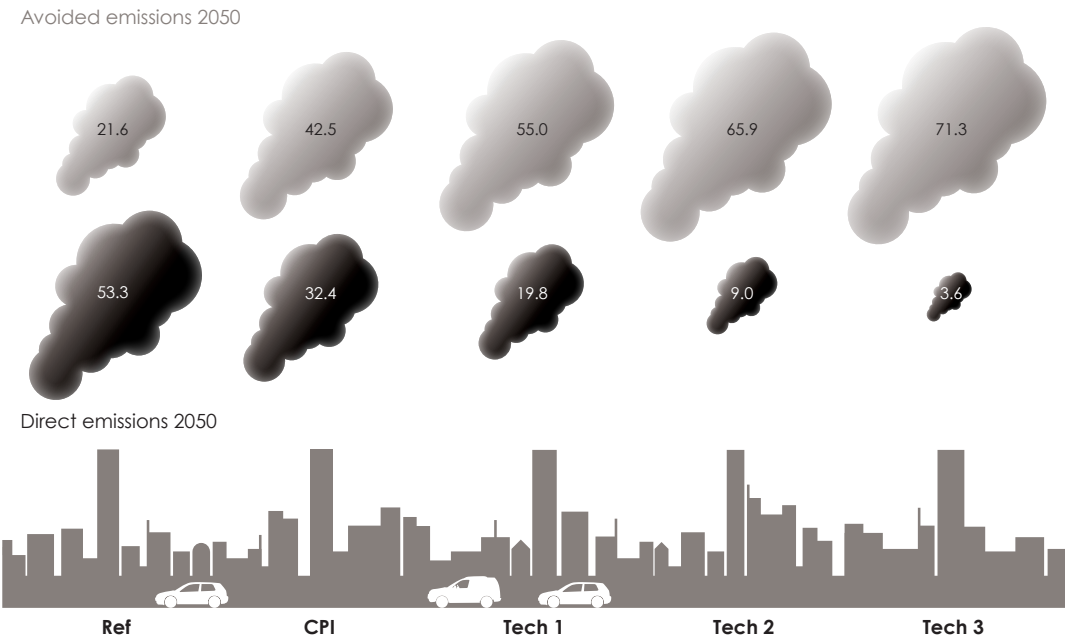
Impacts on the workforce

This study has also looked at the skills needed in the European workforce to ensure Europe can retain a competitive position during the transition to low-carbon vehicles. It has found that some parts of the industry are already experiencing minor skills shortages, particularly in the field of 'mechatronics', where mechanical and electrical engineering skills are combined.

There is also significant competition for software developers needed to develop battery management systems. The pace of the transition to low-carbon vehicles allows time for the development of the relevant new skills in Europe, but only if industry, governments and academic institutions start planning now.

Impacts on pollution

The levels of CO_2 and air pollutants emitted by vehicles are significantly reduced in all three of the more advanced technology scenarios. Cuts to CO_2 are in the range of 64 per cent to 93 per cent by 2050 (Fig. 2.1). For NOx, the reduction is between 85 per cent and 95 per cent, and particulates are reduced by 74 per cent to 95 per cent (Fig. 2.7).

Fig. 2.7

Direct tailpipe particulate emissions and avoided particulate emissions in the 4 scenarios in 2050
Source: SULTAN

Avoided emissions 2050

| | 21.6 | 42.5 | 55.0 | 65.9 | 71.3 |

Direct emissions 2050

| | 53.3 | 32.4 | 19.8 | 9.0 | 3.6 |

| Ref | CPI | Tech 1 | Tech 2 | Tech 3 |

3 Policy Context

The use of regulatory standards to control CO_2 emissions from motor vehicles has been proven to be a cost-effective measure, and is likely to continue to other modes of transport in the future. Understanding the wider potential impact of such future standards on the European economy is therefore of particular interest.

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 140 g/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 (according to the NEDC Test Cycle), backed up by penalties for non-compliance.

For 2020, Regulation 443/2009 set a target of 95 g/km, with an obligation for the Commission to review this target and define the specific modalities for implementation. This regulation was proposed by the Commission in July 2012 and is now under political review by the European Parliament and Council. Similar regulation exists for light commercial vehicles (Regulation No 510/2011), which aims to cut CO_2 emissions from vans to an average of 175 g/km by 2017 and to 147 g/km by 2020.

Historically, Japan and the EU have led in vehicle emission performance, and this is expected to continue. However, Canada and the US have recently introduced measures to reduce vehicle emissions between 2011 and 2016 by around 4 per cent per annum. In 2012, the US agreed a 2025 standard of 107 g/km (93 g/km for cars alone). As a result, the emissions performance in various vehicle markets is expected to converge towards 2025. A list of global vehicle emissions standards is provided in Table 14.1 of the Annex.

Fig. 3.1

Global comparison of light duty vehicle fuel economy standards (passenger cars only)
Source: Icct
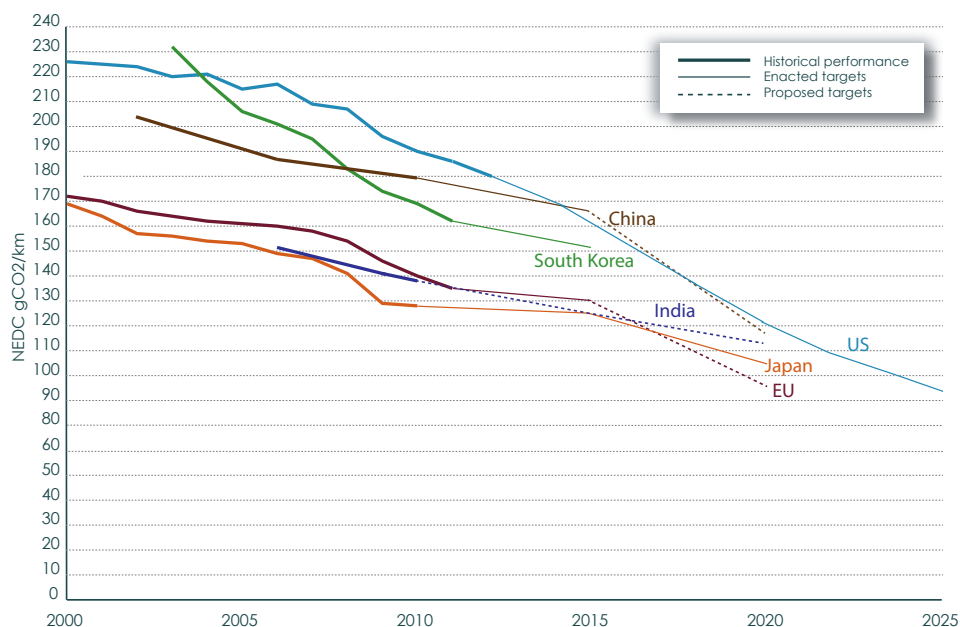
4 Modelling approach

To determine the economic impact of deploying low-carbon vehicles, the additional cost of vehicle technology was calculated in the Road Vehicle Cost and Efficiency Calculation Framework.

The per-unit cost was then applied to the vehicle fleet characteristics in each scenario, using the SULTAN scoping tool, to arrive at annualized total capital costs for the whole EU vehicle fleet. These were combined with the calculated costs of supporting vehicle infrastructure and annualized fuel costs to provide the main inputs for the economic model E3ME.

Road Vehicle Cost and Efficiency Calculation Framework

AEA Technology plc developed a detailed Excel-based calculation framework to estimate the potential changes in road vehicle capital costs and efficiencies from 2010 to 2050 for the UK Committee on Climate Change in early 2012. The framework facilitates the development of consistent/comparable estimates on vehicle capital costs and efficiencies/energy consumption for a wide range of road vehicle powertrains and options for motorcycles, light-duty vehicles and heavy-duty vehicles. The overall methodological approach and key information sources used in the calculation framework were previously tested with experts from industry and academia as part of the work for the UK Committee on Climate Change, and the approach has been further developed, refined and tested with experts from the Working Group by Ricardo-AEA as part of this current project.

SULTAN

The Sustainable Transport Illustrative Scenarios Tool has been developed as a high-level calculator to help provide indicative estimates of the possible impacts of EU transport policy on energy consumption, CO_2 emissions, technology costs and energy security. It was developed by AEA Technology plc as part of the European Commission-funded project "EU Transport GHG: Routes to 2050 II". For further information see the project website at http:// www. eutransportghg2050.eu

E3ME

E3ME is a macroeconomic model that covers the EU Member States' economies, with linkages 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, the 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, DG Ecfin's AMECO database and the IEA. The E3ME model embodies two key strengths relevant to this project. The model's integrated treatment of the economy, the energy system and the environment enables it to capture two-way linkages and feedbacks between these components. Its high level of disaggregation enables relatively detailed analysis of sectoral and national effects.

Fig. 4.1

Interaction between the three models

| Vehicle cost and efficiency calculation framework | Vehicle cost and efficiency characteristics for each type of powertrain | SULTAN model | Capital cost and fuel cost characteristics of the EU vehicle fleet | E3ME model |

5 Scenario Development

This report seeks to quantify the impact on society of reducing the consumption of fossil fuels by cars and vans. This transition is expected to involve a progressive shift to a mix of low-carbon technologies: principally efficient Internal Combustion Engine (ICE) vehicles, Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), Range-Extended Electric Vehicles (REEVs), Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs).

In order to understand the macro-economic impacts of this transition in the timeframe 2010-2050, five scenarios of technology deployment were developed.

- Reference Scenario – No Further Improvement (REF)
- Current Policy Initiatives (CPI)
- Tech 1 scenario
- Tech 2 scenario
- Tech 3 scenario

The scenarios focus on technological improvements alone, on the assumption that vehicle technology becomes the main driver for decarbonizing transport. The scenarios in this project are not an attempt to predict the evolution of future vehicles, which is highly uncertain, but to examine a range of possible future outcomes.

The Current Policy Initiatives scenario and the Tech 1 scenario ignore the penetration of advanced powertrains, focusing on what might be achieved using only conventional ICE and hybrid technology. The Tech 2 and Tech 3 scenarios include the deployment of advanced powertrains and accompanying infrastructure.

The goal of the report is to understand the potential economic impacts of technologies capable of contributing to substantial long-term CO_2 reductions in cars and vans. Therefore, scenarios exploring the potential contribution of natural gas fuelled vehicles have not been developed. However, it is anticipated that this alternative fuel might play an important role in reducing the greenhouse gas emissions of heavy duty road vehicles in the medium-term.

No Further Improvement scenario (REF)

This is the reference case scenario against which the other scenarios are compared in order to establish their potential marginal economic impacts.

The scenario assumes that CO_2 efficiency in European new vehicle sales remains at current levels of 135 g/km; that the current diesel/gasoline split remains unchanged, and that no further technology is introduced to improve efficiency.

Some small efficiency improvements do occur in this scenario due to fleet turnover as older vehicles are replaced by newer vehicles that achieve 135 g/km. Vehicle costs increase in the near term due to the application of measures to further reduce air pollutant emissions. This simple reference scenario has been chosen as it provides a clean baseline against which to compare the other scenarios.

Current Policy Initiatives scenario (CPI)

This scenario assumes that the current EU policy debate leads to the confirmation and achievement of the proposed CO_2 target for cars of 95 g/km in 2020 and a target for vans of 147 g/km in 2020. It assumes that no further policy targets are set after 2020, but there will be some further progress in reducing fuel consumption beyond 2020, driven by consumer concern about CO_2 emissions; fuel price pressure and a continuation of the existing momentum in technology development.

It is assumed that these factors will lead to a rate of improvement of less than 1 per cent per annum after 2020.

In the Current Policy Initiatives scenario, HEV deployment in the new car fleet reaches 5 per cent in 2020, 12 per cent in 2030 and 22 per cent by 2050. In this scenario, direct CO_2 emissions from cars are 95 g/km in 2020, 85 g/km in 2030 and 74 g/km in 2050, according to the test cycle. Vans achieve a CO_2 performance of 147 g/km in 2020, 129 g/km in 2030, and 102 g/km in 2050.

The relative share of diesel, gasoline and all alternative powertrains is based on the assumptions from the Reference Scenario used in the modelling analysis for the European Commission's Transport White Paper and also for the scenario analysis carried out under its "EU Transport GHG: Routes to 2050 II" project.

Tech 1 scenario

This scenario has been adapted and further developed from one of the scenarios used in the European Commission project "EU Transport GHG: Routes to 2050", which explores various pathways to achieve the Transport White Paper goal of reducing overall transport emissions by 60 per cent in 2050.

The scenario seeks to explore the impact of ambitious HEV deployment, while taking account of practical limitations. It assumes market penetration of HEVs of 10 per cent of new vehicle sales in 2020, 50 per cent penetration in 2030 and 96 per cent deployment in 2050. In this scenario, reductions in CO_2 are initially driven by, but not limited to, the 2020 CO_2 targets for cars and vans. The direct CO_2 emissions of cars are 90 g/km in 2020, 60 g/km in 2030 and 37 g/km in 2050, according to the test cycle. Vans achieve CO_2 performance of 141 g/km in 2020, 99 g/km in 2030 and 59 g/km in 2050.

Fig 5.1

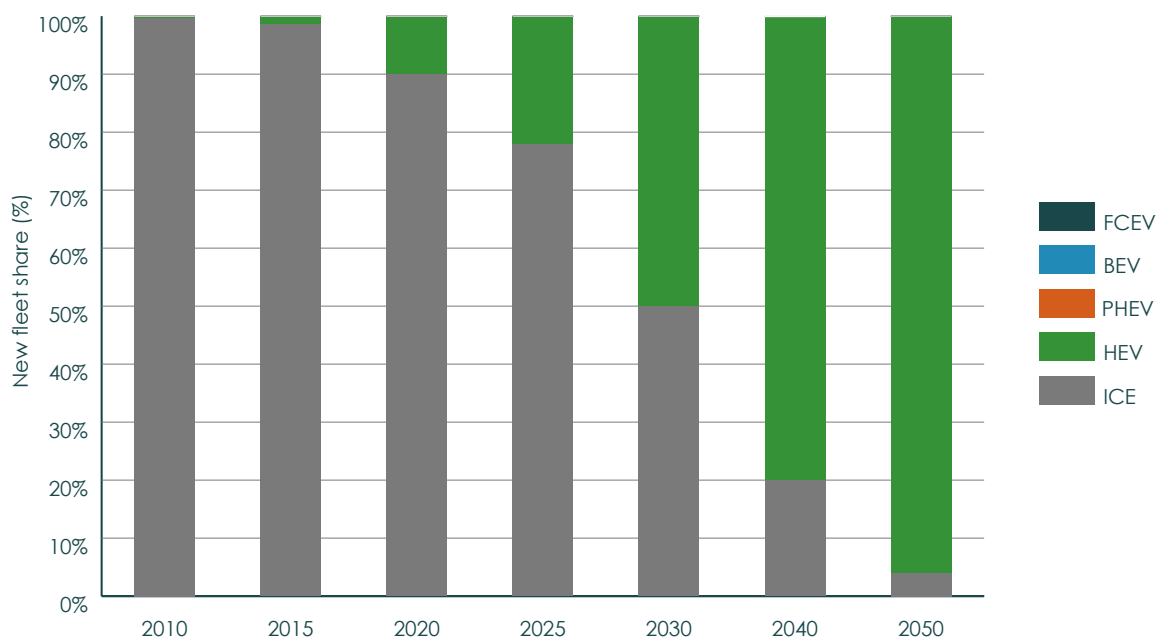Rate of technology deployment in the Tech 1 scenario as a proportion of new vehicle sales

Tech 2 scenario

This scenario has also been adapted and further developed from one of the scenarios used in the European Commission project "EU Transport GHG: Routes to 2050". The original scenario was based on sensitivity analyses to explore how quickly advanced powertrain vehicles must be deployed to achieve necessary reductions in CO_2 without the long-term use of biofuels at significantly greater levels than expected in 2020 (i.e. ~10 per cent substitution for conventional fossil fuels). For example, it is now more commonly accepted that available bioenergy for transport would be most effectively utilised in long-distance heavy-duty vehicles and aviation.

This scenario assumes market penetration of HEVs of 20 per cent of new vehicle sales in 2020, 42 per cent penetration in 2030 and 10 per cent penetration in 2050. Advanced EVs are deployed at 2.5 per cent in 2020, 37 per cent in 2030 and 90 per cent in 2050. Similarly to the Tech 1 scenario, reductions in CO_2 are initially driven by, but not limited to, the 2020 targets for cars and vans. The direct CO_2 emissions of cars are 88g/km in 2020, 41 g/km in 2030 and 8 g/km in 2050, according to the test cycle. Vans achieve CO_2 performance of 139 g/km in 2020, 78 g/km in 2030 and 19 g/km in 2050.

Fig. 5.2

Rate of technology deployment in the Tech 2 scenario as a proportion of new vehicle sales
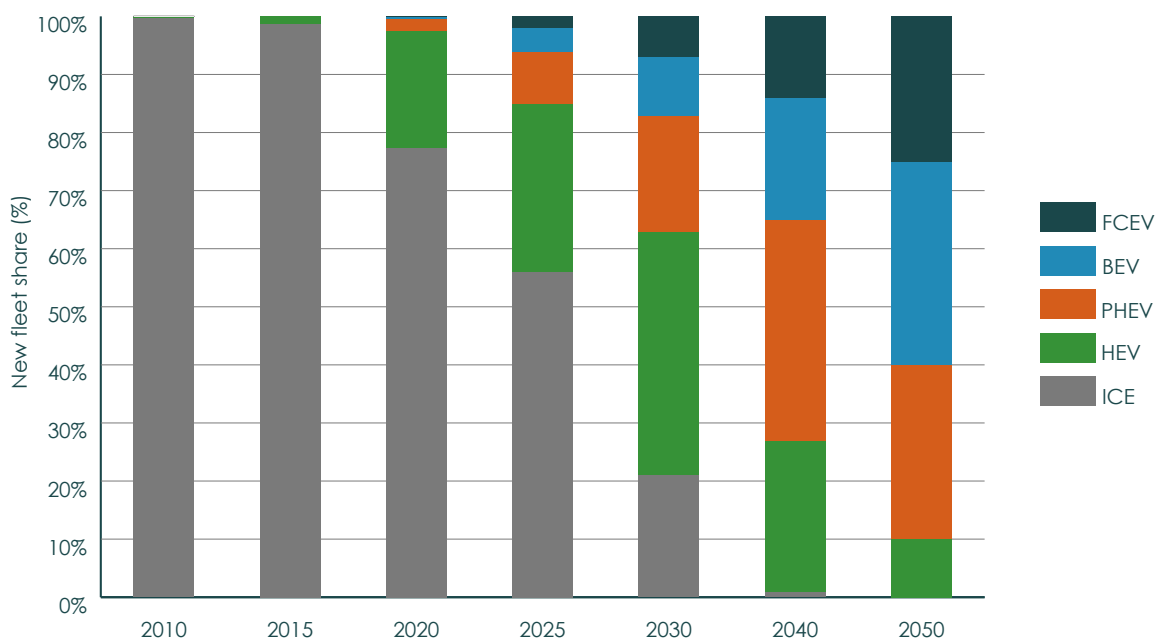
Tech 3 scenario

This scenario assumes a more rapid rate of introduction of advanced EVs, which could be possible with appropriate supporting measures. Uptake rates of BEVs, PHEVs and Range Extended Electric Vehicles (REEVs) are broadly in line with the 'EV breakthrough' scenario from CE Delft (2011)[1], a report for the European Commission that explored possible rates of EV deployment. Some substitution of PHEV/REEVs with FCEV alternatives has been modelled, reflecting our study's more technology-neutral approach.

This scenario assumes market penetration of advanced EVs of 9.5 per cent in 2020, 80 per cent in 2030 and 100 per cent in 2050.

Correspondingly, HEVs reach 20 per cent of new vehicle sales in 2020 and 15 per cent penetration in 2030, but deployment is reduced to 0 per cent of new vehicle sales in 2050. Similarly to the Tech 1 scenario, reductions in CO_2 are initially driven, but not limited, by the 2020 targets for cars and vans. The direct CO_2 emissions of cars are 83 g/km in 2020, 23 g/km in 2030 and 0 g/km in 2050, according to the test cycle. Vans achieve CO_2 performance of 129 g/km in 2020, 40 g/km in 2030 and 0 g/km in 2050.

The future deployment levels of advanced EVs in our Tech 2 and Tech 3 scenarios are shown in Fig. 5.4, where they are compared to a range of market forecasts and scenarios from the literature. This figureure shows that our scenarios fall comfortably within the range in other credible projections.

Fig. 5.3

Rate of technology deployment in the Tech 3 scenario as a proportion of new vehicle sales
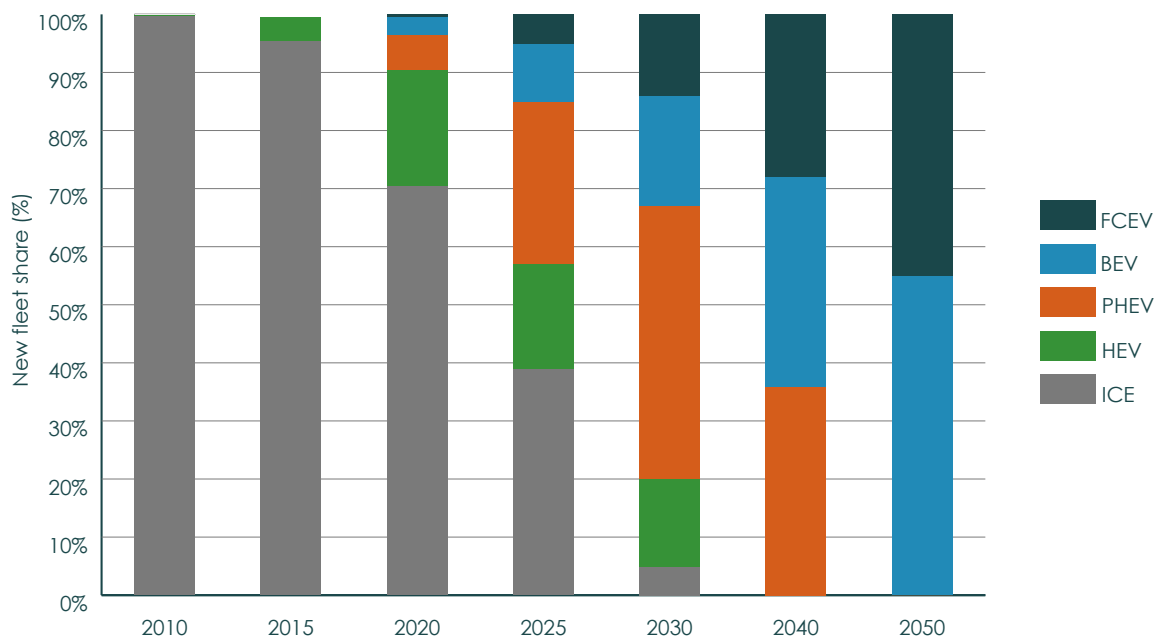
Fig 5.4

EV deployment
assumptions
Source: Ricardo-
AEA

Legend:
- JRC (2010), 'low'
- JRC (2010), 'high'
- CE Delft (2011), 'ICE breakthrough'
- CE Delft (2011), 'most likely'
- CE Delft (2011), 'EV breakthrough'
- IEA (2010), 'BLUE Map' (global)
- Roland Berger (2010), 'High'
- Oliver Wyman (2009), 'Power play'
- Roland Berger (2011), Automotive Landscape 2025 - 'Optimistic'
- PRTM (2010), global
- ACEA (2010), low (PHEV/BEV/REEV)
- ACEA (2010), high (PHEV/BEV/REEV)
- McKinsey (2009), 'Mixed technology'
- McKinsey (2009), 'Hybrid & Electric'
- AEA (2009), 'Prolonged recession'
- AEA (2009), 'Green recovery'
- AEA (2009), 'Green recovery + upfront support'
- AEA (2009), 'Green recovery + upfront support but more advanced diesel'
- European Commission (2012)
- AT Kearney (2012)
- CLEPA (low)
- CLEPA (high)
- Shell (2009), 'alternative'
- Oko-Institut (2012)
- UK CCC target for PHEV+EV
- UK CCC 'Low' scenario
- UK CCC 'Medium' scenario
- UK CCC ' High' scenario
- Minimum
- Maximum
- Average
- Tech 2 Scenario
- Tech 3 Scenario

6 Vehicle Technology Cost

While there is uncertainty about long-term technology development for vehicles, much is already known about the technologies that will be brought to market in the 2020 timeframe, and will still make up much of the vehicle fleet until 2030.

In previous research conducted by Ricardo-AEA involving interviews with very senior R&D decision makers from the automotive industry, there was a strong message that the short to medium-term would continue to be dominated by further improvements to Internal Combustion Engine (ICE) technology. In fact, even in the longer-term, high efficiency internal combustion engines are expected to remain important for use in plug-in hybrids and range extenders. Such views are consistent with the technology roadmaps from various organisations including the Automotive Council UK[1] and EUCAR[2].

ICE improvements

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 2020-2025 timeframe. Start-stop technology using advanced lead-based batteries is perhaps the most cost-effective way of achieving reductions of 5-10 per cent in CO_2 emissions (depending on whether the system is able to recapture braking energy). Ricardo 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[3].

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 the coming 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). In the longer-term (i.e. 2030-2050) it is reasonable to expect that additional (as yet unknown) options may also become available to further improve ICE efficiencies.
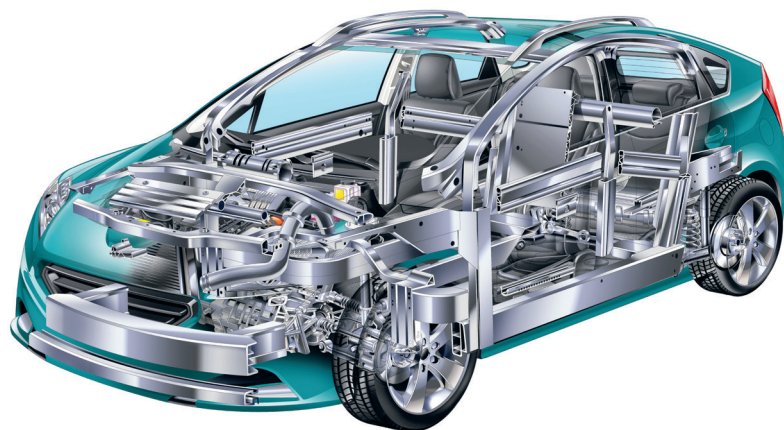
Weight reduction

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.

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)[4] and more recently FEV (2012)[5].

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.

The increased focus on improving fuel economy and reducing CO_2 emissions has led to further demand for lightweight materials innovation, with research focused on a range of options for near, medium and longer-term application:

- Carbon fibres, natural/glass fibres
- High-strength steels and aluminium
- Magnesium technologies
- Hybrid materials and bio-plastics[6]

The Automotive Council UK notes that the longer-term potential for improving vehicle efficiency includes achieving a 50 per cent weight reduction compared to 2008 and the introduction of flexible re-configurable multi-utility vehicle concepts[7]. For electrically-powered vehicles, the benefits of reduced weight, drag and rolling resistance are particularly strong[8]. Because electric powertrains are highly efficient, 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, lightweight materials are being introduced earlier and to a greater extent in electric vehicles. For example, carbon fibre reinforced plastics (CFRP) are to be used for body components in BMW's forthcoming i3 battery electric and i8 plug-in hybrid vehicles where this use is reported to achieve a 50 per cent weight saving over steel and 30 per cent over aluminium [9], [10].

In the past, the high cost and time taken to produce and use carbon fibre has limited it to niche/small-scale and high-end applications in vehicles.

However, recent research has made significant strides in both areas. It is uncertain by when or how much costs might be reduced.

A significant transition to lighter-weight vehicles is likely to be restricted unless current policy disincentives are removed. For example the current weight-based standard for CO_2 limits ideally needs to be replaced with a size-based standard to provide a sufficiently strong incentive for the full potential of lightweight materials be achieved.

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 are widely accepted as among the most important, if not the most important factors that will affect the speed with which these vehicles gain market share.

There are four key areas where breakthroughs are needed:

- Reducing the cost
- Increasing the specific energy (to improve vehicle range/performance for a given battery weight or reduce weight for a given battery kWh capacity)
- Improving usable operational lifetime
- Reducing recharging time

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), but these technologies are believed to be many years from commercialisation.

Currently the battery of a plug-in electric vehicle is estimated to cost between €6,000 and €16,000 (ACEA, 2011) although this is expected to halve in the next decade, and in the longer-term to decrease to around €3,000 to €4,000[11]. Recent detailed analysis for the UK Committee on Climate Change[12] has estimated current costs at ~$700-800/kWh (~€560/kWh) and predicts a reduction to $318/kWh (€245/kWh) by 2020 and $212/kWh (€160/kWh) by 2030 for a mid-size battery electric vehicle in the baseline scenario. These figures have been used as a basis for the central case estimates used in the technology costs calculations of this study for BEVs.

They are more conservative estimates than other recent estimates from Roland Berger[13] (~US$316-352 /kWh for the total pack by 2015) and McKinsey[14] (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[15].

These lower cost estimates for batteries fall within the envelope of the low-cost sensitivity assumptions used within this study.

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 are needed 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 emissions 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 of supply.

- 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 these problems, the focus over the last five years has been on battery technology and plug-in vehicles. However, at least one market analyst is predicting re-emerging interest in FCEVs, given the disappointing sales performance of some battery electric models, and highlights that OEMs are still stating that initial rollout will be between 2013 and 2015[16].

Although there are currently no production FCEVs available to purchase, Honda has already produced a limited run of 200 FCX Clarity FCEVs available for lease in California, and Hyundai started limited production in February 2013 for lease to public and private fleets (and expects to build 1,000 vehicles for lease by 2015)[17]. Toyota has also recently stated that it is to launch a saloon-sized fuel cell car by 2015, and some other manufacturers have similar expectations[18].

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[19] 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 that polymer fuel cell technology will 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 McKinsey[20], which suggested fuel cell stack costs could reach €43/kW as early as 2020. This analysis has utilised slightly more conservative figures for the whole fuel cell system costs, based on feedback from Daimler and ICCT (presented in Table 14.2 in the Annex to this report).

Other technologies

Whilst we have included the main technological options being developed for light-duty vehicles, there are also several other technologies under development, but these were not included due to insufficient data/characterisation. There is currently a huge interest in developing further cost-effective options for improving vehicle efficiency, in part due to the existing CO_2 emissions regulations, but also due to ever-increasing fuel costs.

Examples of recent innovations that have not been included in our analysis include various alternatives to hybrid electric vehicles – for example the light-duty 'Flywheel KERS' (Kinetic Energy Recovery System) being developed by Volvo[21] and the 'Hybrid Air' system being developed by PSA Peugeot Citroën[22].

Both of these systems reportedly offer the potential for similar efficiency savings to HEVs, but at lower manufacturing costs. It is to be expected that new innovations will also emerge in the coming years. For this reason, we have included estimates for as yet unidentified long-term ICE improvements in our modelling for the 2030-2050 period.

Methodology

There is significant uncertainty with respect to future developments in the cost and performance of some transport technologies, particularly when projecting out to 2050. The absence of historical data can make it difficult to use learning rates and instead requires a detailed knowledge of the likely sources of potential cost reductions and performance gains at an aggregate vehicle level.

This project has taken a conservative approach by basing its technology cost projections on the base case presented in TNO et al (2011)[23] for the European Commission's impact assessment for the proposed 2020 targets.

These data were provided to the Commission by the European Automobile Manufacturers Association (ACEA) and the European Association of Automotive Suppliers (CLEPA).

This dataset was reviewed by the project's Working Group and modified where other evidence indicated the need. In particular, the central-case weight reduction costs and energy reduction potentials take account of vehicle data from the U.S. Environmental Protection Agency. These U.S. data were used in the alternative Scenario B of TNO et al and resulted in a similar cost-curve to that of Scenario A, which was used in the Commission's Impact Assessment analysis. TNO et al focused on assessing technology costs in 2020, but in this project it has been necessary to estimate future technology costs as far as 2050.

Future cost reductions have been estimated in Ricardo-AEA's calculation framework to factor in the effects of (i) cost reduction due to deployment/mass production, and (ii) cost reduction over time independent of deployment rates (at 1 per cent per year).

Ricardo-AEA used its Road Vehicle Cost and Efficiency Calculation Framework to develop the final technology cost and vehicle efficiency datasets.

The methodology and assumptions of this framework were developed through previous work for the UK Committee on Climate Change[24]. They were derived from a range of major UK and European studies and have been previously tested with experts from industry and academia. The powertrain types covered by the framework include ICEs, HEVs, PHEVs, REEVs, BEVs and FCEVs. As part of the current project, these existing datasets and assumptions were shared and further discussed and agreed with experts from the project's Working Group.

These consultations were conducted via a combination of telephone interviews, meetings and other exchanges between Ricardo-AEA and key experts from the Working Group (e.g. from Nissan, CLEPA, ICCT, EAA, EUROBAT, etc). Additional feedback was also provided separately from a number of members of EUROBAT and CLEPA.

Additional capital costs for cars (central case) under the Tech 1-3 scenarios Source: SULTAN
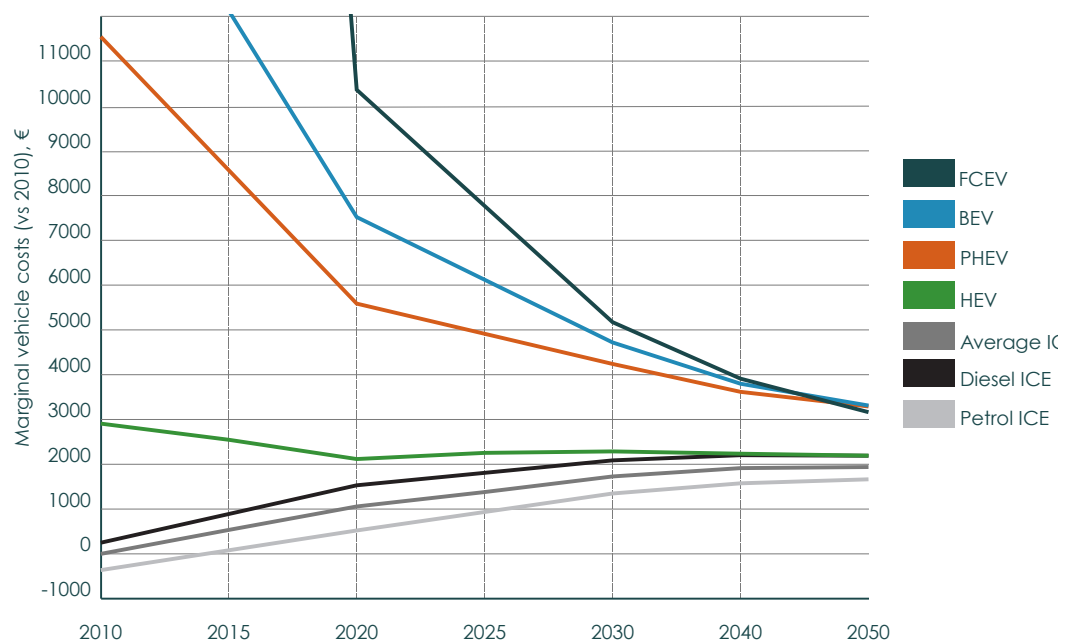
As part of this process, additional evidence from the literature was also identified to support revisions made to key assumptions and calculations.

The key revisions included the following elements: Key technology data assumptions were revised in the central-case, in particular those for the costs of weight reduction, batteries and fuel cells.

- Other elements of the methodology and calculations were revised. A cost reduction factor of 1 per cent per annum due to learning over time was applied, to supplement existing volume-related cost reduction factors. Revised assumptions were introduced on battery sizing for different powertrain types, including useable State of Charge (SOC) reserve and range in electric-only mode.

- Central case estimates for individual technology costs for mass-manufacture at 2010, were estimated by back-calculating from corresponding data from TNO et al (2011) for 2020 mass manufacture using the assumptions of cost reduction due to learning over time.

- Long-term (2030-2050) technology options were added e.g. additional levels of weight reduction and as-yet-unidentified potential future technologies to improve ICE efficiency.

A 'technology packages' methodology was also developed to better conceptualise and build assumptions about the deployment of particular technologies. Table 14.3 in the Annex provides a summary of the allocation of technologies into a series of eight indicative 'technology packages'.

The packages were developed to achieve nominal efficiency improvement objectives in five-year increments from 2010 to 2050, assuming a challenging, but achievable rate of roll-out of the technologies (based on their relative cost-effectiveness).

The overall deployment of individual technologies in different periods was subsequently estimated based on indicative shares of deployment of these packages under the different scenarios.

The assumed package deployment shares under the three scenarios are summarised in Table 14.5 in the Annex. Key technology assumptions related to HEVs are summarised in Table 14.6 in the Annex.

Results

The data show that improving the fuel-efficiency of light-duty vehicles will result in additional capital costs (Fig. 6.2). In the Current Policy Initiatives scenario, the additional cost of meeting the 2020 CO_2 target of 95 g/km is anticipated to be around €1,056, compared to the 2010 baseline vehicle on average. The slightly more ambitious Tech 1 scenario leads to around €1,154 of additional manufacturing costs. Corresponding costs for the Tech 2 and Tech 3 scenarios that include more significant deployment of Advanced EVs (and slightly higher emissions reductions) are €1,400 and €1,800.

These higher costs are in the same range as two other studies on the subject. In its study for the European Commission impact assessment on the 95g/km target, TNO found central-case additional manufacturing costs of €1,159 per vehicle on average, relative to the 130 g/km target in 2015. The International Council on Clean Transportation[25] used a tear-down analysis approach, concluding that the 95 g/km target would lead to less than €1,000 of additional manufacturing costs, compared to a 2010 vehicle. The cost was considerably lower if full use was made of weight reduction.

After 2020, technology costs continue to rise to meet increased fuel-efficiency requirements in the scenarios presented here, for example to €1,998 in 2030 to meet a CO_2 performance of 60 g/km in the Tech 1 scenario, and to €2,172 in 2050 to reach 37 g/km. For the Tech 2 and Tech 3 scenarios, the corresponding figures are €2,996 and €4,031 of additional costs in 2030 to achieve respective CO_2 performance of 41 g/km and 23 g/km. Detailed estimates for future costs of cars and vans in both scenarios are presented in Tables 14.7 and 14.8 in the Annex.

Fig. 6.2

Average new
vehicle capital
costs for different
deployment
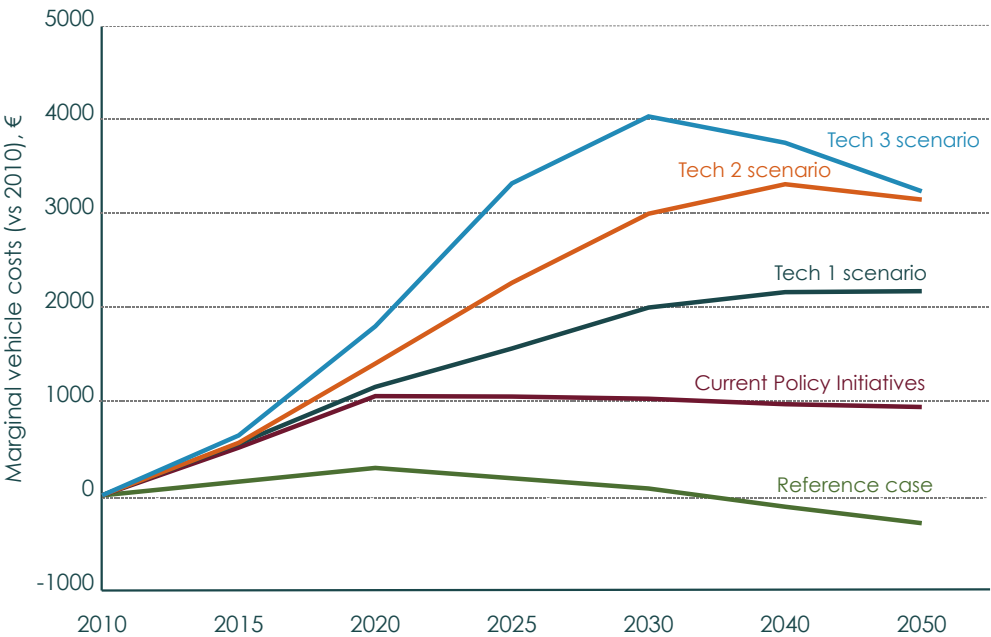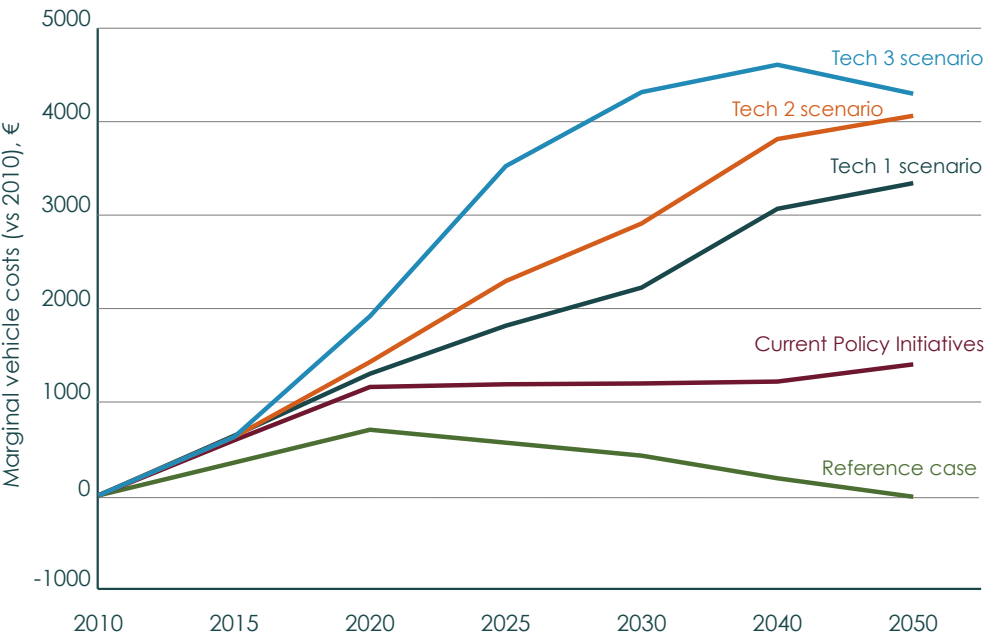scenarios
(cars)(includes
advanced
technology)
Source: SULTAN

Fig. 6.3

Average new
vehicle capital
costs for different
deployment
scenarios
(vans) (includes
advanced
technology)
Source: SULTAN

Total cost of ownership

Consumers select their vehicles on the basis of a wide range of factors, of which 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.

Estimates for the total cost of ownership (TCO) for the consumer are presented for the different car powertrain technologies in Fig. 6.4, 6.5 and 6.6. While the calculations endeavour to use central-case estimates for future fuel prices and annual kilometres travelled, the results are extremely sensitive to changes in these assumptions. The results are also particularly sensitive to the level of discount rate modelled.

The analysis shows that under the intermediate discounted cash flow assumptions (5 per cent discount rate) the TCO of the different auto technologies are expected to converge somewhat by 2020 – with the TCO of all powertrains being lower than in 2010, despite significant (~30+ per cent) increases in fuel prices. The exception is for FCEVs, due to a combination of (i) higher capital costs, (ii) the relatively high anticipated price of hydrogen fuel at this point (compared to petrol and diesel), and (iii) their lower energy efficiency relative to BEVs.

Under the lower social discount rate sensitivity assumption (3.5 per cent), BEVs and PHEVs could become as cost-effective on a TCO basis as the average ICEV or HEV by 2020. By 2030, BEVs and PHEVs could have the lowest TCO of all technologies.
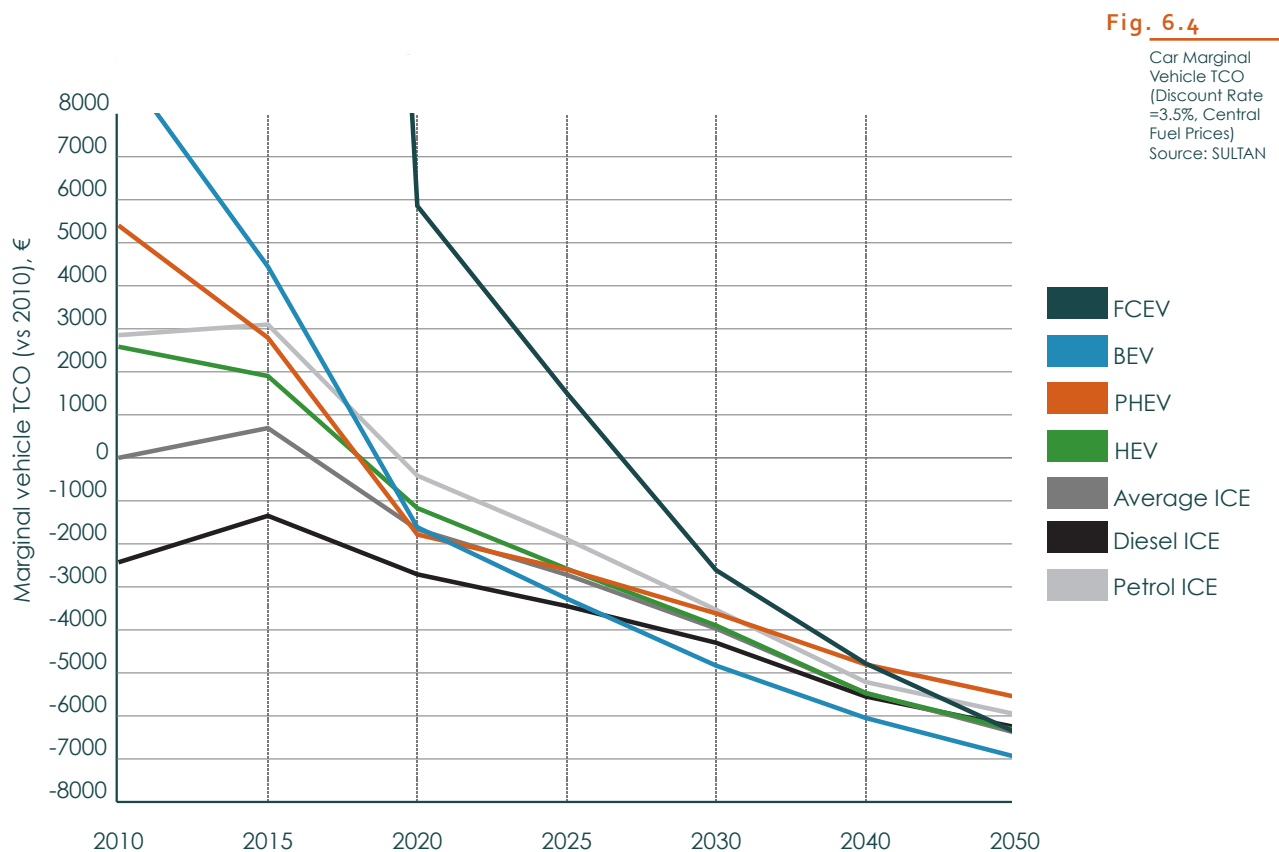
However, under the higher discount rate assumptions (10 per cent), more typical for private car finance deals, the TCO for HEVs, PHEVs and BEVs is expected to remain significantly higher than for conventional ICEVs by 2020 and 2030, and potentially even to 2050.

In all three discount rate sensitivities, FCEVs do not approach similar TCO to other technologies until after 2030. However, it should be noted that both PHEV and FCEV technologies are more suited to larger vehicles travelling longer distances/with higher annual km. Under such conditions their TCO might be expected to be more favourable at an earlier time-point.

Furthermore, there are additional benefits of electrified powertrains that are not accounted for in this analysis, including reduced external costs due to lower levels of air quality pollutant emissions and reduced local noise impacts.

Therefore, policymakers might choose to continue to provide incentives for such vehicles into the medium-term to encourage their uptake. Currently, there are incentives for various alternative powertrain vehicles applied across Europe, which help to offset the additional upfront capital costs of these vehicles. These include various forms of tax relief, grants to help with vehicle purchase, discounts, or exclusion from local congestion zone or parking costs, etc.

TCO methodology and assumptions

It is important to note that the comparisons presented are also highly influenced by the assumptions on total annual activity of the vehicles (which will vary for different users), and on future fuel prices.

Under conditions where fuel prices or the annual km travelled by the vehicles (previously mentioned) are higher, the competitiveness on a TCO basis of HEVs, PHEVs, BEVs and FCEVs is further enhanced so that these powertrains reach equivalence with ICEVs much sooner. For example, under the high fossil fuel price sensitivity BEVs have the lowest TCO by 2020 using a 5 per cent discount rate, and have a TCO below that of ICEVs by 2030 even under the higher 10 per cent discount rate assumption. Conversely, under the low fossil fuel price sensitivity assumptions, BEVs continue to have a ~€1,000 higher TCO than ICEVs and HEVs even by 2030 at the intermediate 5 per cent discount rate.

The TCO calculation has been performed on the basis of time-discounted cash flows using the total car purchase price (including all taxes and margins, annual maintenance costs and fuel costs (including all taxes). Since there is considerable uncertainty about the future residual/resale values of new powertrain technologies in the short-medium term, the analysis has been carried over the lifetime of the vehicle, rather than over three or five years, which is also common. It should also be noted that uncertainty over re-sale values might act as an obstacle to adoption of advanced powertrain vehicles.

Indeed, some of the scenarios in this analysis rely on the assumption that policymakers can provide sufficient investment security for these barriers to be overcome. The European Commission[26][27] typically recommends the use of a 3.5 per cent social discount rate for economic analysis and a 5 per cent discount rate for financial analysis (for private equity at country level averages). However, interest rates between 10-15 per cent are common for financing of private car sales (though typically only for a proportion of the car's full value, and over a period well below the full lifetime of the vehicle).

In these figures the TCO has been calculated over the full vehicle lifetime (taken to be 13 years), with an annual activity of 12,000 km. In converting from capital costs (i.e. on a manufacturing basis) to capital prices to the consumer, VAT is added at 19 per cent (also to fuel costs), together with an EU average purchase tax of 5.7 per cent, and an additional margin for the manufacturer and dealer. This manufacturer and dealer margin is assumed to be 24.3 per cent for all ICEVs and HEVs across the timeseries. For BEVs, PHEVs and FCEVs the margin is assumed to change from 0 per cent in 2010 to the same margin for ICEVs and HEVs in the medium-long term, as BEVs, PHEVs and FCEVs become more cost-competitive.

The detailed assumptions on capital costs, maintenance costs, manufacturer and dealer margins and on fuel prices and taxes are provided in Table 14.9 in the Annex. Detailed estimates for the costs of electric and hydrogen infrastructure in chapter 7. Fuel costs are discussed in chapter 8.

Fig. 6.5

Car Marginal
Vehicle TCO
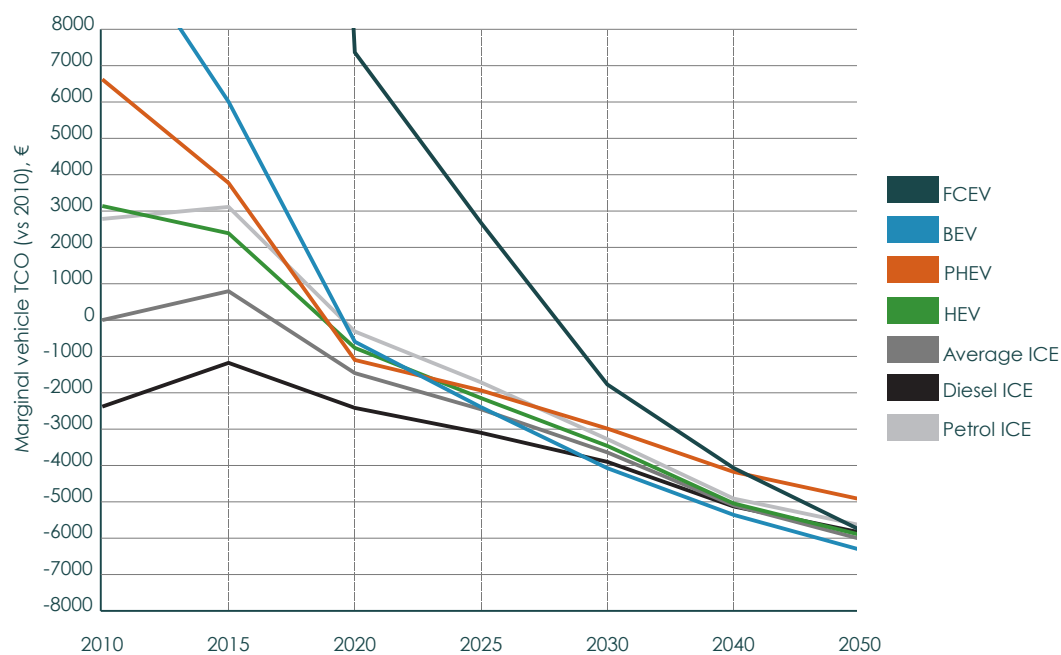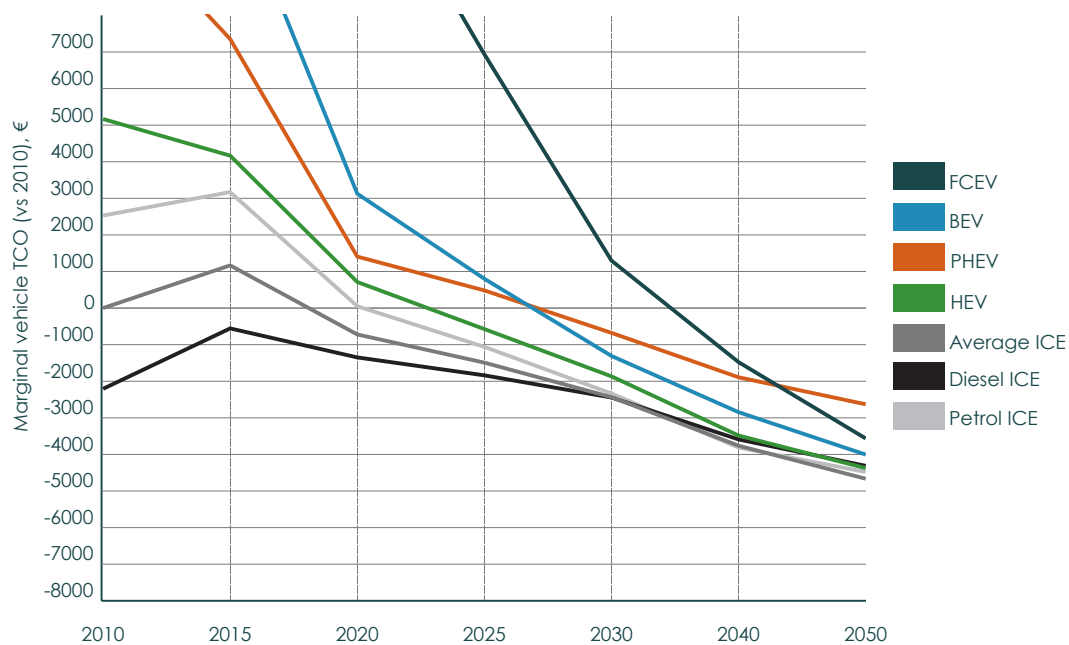(Discount Rate
=5%, Central Fuel
Prices) Source:
SULTAN

Fig. 6.6

Car Marginal
Vehicle TCO
(Discount
Rate=10%,
Central Fuel
Prices) Source:
SULTAN

7 Infrastructure technology costs

The aim of this chapter is to analyse the need for investment in charging and fuelling infrastructure that arises from the scenarios developed in SULTAN for the deployment of advanced vehicles.

The costs of hydrogen infrastructure for FCEVs is examined, along with three ways of deploying the infrastructure for charging electric vehicles. The potential macroeconomic impact of deploying this infrastructure is then considered.

The provision of the right quantity and mix of infrastructure raises a number of complex questions for private and public sector organisations involved in its delivery. They include:

- How will vehicles be charged? This relates to the technical specifications of the network of charging and refuelling infrastructure, and in particular the need for standardisation across suppliers and countries.

- Where will the infrastructure be located? This will depend on a wide range of factors including battery range and charging behaviours.

- How many charging / refuelling stations are needed? This will depend on the speed at which EVs and FCEVs deploy as well as charging behaviours.

- Who will pay for this infrastructure and who will provide it? Depending on the business models, the need for public finance will vary. It will also change over time, with more public investment needed at the beginning when the market is still emerging.

Each of these questions must be addressed in order to estimate infrastructure costs. Precise forecasts are difficult at this early stage of the market development of EVs, PHEVs and FCEVs because data are scarce and because it is too early to say how the market will evolve, what shifts in consumer behaviour might occur, and how costs will change over time.

The analysis bases its assumptions on a thorough review of the existing literature on the subject and on discussions with the working group, which includes several companies at the forefront of electric vehicle and infrastructure deployment, such as Nissan and SSE. It has also been reviewed by members of industry organisations including EUROBAT and Eurelectric.

By considering a range of possible scenarios, both for vehicle and infrastructure deployment, and by comparing those to a reference scenario, many of the uncertainties around EV market development can be captured. This chapter explores three deployment methods for infrastructure, their associated costs and their potential macro-economic impact.

Methodology

The approach used to quantify infrastructure costs is summarized in Fig. 7.1. Infrastructure density per vehicle was determined via a comprehensive review of existing literature, which was then discussed with industry members of the working group.

The infrastructure density was then applied to the number of advanced powertrain vehicles to determine the total number of hydrogen fuelling stations or electric charging points required to service the fleet in the various scenarios. Infrastructure unit costs were also determined through a literature review and group discussion, before applying them to the total number of charging or fuelling points to arrive at a total infrastructure cost. Three methods of charging were examined for EVs.

While seemingly straightforward, each step of this methodology in fact raises very complex questions that can affect the level and costs of investment. There is uncertainty about future utilisation rates, the preference for home versus public charging, and how the mix, density and costs of infrastructure will evolve over time. Assumptions have been based on the best knowledge of the stakeholders involved in this project.

Fuel cell vehicles

FCEVs offer an opportunity for zero-emission transport for all individual driving patterns including urban, intercity and longer-distance. However, as with all-electric car variations, a dedicated refuelling infrastructure would need to be built up. This chapter presents estimated costs of infrastructure needed for the rate of FCEV deployment in the vehicle scenarios developed in the SULTAN tool.

As the market is currently in development, fast changes in terms of technologies and processes result in a fragmented offer across countries and providers. It also makes it difficult to predict which mix of technologies will dominate in Europe in the future. Bearing this in mind, this section offers a short overview of the broad categories of infrastructure and the cost associated with two possible production and distribution combinations or 'energy pathways'.

H2 production

Hydrogen can be produced on both a small and large scale, and from a variety of sources and processes. Possible sources include fossil resources, such as natural gas and coal, as well as renewable sources such as sunlight, wind,

biomass and water. Processes include chemical, biological, electrolytic, photolytic and thermo-chemical techniques.

Each technology is at a different stage of development, and each offers distinctive opportunities, benefits and challenges. Local availability of feedstock, the maturity of the technology, market applications and demand, policy issues, the regulatory framework and costs will all influence the choice and timing of the various options for hydrogen production.

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.

A study by UC Davis[1] indicates that distributed (or onsite) production of hydrogen from natural gas is an attractive option for early hydrogen supply to vehicles as it avoids the cost and complexity of hydrogen delivery. Distributed production also requires less capital investment than central production. The study predicts that that large onsite reformers in the range of 1000 kg/d will become available over the next five years.
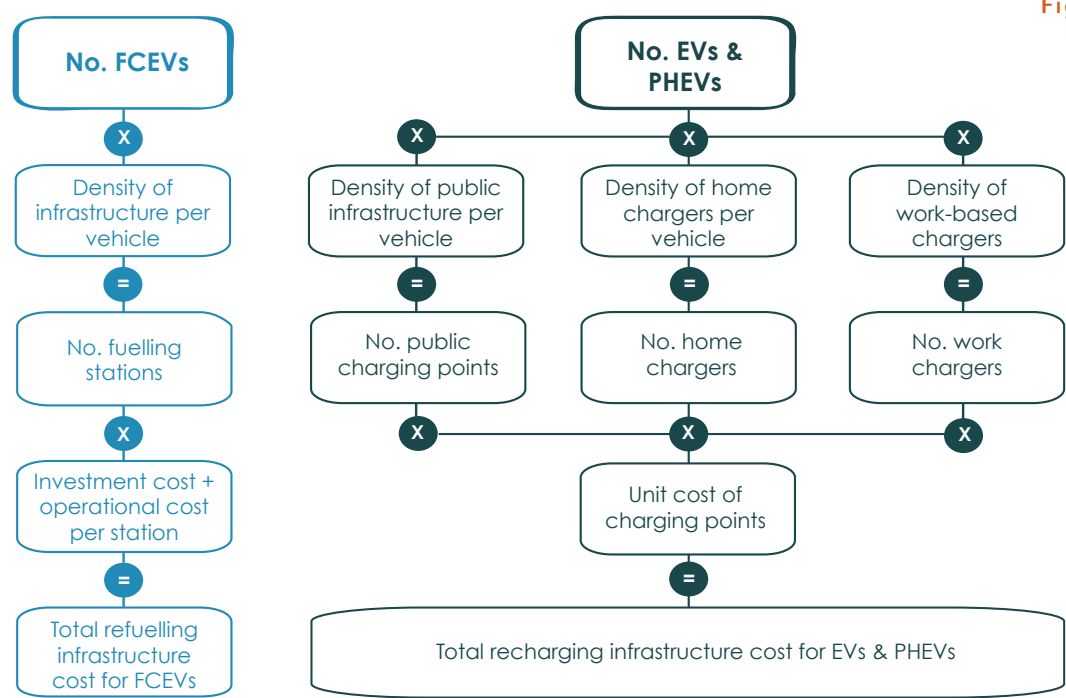

Fig. 7.1

Methodology for calculating cost of refuelling / re-charging infrastructure

H2 distribution

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 economical 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 5-10 times more hydrogen on a truck than when using compressed gas. This can significantly lower the delivered cost of H2, 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 can 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[2]) 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 summarised in Table 7.1.

This allows us to explore both a centralised and decentralised approach based on electrolysis. For this study, we assume that the overall demand for hydrogen is served equally from centralised and decentralised sources. It is worth bearing in mind that the costs of delivered hydrogen in these chains are generally higher than in Steam Methane Reforming (SMR) but unabated SMR has a carbon intensity that is not consistent with this study's objective of examining carbon reduction, so this energy chain was not included.

In order to produce cost estimates for the two energy chains presented above, capital and operating expenditure data were originally taken from the H2A model[4].

Table 7.1

Main components in the hydrogen chain

	CENTRALISED CHAIN	DECENTRALISED CHAIN
Primary energy source	Wind	Natural gas and wind
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 1: 30-170 bar (refuelling compressor at station)

The data were then updated and revised with data available to the project team, and through consultation with expert stakeholders.

Projecting how the cost of hydrogen supplied to the refuelling stations varies over time is achieved by using a combination of learning rates and changes to equipment utilisation rates. The cost and performance datasets are a function of time and are not linked to hydrogen vehicle uptake levels.

The estimated cost of H2 delivered to the hydrogen refuelling stations is shown in Figure 7.2.

In both sets of results, electricity is the largest cost component, by a significant margin. While the cost of electricity increases over time (nearly doubling by 2050), efficiency improvements to 2025 mean that the overall cost of hydrogen is static, or reduces slightly.

Thereafter, improvements are more incremental and the cost of electricity pushes overall hydrogen cost upwards. Annualised capital expenditure decreases significantly in both chains, primarily a function of lower capital unit cost through learning rates. The potential revenues from provision of grid balancing services have not been included in this analysis[5].

H2 Cost to HRS per component, Euro/kg, centralised chain

■ Electrolysis-Cent.   ■ Compression 1   ■ Compression 2   ■ Trailer

H2 Cost to HRS per component, Euro/kg, decentralised chain

■ Electrolysis-DeCent.   ■ Compression 1

H2 cost to HRS, Euro/kg, centralised chain

■ Annualised capex   ■ Annualised opex   ■ Annualised electricity & fuel

H2 cost to HRS, Euro/kg, decentralised chain

■ Annualised capex   ■ Annualised opex   ■ Annualised electricity & fuel

H2 refuelling

The hydrogen refuelling infrastructure can take the form of:

- Mobile refueller stations (50-100 kg/d). A mobile refueller station consists of high-pressure gaseous hydrogen storage (mounted on a truck trailer), a compressor (optional) and a dispenser. The hydrogen storage truck trailer is towed to and from hydrogen production facilities so that the hydrogen tanks can be refilled when needed. This allows refuelling sites to be added or changed rapidly as the need arises.

- Portable refueller stations with compressed gas truck trailer delivery (100 kg/d). Portable refueller stations could have a compressor and dispenser mounted into a separate trailer located at the station. Compressed hydrogen is delivered by truck in a tube trailer and connected to the compressor/dispenser system. These stations are portable in the sense that they could be moved to another site.

- Fixed 'brick and mortar' stations, in the same style as traditional petrol stations. Most current stations have liquid delivery and storage, and dispense fuel as compressed H2 although some may have on-site production through Steam Methane Reforming (SMR) or electrolysers.

Mobile refuellers may be seen as an attractive near-term option because of their lower capital cost and flexibility and in terms of addressing investors' concerns with regard to the utilisation of stations in the early years.

However, in the longer-term, it is likely that the trend will be toward building stations, in order to benefit from economies of scale as the market develops and to respond to consumer preference for familiar bricks and mortar fixed stations[3]. The analysis for this study focuses on permanent retail stations.

The question of how many stations to build, what type of stations, and where to locate them is critical in supporting the deployment of FCEVs as the lack of infrastructure is a key limiting factor in the uptake of FCEVs.

According to the latest annual assessment by H2stations.org[6], a website of Ludwig-Bölkow-Systemtechnik (LBST) and TÜV SÜD, twenty-seven new hydrogen refuelling stations opened throughout the world in 2012, bringing the total number of hydrogen refuelling stations in operation to 208 (March 2013), of which 80 are located in Europe, 76 in North America, three in South America and 49 in Asia. A further 104 are currently planned.

Studies have estimated possible density ratios for refuelling stations in Europe and the US. The results are presented in Table 14.10 in the Annex. This study assumes a density of 0.04 stations per vehicle in 2015; 0.004 in 2020; 0.0005 in 2025 and 0.0003 in the period 2030-2050.

The density ratio is higher at the beginning of the period because it is expected that upfront investment in stations will be needed ahead of FCEV uptake. To provide a sense-check of the final ratio, one can look at the density of petrol stations, which in Britain was 0.00025 in 2011.

An extensive literature review was undertaken in order to determine the likely unit costs of retail stations. Estimates vary, however, and a range of factors will influence the ultimate cost, such as station capacity; planning and site-preparation costs; the mix of dispensing options, and whether the station has on-site production of H2 or not.

For this study, a unit cost of €1.5m in 2010 has been used. A learning rate of 10 per cent was then applied to capital costs for every doubling of capacity to reflect improvements in technology as well as economies of scale. This is in line with McKinsey's evaluation of learning rates for hydrogen production technologies in "Portfolio of Powertrains for Europe"[7].

The operating costs of stations include the cost of purchased hydrogen, electricity and labour among others. A flat rate of 10 per cent of capital costs has been applied, and a 30-year lifetime is assumed. Cost estimates for hydrogen retail infrastructure are presented below.

Table 7.2

SULTAN SCENARIO	2010	2020	2030	2040	2050
Tech 2	-	8	738	2,872	8,014
Tech 3	-	416	2,235	6,604	15,748

Plug-in electric vehicles

This chapter presents the estimated costs of infrastructure related to the deployment of BEVs and PHEVs under various methods of charging. For simplification, PHEVs and BEVs are treated as one category, although it is likely that BEV infrastructure requirements will be higher than for PHEVs. The charging infrastructure is under development, as are the vehicles themselves. This results in a fast changing and fragmented market and much uncertainty about costs, infrastructure density and learning rates.

All assumptions were based on a thorough review of the existing literature on the subject and on discussions with the working group, which includes several companies at the forefront of electric vehicle and infrastructure deployment, such as Nissan and SSE.

A range of devices is available to charge electric vehicles. Table 7.3 presents the main types of charging points used in the cost model as well as the capital and operating cost assumptions.

Residential charging will occur in garages of single homes and multi-unit apartment complexes as well as at on-street residential spaces. While it is possible to use an existing outlet, with hardly any investment for residential charging, the model assumes that a wall-mounted point will be installed. Charging with household connections has relatively low implementation costs; poses few health hazards; and has little impact on the lifetime of batteries[8].

Standalone charging posts offer dedicated outlets that can be placed in private, semi-private (work) and public places, such as supermarkets and hotels.

Table 7.3

Technical features and costs of EV charging points

MAIN APPLICATION	CHARGING POINT FEATURES	POWER (KW)	CHARGE TIME	PRODUC-TION COST (€)	INSTALLA-TION COST (€)	OPERATING COST (AS % OF CAPITAL COST)
Residential	Wall box One plug Mode 1 or 2 User protection during charging Options for individual metering system	3kW	4-8 hours	400	1,000	1%
Workplace	Ground mounted Two plugs Choice of access control systems e.g. cards, keypad with code.	7kW	4-8 hours	800	1,000	5%
Car parks and street-side parking, shopping centers , hotels etc.	Ground mounted High resilience 2 plugs or more Different access options	22kW	1-2 hours	6,000	3,000	5%
Stations on highways	Fast charging Mode 3 and 4 2 plugs or more High resilience	43kW	30 min	22,000	25,000	5%

They are more expensive than home chargers, but allow faster charging, and communication between the vehicle and charging point makes smart charging possible. As a result, they are also more expensive than home chargers. Public charging points are more expensive due to requirements for higher resilience and security.

Finally, fast-charging is a necessary part of the infrastructure offer, allowing range extension through service station charging on long journeys. It addresses EV-owner's fear that the battery energy is limited ("range anxiety") and offers efficient charging solutions for commercial fleet operators, inter-city travelling and for heavy vehicles (buses and trucks). Fast-charging points are considerably more expensive than all other charging points. This is due to the fact that a fastcharger is in fact a high power AC/DC converter with communication and safety features
Charging a battery takes time. Even with fast-charging, this time is not insignificant for motorists who are accustomed to the speed of using petrol stations. One idea that is being explored and developed in various cities is that of battery-swapping stations. Battery-swapping reduces charging times at stations by replacing the entire battery instead of charging it.

There are advantages and disadvantages with battery-swapping over fast-charging. The obvious advantage is that it will be much faster than charging stations, with swap times of only about 3 minutes. Secondly, the batteries could be charged more slowly between uses, thus improving battery life. Thirdly, it would make it possible to separate the investment in the car from the investment in the battery, and this would make the upfront cost of an EV more competitive with that of a conventional car.

There are also a few disadvantages associated with battery-swapping. The main drawback is the high level of upfront investment required for the swapping station and, to a lesser extent, in the battery inventory.

The other problem is battery standardization. For battery-swapping to be viable, batteries need to be swappable i.e. many models need to share the same battery lay-out, otherwise each station will need several types of batteries to cater for all potential customers.

Although the business case for battery-swapping has so far proved challenging, this study includes a low level of battery-swapping in its infrastructure assumptions to take account of the possibility that the business model might prove viable in future.

The assumptions in Table 7.3 rely on our best knowledge of charging unit costs at present. In order to estimate costs to 2050, assumptions must be made about how these costs will evolve in the coming decades.

Research on learning rates for new technologies shows a wide range of figures, generally between 5 per cent and 20 per cent. It was agreed with the Working Group to apply a 10 per cent reduction in production costs for every doubling of capacity to reflect improvements in technology and economies of scale as production expands.

Data are too limited to make assumptions about how the learning rate itself might change over time, so a linear approach is taken. Installation costs are less affected by economies of scale, so no learning rate is applied.

Infrastructure density

Having established a set of credible vehicle technology trajectories with SULTAN, in this section we develop scenarios for the infrastructure that will be needed to service the EVs within the fleet. While we have considered the prospects for each type of charging point, it is also important to understand that the scenarios should not be read as projections or forecasts.

Given the level of uncertainty and limitations in the underlying data, they should only be seen as a range of possible future outcomes that can be used to explore the range of possible economic impacts.

There is a broad consensus that the majority of electric vehicle charging will take place at home. This is the preferred method of charging by consumers and it provides benefits for the energy system as a whole because:

- It is safe and does not adversely impact on the lifetime of the battery.

- It makes use of the long periods of time during which cars are parked at home.

- By charging during off-peak times, the consumer can benefit from lower cost energy tariffs.

- The off-peak charging of electric vehicles minimises demand on the local network, limiting the level of local network reinforcement and additional generating capacity that would be necessary if everyone charged during peak periods.

A recent survey of potential EV users by G4V[9] across eight European countries found that the large majority of respondents prefer home recharging.

The G4V study also refers to a survey performed within the MERGE project, which found that 56 per cent of cars are parked either in the garage or on the driveway on weekdays, rising to 72 per cent on weekends. Availability of private parking does not appear to pose a constraint.

Another survey by G4V found that the majority of the respondents in all countries have a private parking place at home or at work where they could charge their car. A recent survey of eight European countries by Uppsala University had similar results – around 80 per cent of car owners had access to a garage or designated parking area[10].

However, this average hides significant differences between rural and urban areas, with lower parking availability in the latter. This might have an impact on the initial uptake of EVs, as it is expected to occur first in cities.

Given the share of car travel in commuting, the availability of parking at many workplaces and the fact that cars remain parked at work for a significant amount of time, workplace charging is an important option to complement home charging. In addition, providing charging at work may increase confidence for users, in particular those who do commuting trips longer than 40-50 km[11].

Compared with public charging points, the utilisation rate of workplace chargers can be accurately predicted. It will be easier to guarantee a parking spot with recharging facilities without losing revenue, and this is crucial from the investor's perspective. However, it is unclear what rate of EV deployment is necessary before there is a compelling business case for installing workplace charging.

Despite this uncertainty, the 3 infrastructure scenarios allow us to explore different approaches where workplace charging plays a greater or lesser role in the provision of infrastructure charging.

Public recharging infrastructure for EVs is currently very limited, although a few cities have installed substantial infrastructure as part of pilot projects.

While it is likely that car owners will mostly charge their vehicles at home and at their workplace, and only incidentally in public places, some experts point out that a publicly accessible infrastructure is crucial for promoting electric cars, because it is needed to increase the daily driving range of EVs, along with motorists' confidence and flexibility.[12]

SCENARIO	KEY FEATURES	RATIONALE FOR THE SCENARIO
Low cost deployment	• Home and work charging dominate and public charging only plays a minimal role. • Home charging will deploy in line with EVs and PHEVs. • Convenience and fast public charging involves some upfront investment although this will tail off over time. • Workplace charging is assumed to be more of a reactive offer i.e. responding rather than anticipating deployment. • Battery swap: the density is expected to halve from 2030 onwards as a result of extended driving range.	• It provides the opportunity to question the a priori acceptance that significant public investment will be needed without clear underlying evidence supporting this statement. • It is the most affordable option. • Scenarios which assume large shares of public infrastructure will require significant public and market impetus. This scenario explores a future where this impetus never fully happens. This may be because of a lack of political will, a lack of compatibility, or a lack of public finance allocated to this issue. • This approach (where home and work dominate) was used by the ITF and the General au Développement Durable in recent studies.
Grazing	• Home charging is the main mode of charging but over time its importance diminishes as fewer EV owners have access to private parking. • Convenience public infrastructure plays an important role. Heavy investment in the early part of the period is involved in order to build the network's critical mass and consumers' acceptance. • Some significant upfront investment in fast-charging is also included. • Battery-swapping and work chargers follow the same profile as under Scenario 1.	• This scenario explores new charging and ownership behaviours based on a 'grazing'approach to charging: instead of completely charging the battery (as one would fill a tank), consumers adapt their mode of consumption to the specific features of EVs and regularly top off their battery by charging them in bursts as and when they are parked, for instance at the movies, at the supermarket, at the gym. • This scenario reflects a future in which short driving distances dominate and in which compatibility issues have been addressed.
High technology	• Same assumptions as Scenario 2 for home, work and convenience charging. • Higher density assumptions for fast-charging and battery-swapping	• This scenario reflects the need to address EV owners' range anxiety. The inability to address consumers' large (albeit hardly utilised) range requirement is, after capital cost, the most frequently mentioned barrier to EV adoption. At this time it seems unlikely that battery performance improvements and cost reductions sufficient to provide this range will occur while approaching any reasonable level of affordability. Providing battery-swapping and faster charging is one response to this limitation of electric vehicles. • This scenario also reflects more ambitious public and market engagement in the deployment of infrastructure.

Changing models of car ownership might also have an impact. The deployment of EVs could lead to new car rental or car sharing solutions which in turn would rely more on a 'grazing' model of charging (using multiple public charging points for short periods of time, rather than relying on a main one for a long period of time).

Infrastructure scenarios

Drawing from the data and intelligence gathered to date both from the Working Group and existing research, we have developed three infrastructure development scenarios:

Scenario 1: Low cost
Scenario 2: Grazing
Scenario 3: High coverage

The infrastructure scenarios in Table 7.4 help to reflect the dynamic changes in infrastructure provision over time. They enable sensitivity analysis of the cost estimates as well as a sense of how different approaches (with more or less public infrastructure) may impact on costs. The underlying density assumptions are provided in tables 14.11, 14.12 and 14.13 of the Annex.

EV infrastructure cost

As well as the assumptions in terms of unit cost, learning rates and density presented in the previous sections, the cost analysis uses the following assumptions: a lifetime of 20 years for residential, home and convenience charging points and 30 years for fast-charging points and battery swap stations[13]. Borrowing rates of 5 per cent and 10 per cent are used to calculate the present value of cost estimates.

A reality-check was also undertaken to make sure that vehicle scenarios that assumed high deployment of EVs were matched with infrastructure scenarios that were capable of servicing them. For example, the Tech 2 scenario could be accommodated by all three charging scenarios, but the more rapid deployment of EVs in the Tech 3 vehicle scenario could only be accommodated by the "High Coverage" infrastructure scenario presented in Table 7.4.

Total infrastructure cost-estimates are presented in Table 7.5. The scenarios demonstrate the range of possible futures with regards to infrastructure costs for electric vehicles.

Table 7.5

Total infrastructure cost estimates for EVs (2010 real terms)

SULTAN SCENARIO	2015		2020		2030		2050	
	No. vehi-cles (000)	Costs (€m)	No. vehi-cles (000)	Costs (€m)	No. vehi-cles (000)	Costs (€m)	No. vehi-cles (000)	Costs (€m)
Tech 2 - Low cost	1,7	0,19	1445	164,35	35289	4.251,35	174484	25.616,60
Tech 2 - Grazing	1,7	0,44	1445	1.282,23	35289	8.911,91	174484	48.387,65
Tech 2 - High tech	1,7	0,44	1445	1.282,23	35289	9.642,21	174484	58.492,90
Tech 3 - Grazing	253	65,15	5598	5.130,84	81948	22.816,59	197263	65.783,38
Tech 3 - High tech	253	65,15	5598	5.130,84	81948	24.664,64	197263	79.966,32

The estimates do not reflect the likely differences in density requirements between PHEVs and BEVs; the variations in the number of outlets which may be provided at public or workplace charging points, or the likely large differences across countries, regions, urban and rural areas.

As well as the level of funding required, it is important to consider how the funding will be paid for over its lifetime. This is an important consideration in a macroeconomic assessment since it affects the distribution of income across the economy.

It is expected that the funding will differ widely depending on the type of infrastructure considered. As a result of discussions with industry, the following business models were assumed for the macroeconomic modelling.

Home infrastructure will be paid for as part of the vehicle purchase, so that EV owners will finance the installation of home charging stations at the time of purchasing the vehicle. Work-based charging points will be paid for by the businesses investing in EVs. Convenience public infrastructure is assumed to be part financed by government in the short-term. Following the example of the UK[14], public infrastructure projects are assumed to receive 50 per cent funding in the period to 2020.

After that, such projects should become commercially viable. It is expected that shopping centre charging points will be installed at the shopping centres' own expense to encourage visits from customers with EVs.
Public infrastructure is likely to be co-funded by electricity suppliers who will benefit from the additional electricity sales generated.

Fast-charging stations are expected to be funded through a combination of margins on electricity sales and margins on retail sales made at the stations; this is particularly relevant for fast-charging stations (compared to the current business model for petrol stations) since it will take around 30 minutes to re-charge an EV at a fast-charging station and so there is more time to offer retail options to consumers.

For EVs the infrastructure associated with the production and distribution of electricity is considered separately in the economic modelling, but it is financed through the increased sales of electricity both on the wholesale market (to fund the generation/production cost) and also through margins in the retail market to fund improvements to the distribution grid.

Since hydrogen vehicles follow a more traditional usage pattern, i.e. vehicles are re-fuelled at re-fuelling stations and not at home or work, the cost of the infrastructure will be funded through the sales of hydrogen, such that the final price for hydrogen includes:

• The electricity input cost to the electrolysis process (centralised and decentralised)

• The capital cost of the production facilities

• The distribution cost (fleets of trucks to distribute the hydrogen)

• The capital cost of the refuelling stations

This is similar to the traditional model for petrol and diesel sales.

Economic impact

The different infrastructure scenarios were modelled for each of the selected SULTAN scenarios to provide an insight into the potential macroeconomic impact of possible infrastructure pathways.

The macroeconomic impact of the infrastructure deployment depends on two competing factors:

• The impact of the increasing costs of higher infrastructure provision on consumers, which will serve to reduce real incomes and worsen European price competitiveness.

• The impact on the supply chain that arises from building the infrastructure, which will serve to increase employment and real incomes.

The modelling results suggest that more infrastructure investment would be better for the economy. In other words, the supply chain impact is larger than the impact of the cost of provision.

This is because infrastructure investment has a much larger associated supply chain in Europe than alternative expenditure. Fig. 7.3 shows that the differences between the infrastructure scenarios are more pronounced in the Tech 3 scenario, because of the much greater EV vehicle deployment. There is also more variation in the impact of infrastructure costs by 2050 because the deployment rates are linked to the rising number of EVs and FCEVs in the vehicle stock.

Since the limits to infrastructure funding will be guided by the possible direct returns on capital expenditure (rather than a notion of improving GDP) the conclusion of this analysis is that increasing infrastructure investment up to the optimistic deployment levels illustrated by the third deployment scenario will not negatively impact on GDP.

This is a particularly important finding for EV infrastructure, not only because of the scale of investment that might be required, but also because there might be an important role for government to play to provide the infrastructure in the short-term to encourage the take-up of EVs.

GDP impact of Low Cost, Grazing and High Coverage infrastructure investment scenarios for each deployment scenario in 2030 and 2050 (compared to the reference scenario) Source: E3ME
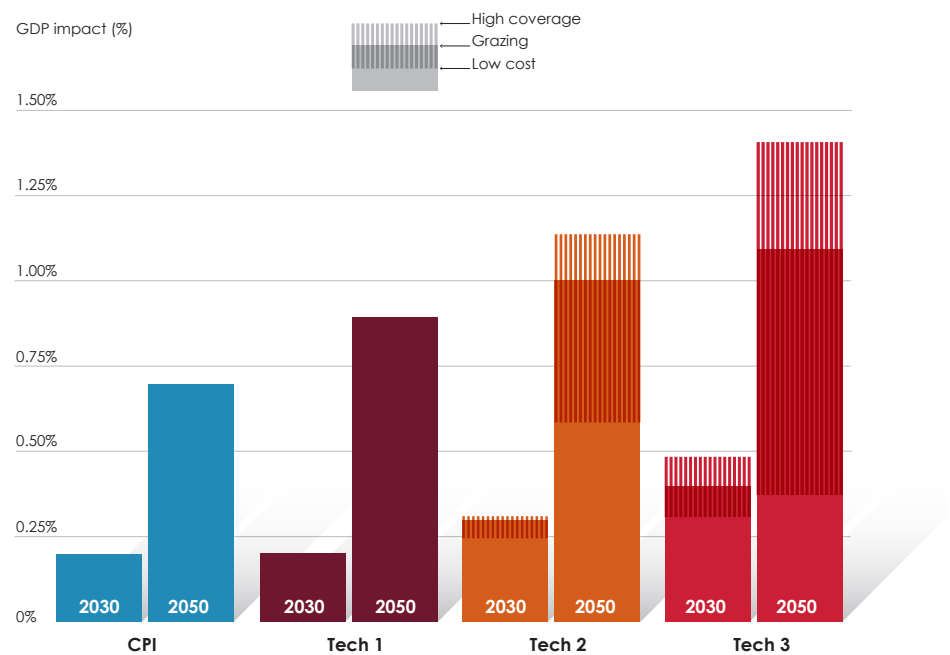
8 Fuel costs

The aim of this chapter is to examine the impact of technology deployment in the four scenarios and Reference scenario on fuel costs, both for motorists and for the EU as a whole.

Methodology

In the scenarios, the average fuel prices reflect the costs of the different fuels required to power the future possible vehicle stocks: petrol, diesel, hydrogen and electricity. The oil price assumptions are based on the central assumptions made by the IEA. By 2030 real oil prices reach €105 (2010 real terms) per barrel, and then €117 per barrel by 2050. The price of electricity is an important determinant of the relative economic impact of the Tech 2 and 3 scenarios, as high electricity prices would inevitably increase costs for PHEV and EV users relative to users of other types of vehicle (and vice versa). The same applies to the price of hydrogen for FCEVs.

The electricity price paid by EV users in each of the scenarios is dependent on two key assumptions: an 80 per cent renewables grid is achieved by 2050, and the final price of electricity paid by EV users is the same as that paid by households (there are no additional taxes beyond those levied on domestic electricity consumption).

The future technology mix of the power sector in the EU is largely uncertain and heavily dependent on future policy decisions. However, there is considerable potential for a highly decarbonised electricity grid. The EU is currently on track to reach 2020 renewables targets[1] and on-going climate negotiations suggest that stricter decarbonisation targets in the future will be agreed. This partly explains the rationale for modelling scenarios in which 80 per cent of electricity in the EU in 2050 is generated from renewable sources.

An 80 per cent share of renewables in the power sector is at the high end of most estimates; the primary reason for modelling a grid with high renewables content was in order to obtain a fully decarbonised vehicle stock.

However, even if this assumption were relaxed, and the current share of renewables in the grid were maintained, the scenarios with high vehicle technology would still have environmental benefits.

Fig. 8.1

Capacity mix and total generation for Europe
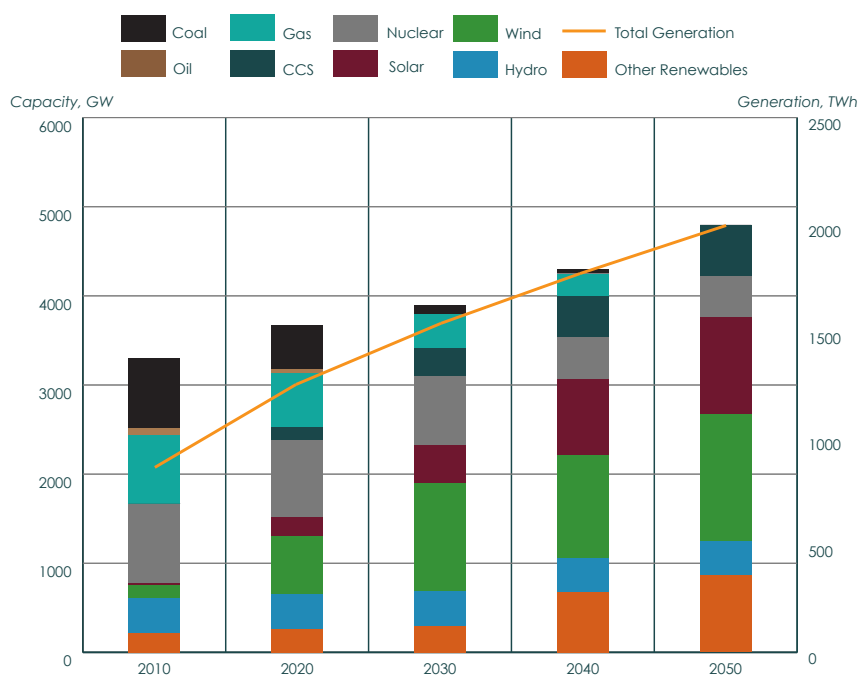
Electric vehicles using the average EU electricity mix are already lower carbon than the conventional ICE, as the power sector already contains some renewables and is more efficient at converting fossil fuels into energy than an ICE. Therefore, total emissions per km travelled are already lower for EVs than for ICE vehicles.

The same grid assumptions are maintained in all of the scenarios in order to isolate the environmental impact of the varying vehicle technologies. The impact of these technologies under different power sector assumptions is not considered.

The implications of a high- renewables grid are two-fold. Electricity prices are higher, due to the higher lifetime costs (on current estimates) of renewable technologies compared to gas and coal-fired power generation. And an increase in electricity consumption because of the increasing number of electric vehicles, will have a diminishing impact on total emissions over time.

With regard to electricity prices, as a consequence of the high renewable content in the grid and the relative cost of renewable technologies compared to coal and gas- fired power generation, electricity prices (and

therefore the cost to owners of EVs) will be higher than if the scenarios were run using the current shares of power sector technologies. This may slightly reduce the size of the positive economic impact of the high technology scenarios, as the higher costs would translate to reduced consumer surplus.

The shares of each technology to reach the 80 per cent decarbonised grid are based on the ECF Energy Roadmap, but updated for revised demand projection (Fig. 8.1).

In the more radical Tech 2 and Tech 3 scenarios, FCEVs, which are reliant on hydrogen as a fuel source, are deployed in the vehicle stock. There are a number of potential methods for producing hydrogen, but since this study focuses on decarbonising light duty vehicles, we assume that all hydrogen is produced by electrolysis and therefore requires electricity as an input into the process.

As discussed in the infrastructure chapter, in order to quantify the impact of an increase in the supply of hydrogen, we modelled a hydrogen system which contained 50 per cent centralised electrolysis and 50 per cent decentralised electrolysis.

Fig. 8.2

Annual fuel cost savings for motorists under the four scenarios modelled, as compared to the Reference Case. (including tax, duties) (IEA central case fuel costs) Source: SULTAN

2030

2050
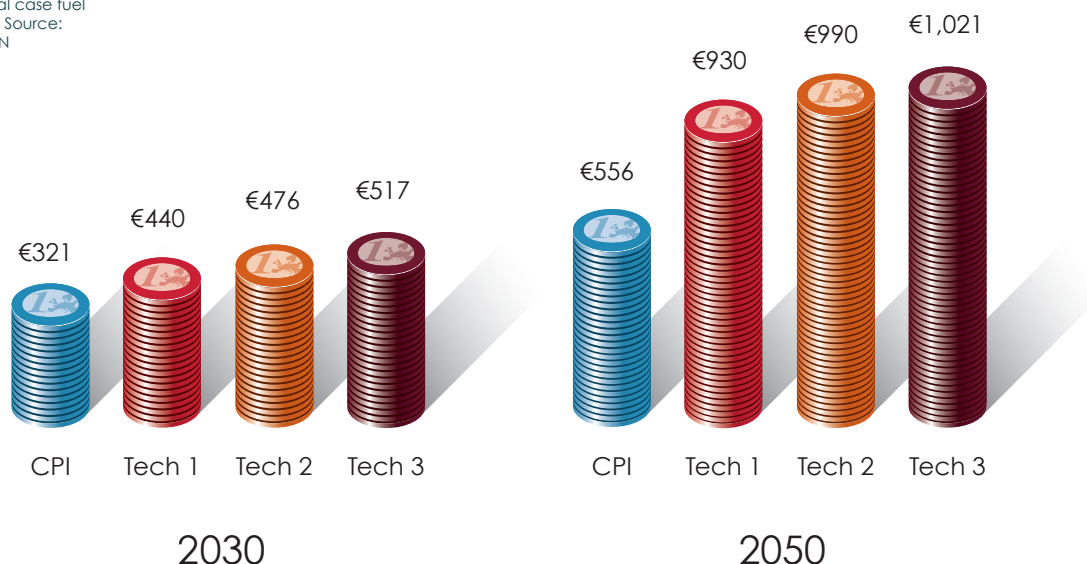
Under a centralised system, we assumed that the hydrogen production plant would be attached to an wind farm. As it made use of the electricity directly at the source of production, the price followed the price of electricity from wind, but was slightly higher due to margins and distribution costs. Under a decentralised system, electricity was tapped from the grid and followed the price paid by large industrial electricity consumers.

Results

The average motorist's fuel bill is significantly reduced in both the Current Policy Initiatives Scenario and the Tech 1-3 scenarios, when compared with the Reference scenario where technology improvements are frozen at current levels.

As an illustration of reduced spending on fuel, in the Current Policy Initiatives scenario, the owner of the average new car in 2020 will spend around €400 less on fuel each year than the owner of the average 2010-manufactured car. This reduces to around €320 per car when compared to the Reference scenario, which also factors in some efficiency improvement due to fleet renewal (Fig. 8.2). This is based on using constant fuel prices and an assumption of 12,000 km driven annually, which is close to the EU average. In reality, new cars are driven longer distances than older cars, so the annual savings will likely be higher initially.

However, some of those gains will also be offset because motorists choose to make use of the improved efficiency by driving further (the direct rebound effect is discussed at the end of this chapter). Nevertheless, these examples serves to illustrate the impact on fuel costs for motorists.

CO_2 standards only apply to new cars and vans sold. Market penetration of new technologies takes time, and there is therefore a time-lag before the whole vehicle fleet reaches the same level of performance as the newest vehicles. As

Evolution of
EU fuel bill
(cars only) in
Reference
scenario
(excluding taxes)
Source: SULTAN

€124bn   +18   +69   -33   €178bn   +15   +33   -23   €203bn   +12   +26   -12   €229bn

2010   2020   2030   2040

Impact of activity   Impact of price   Impact of technology
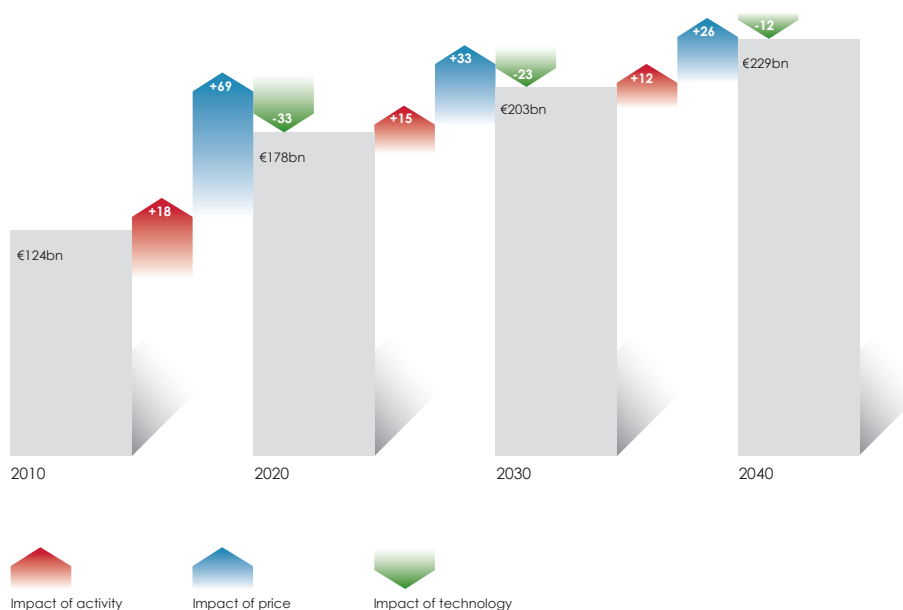
an example, fuel-savings as an average across the whole EU fleet in 2020 will be lower than the fuel savings for the new vehicles in that year designed to comply with the 2020 targets.

Not until 2032, are the full savings achieved from the 2020 efficiency targets. By 2030, the 2020 standards have fed through to most of the fleet, and at this point, the average fuel savings in the Current Policy Initiatives Scenario for cars reach around €320 per vehicle in the EU, compared to the Reference scenario. (Fig. 8.2)

Under the Tech scenarios, the savings reach the range of €440 - €520 per vehicle, compared to the Reference scenario. The savings for these three technology scenarios are even greater by 2050.

At the EU level, the savings are substantial. A step-change in fuel costs is observed after 2015, as the vehicle fleet switches from an annual rate of improvement of around 2 per cent a year to

a rate of around 4 per cent annual improvement to reach the EU's 2020 efficiency goals. The four scenarios represent various annual rates of improvement after 2020.

Examining the impact at a societal level requires excluding fuel taxes, duties and VAT. The EU-wide total annual fuel bill for all motorists is reduced by €58 billion in 2030 under the Current Policy Initiatives scenario (excluding taxes and duties) versus the Reference scenario. Corresponding fuel savings in the Tech 1-3 scenarios reach €80-83 billion in 2030, and €180-190 billion in 2050, compared to the Reference scenario.

Fig. 8.3 shows how Europe's fuel bill would increase if technology were frozen at current levels (Reference scenario). In order to better understand the different elements at work, the change across each decade is broken down to its three components.

Fig. 8.4

Evolution of EU fuel bill (cars only) in Tech 1 scenario (excluding taxes)
Source: SULTAN
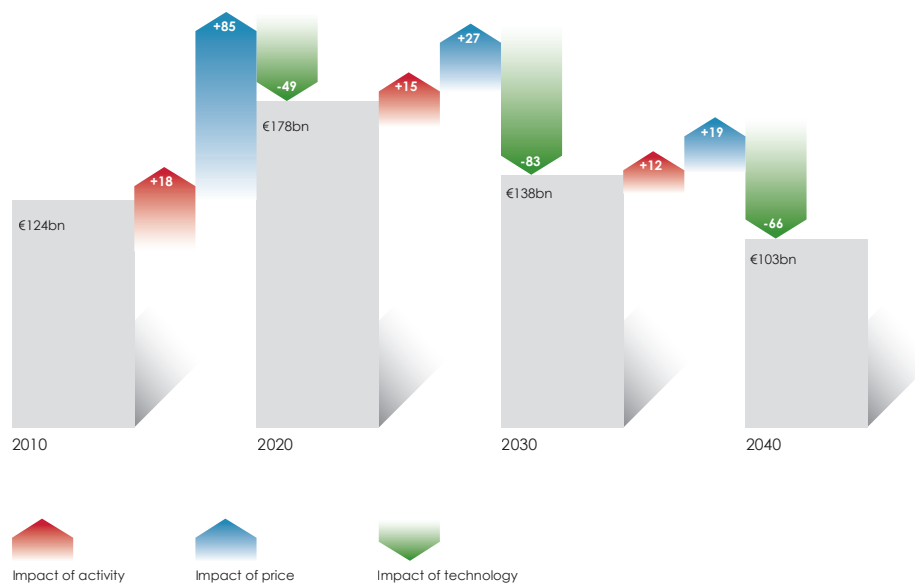
Activity increases 18 per cent in the first decade due to changes such as increased car ownership in Eastern Europe, and increases more moderately in the decade after 2020. The fuel price component also increases steeply in the decade to 2020, but moderates somewhat, in line with the IEA central case that has been used in this study.

Vehicle efficiency has the opposite effect, moderating the rise in the total fuel bill, even in the Reference scenario, where technology is frozen at the current level of 135 g/km. This results from renewal of the car and van fleet and an increasing proportion of the fleet reaching the 135 g/km level. This is combined with a continued shift towards more efficient diesel engines. However, after 2030 these effects are small, and as a result the total fuel bill is almost doubled.

Fig. 8.4 illustrates how Europe's fuel bill would evolve with increased vehicle efficiency in the Tech 1 scenario.

Activity trends remain the same as in the Reference scenario. Efficiency increases dramatically to meet the 95 g/km goal in 2020, with a particularly large impact in the following decade as fleet renewal takes place. This has an impact on the size of the fuel price component.

While the contribution of international oil prices remains the same as in the Reference scenario, the absolute impact of per-unit price increases is gradually diminished as a result of the steadily reducing volume of consumption.

Fig. 8.5 shows the evolution of the EU fuel bill in the Tech 2 scenario. The activity component is the same as in the other scenarios, while the efficiency component is substantially larger. The energy price component is more complicated, due to the inclusion of hydrogen and electricity from 2020 onwards.

Fig. 8.5

Evolution of EU fuel bill (cars only) in Tech 2 scenario (excluding taxes)
Source: SULTAN

€124bn +18 +85 -50 €177bn +15 +36 -95 €136bn +12 +66 -108 €106bn

2010   2020   2030   2040

Impact of activity   Impact of price   Impact of technology
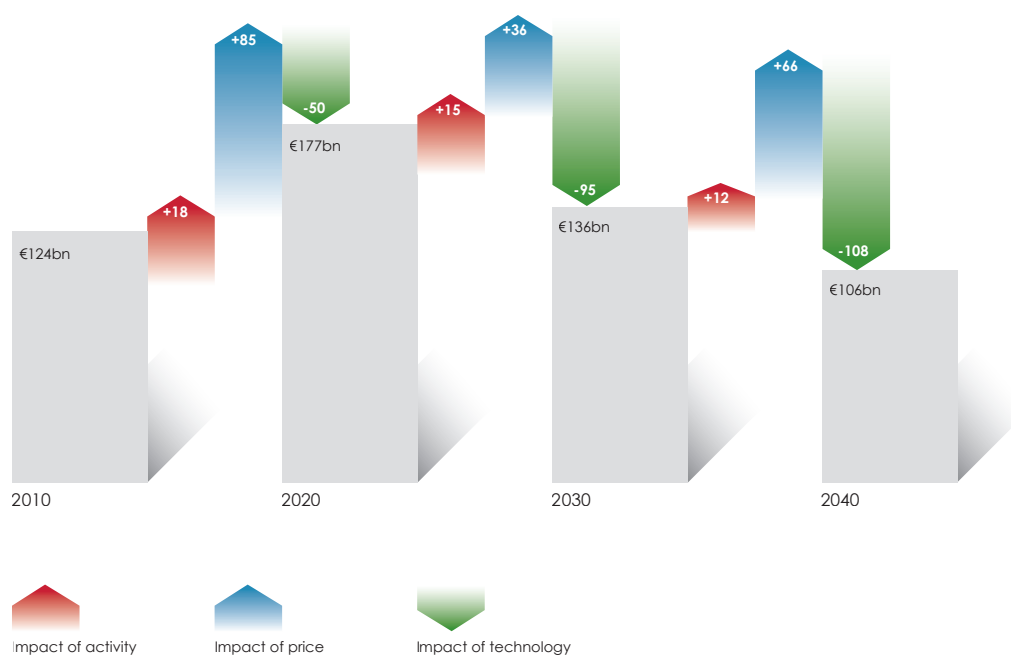
While the unit price of these energy sources is significantly higher than for fossil-fuels, the relative efficiency of FCEVs and EVs, compared to ICE vehicles, means that less units of energy are required per kilometre travelled.

Sensitivity analysis

High and low fossil-fuel price sensitivities were also considered in this analysis. This enabled the robustness of the results to be tested against uncertainty around future fossil-fuel prices. A range of +/- 25 per cent in oil prices by 2030 was used in these scenarios, and +/- 50 per cent in oil prices by 2050.

The aim of this exercise is not to predict the impact of a rather arbitrary permanent change in international energy prices on the European economy, but to identify whether or not the results are specific to a particular set of assumptions.

The results are to some extent dependent on energy price assumptions, with the positive economic impacts becoming larger if prices are higher, and conversely, smaller if prices are lower (Fig. 8.7). This makes intuitive sense, because the energy savings from fuel-efficient vehicles become more valuable if energy prices are higher.

If fossil-fuel prices are high then not only does the value of European imports increase relative to exports, but higher prices in the economy also reduce real incomes. In a future world of high fossil-fuel prices, the transition to more efficient vehicles becomes ever more important. Reduced fuel consumption has an inflated economic impact because imports are reduced to a greater extent relative to the Reference scenario, but also because real savings to consumers are greater, increasing their relative spending power.

Fig. 8.6

Evolution of EU fuel bill (cars only) in Tech 3 scenario (excluding taxes)
Source: SULTAN
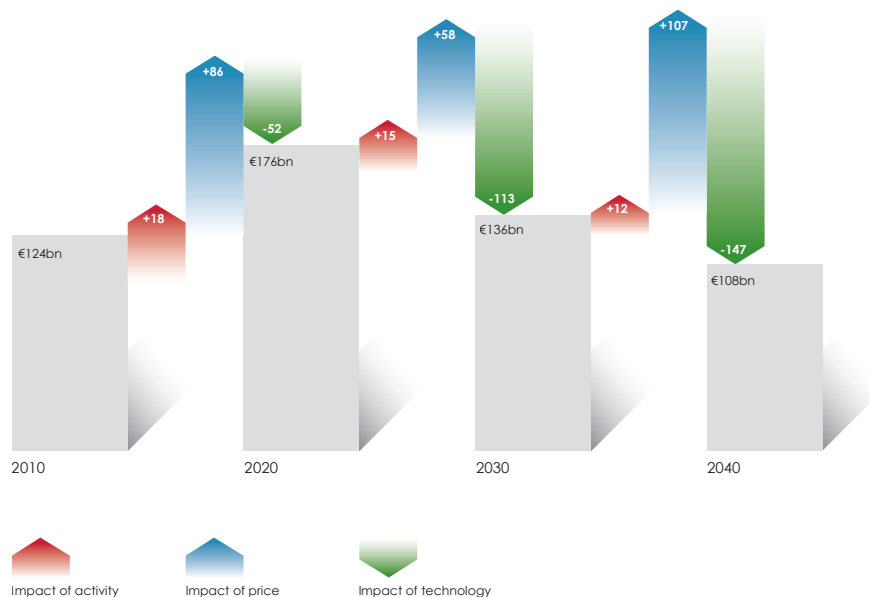
The converse is equally true. In a future world of low fossil-fuel prices, the transition to more efficient vehicles becomes less important, from a macroeconomic perspective. However, it should be noted that even in a world with oil prices at $88 per barrel by 2050, the GDP impact of the Tech 2 scenario remains positive at 0.94 per cent and over 2 million jobs are created compared to the counterfactual of continued investment in an inefficient vehicle stock. We would also expect a fossil-fuel price shock to have a smaller economic impact as we move to scenarios with a more fuel-efficient vehicle stock. A positive or negative oil price shock will not have a large impact if not much oil is being consumed. This has important implications for maintaining a stable economy where consumers and governments are better able to plan for the future.

However, oil and gas are used for purposes other than road passenger transport, such as heating, air transport and freight. High fossil fuel prices will therefore still have a negative effect on the economy when compared to an equivalent scenario with lower fossil-fuel prices, even in cases where there is a high percentage of electric and fuel-cell electric vehicles in the total car and van stock. In fact, the impact of a fuel price shock on other fuel users is likely to be higher than that for the road transport sector, as high taxes on diesel and petrol softens the impact of any oil price shocks.

This sensitivity analysis shows reductions to the average annual fuel bill of car owners are expected to range from €269 - €379 per car for the Current Policy Initiatives scenario by 2030, and €355 - €738 per car by 2050. For the Tech 1 scenario the corresponding savings are €367 - €517 per car by 2030, and €595 – €1,236 by 2050. Savings for the Tech 2 and Tech 3 scenarios are even greater, reaching as much as €1,461 by 2050 for the Tech 3 scenario under high oil prices.

At an EU-wide level in 2030, these savings would be equivalent to reductions in the total fuel bill (excluding taxes and duties) in the order of €39 - €65 billion in the Current Policy Initiatives scenario, €54 - €89 billion in the Tech 1 scenario and up to €47 - €99 billion in the Tech 3 scenario.

Fig. 8.7

Economic impact of decarbonising vehicle stock under different fossil fuel price assumptions
Source:E3ME

GDP impact (%)

High
Central
Low

1.5%

1.0%

0.50%

0%

CPI   Tech 1   Tech 2   Tech 3
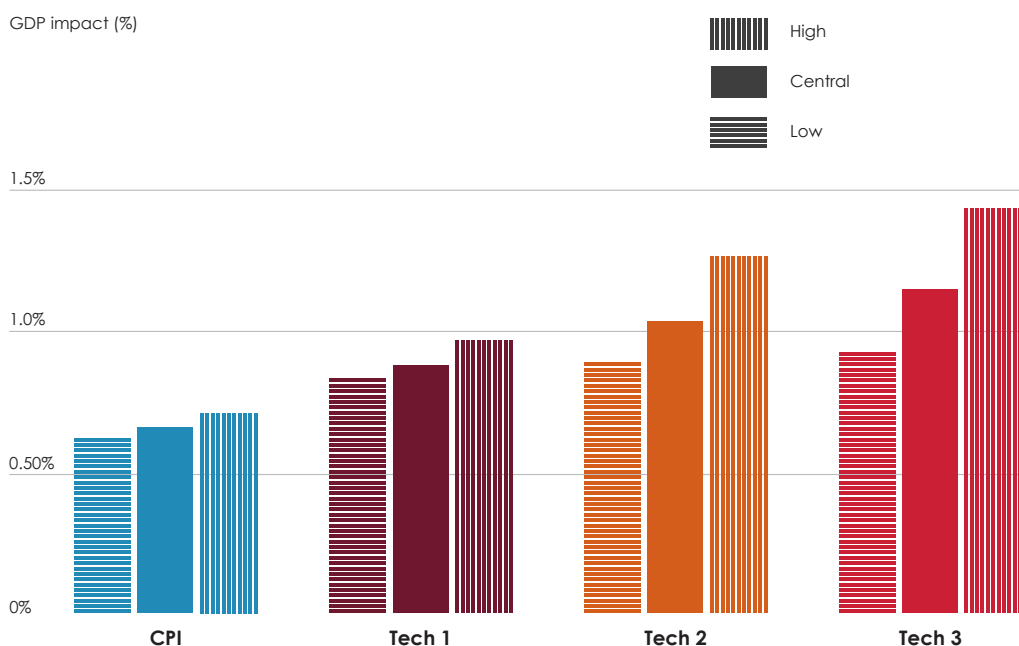
Rebound effects

The fuel savings in the Current Policy Initiatives and Tech 1-3 scenarios could be reduced if there were rebound effects. This could reduce the economic impacts of the transition.

The rebound effect can be separated into two effects:

- the direct rebound effect
- the indirect rebound effect

The direct rebound effect comes about when consumers, following an energy saving, spend the monetary savings by increasing the use of the more efficient product or service.

The typical example in the literature would be that as a result of energy savings from insulation measures installed in a home, the household increases the thermostat setting to achieve a greater level of comfort for the same cost as previously. In personal transport, the purchase of a more efficient vehicle might lead to direct rebound effects if the vehicle were driven further.

This might happen for two reasons:

- the income effect: the net saving on the fuel bill increases the disposable income of the vehicle owner, allowing them to do more, which might well require driving to get there.

- the price effect: since the running cost of a vehicle has become less

There is considerable evidence of a rebound effect in personal transport. In a review of the literature, Sorrel (2009)[1] states that there is a high degree of confidence that the direct rebound effect is between 10 per cent and 30 per cent in OECD countries.

The indirect rebound effect occurs when consumers, following an energy saving, spend their monetary savings on goods and services which require energy as an input. A typical example from the literature would be that as a result of an energy saving in the home, consumers have enough extra disposable income to take an additional holiday abroad. The holiday requires flights to and from the destination which require energy. Depending on the energy required, the effect might wholly outweigh the initial saving. The economic analysis presented in this report includes the indirect rebound effect.

Since the direct rebound effect is not captured directly in the economic modelling, we have undertaken a sensitivity analysis, whereby a 30 per cent direct rebound effect occurs in the Tech 1 scenario. The direct rebound effect reduces the GDP impact from 0.9 per cent to 0.4 per cent by 2050, but does not lead to negative economic impacts.

A direct rebound effect in the Tech 2 and Tech 3 scenarios would have less impact on the economy, since by 2050, the fuels consumed are hydrogen and electricity which are produced in Europe.

9 Economic Impacts

This chapter explores the macroeconomic consequences of different futures that are envisaged in the four scenarios and the Reference scenario.

The analysis uses the assumption that Europe's future share of automotive manufacturing follows historic trends. This assumption largely depends on the competitive position of EU manufacturers in global markets and the degree to which non-EU brands choose to import the vehicles they sell here or manufacture them locally.

The European Commission-led initiative CARS21 has extensively examined the issue of competitiveness of the EU auto industry. In June 2012, CARS21 published its latest report, representing the consensual view of the automotive stakeholders involved, including the following observations:

"Technology leadership has clearly remained the key competitive factor of the European industry on the global scale…. The key areas of competitive advantage are safety technology, environmental performance (strongly linked to the ambitious regulatory framework) as well as performance in design, style and comfort."

With climate change one of the main challenges faced by humanity over the next decades, environmental regulations are expected to increase across the world. As shown in Fig. 3.1, an increasing number of countries globally are starting to enact fuel-efficiency or CO_2 standards for vehicles, including important emerging economies. A recent survey of executives in the automotive industry by KPMG[1] found that the majority expected environmental restrictions to increase in all BRIC regions. Competitiveness is clearly an important economic factor, and will be examined in more detail in a later phase of the project.

The economic analysis starts by defining the relevant characteristics of the European economy. Then it describes how the costs of vehicle ownership have macroeconomic consequences. Finally, it describes the different macroeconomic results in the five scenarios as modelled in the pan-European analysis in E3ME.

Europe is a major oil importer. Nearly 4 billion barrels of oil were imported into the European Union in 2012 at a value of €385 billion[2]. Crude oil imports are unevenly distributed across the EU, depending on the refining capacity of member states (Fig. 9.1)

Fig. 9.1

Annual crude oil imports to the EU (includes imports for refining).
Source: COMEXT, Eurostat

Ireland 2.57mt
United Kingdom 53.98mt
The Netherlands 79.92mt
Denmark 3.01mt
Sweden 15.83mt
Finland 11.09mt
Estonia 0.00mt
Latvia 0.00mt
Lithuania 8.52mt
Belgium 3.80mt
Germany 74.89mt
Luxembourg 0.00mt
Poland 24.62mt
Czech Republic 7.01mt
Slovakia 5.35mt
France 52.72mt
Austria 7.42mt
Slovenia 0.00mt
Hungary 5.49mt
Romania 5.13mt
Italy 68.81mt
Spain 58.18mt
Portugal 11.46mt
Bulgaria 5.82mt
Greece 19.92mt
Malta 0.00mt
Cyprus 0.00mt
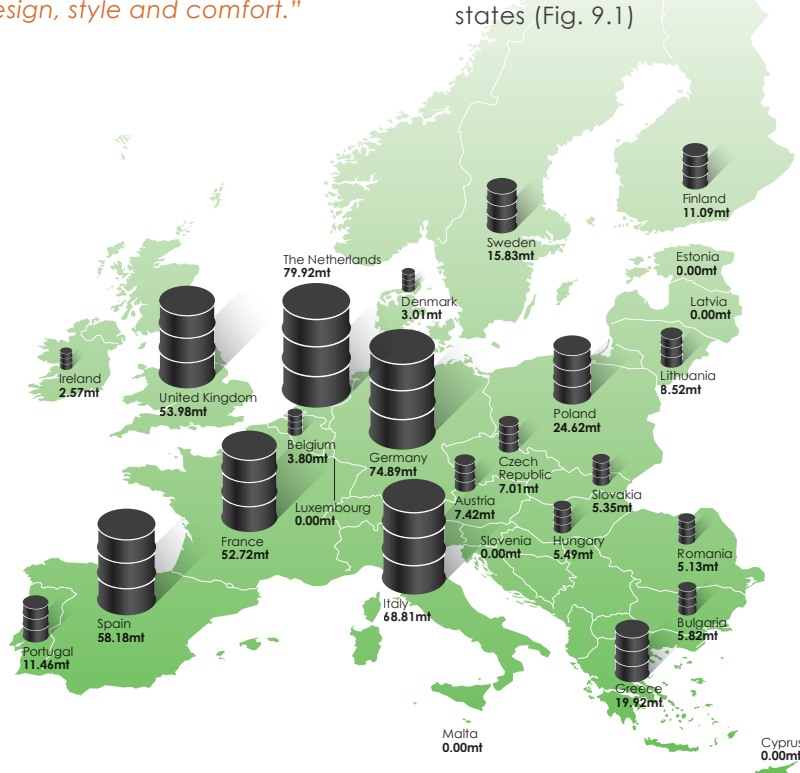
Refined petroleum products, such as petrol and diesel, are traded between European member states and so the cost of oil imports is distributed across the EU.

It should be noted that not all crude oil goes to petrol and diesel for cars and vans. A substantial amount is used for freight, aviation, shipping (diesel and heavy oil), industrial processes, household oil-based heating systems, and also for non-energy uses, such as industrial lubricants and as a feedstock for plastics. However, energy demand from cars and vans does account for around 40-45 per cent of final energy demand for oil.

More than for most other goods and services bought by Europeans, the value chain associated with petrol and diesel:

1. Is located outside of Europe; and

2. Has a low intensity of labour

The combination of these two characteristics means that a large proportion of the value-chain is lost, rather than retained within the European economy. On average, Europeans spend a total of €387 million per day on petrol and diesel, before tax. This translates to around €536 each year for an average vehicle[3] before tax, of which a substantial proportion leaves the EU in return for crude oil imports.

There is a notional argument that much of this oil-related revenue that accrues to crude oil exporters is recycled back into the European economy, so called petro-dollar recycling. Undoubtedly, some of the money will be spent on European goods and services. For example Norway supplies 12 per cent of EU oil imports and due to its proximity to Europe and its inclusion in the free trading area, clearly some of the revenue will return to the EU.

However, for many oil exporting regions, especially those with state owned oil reserves, the revenues from the crude oil fund are retained in wealth funds and are often invested in their domestic economies.

Fig. 9.2

Top 10 exporters of oil to the EU and their relative share of EU exports. Source: COMEXT, Eurostat
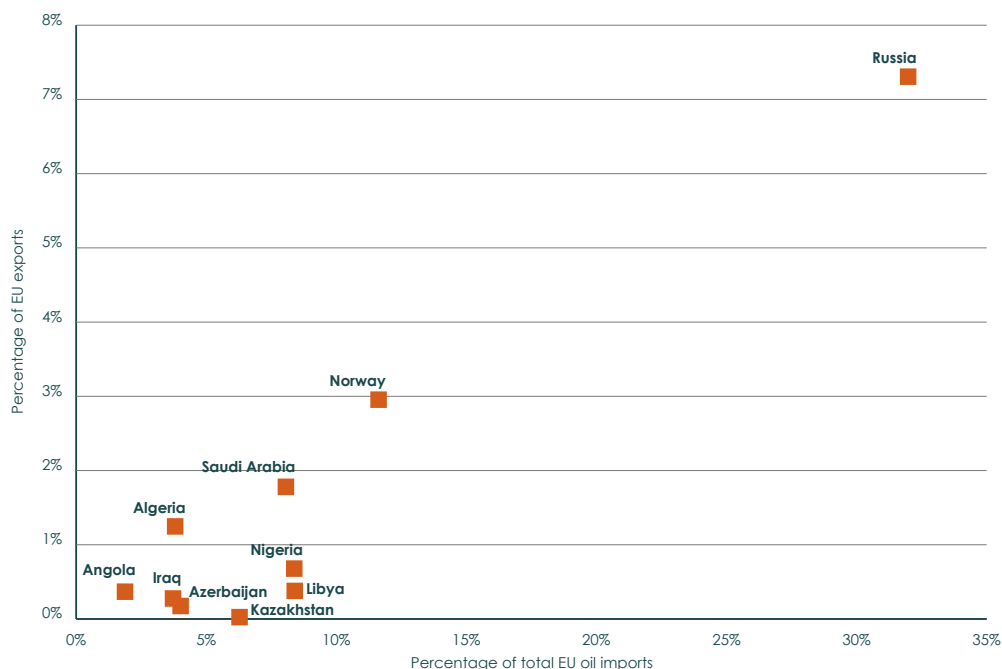
The top ten countries exporting crude oil to Europe in 2012 are shown in Fig. 9.2, plotted against their share of Europe's export market.

These ten countries account for 15 per cent of European exports. However, considering that not all the income generated by oil exporting countries accrues from oil revenue, especially for Norway and Russia (where oil exports account for 11 per cent and 8 per cent of GDP); and that very little of what is consumed within these economies is sourced from Europe and that taken together these countries account for such a small proportion of EU exports (excluding Russia and Norway the figure is 4 per cent of exports for the remaining eight countries), then the evidence suggests that the secondary impact of 'petro-dollar' recycling will be small.

The cost of oil is expected to rise. In its central case (as used throughout this analysis), the IEA projects that crude oil prices will increase in real terms from €59 per barrel in 2010, to €105 per barrel by 2030 and then perhaps as much as €117 per barrel by 2050, if this trend is projected forwards.

This represents a continuation of recent trends. According to the COMEXT database provided by Eurostat, the value of European oil imports has increased from €130 billion in 2000 to €350 billion in 2012 (in 2010 prices).

Even if Europe were able to maintain domestic extraction rates, the value of imports would rise to €590 billion by 2030 and further still to €705 billion by 2050 based on price increases alone (in 2010 prices). Without reductions in the demand for oil, imports are also likely to increase in volume as domestic production draws down Europe's known oil reserves.

In contrast, the European motor vehicles sector has very different economic characteristics:

• It has a long supply chain that is dominated by European suppliers

• Europe exports vehicles (and vehicle designs) to other world regions

• The value chain has many more jobs associated with it than the oil supply chain

Fig. 9.3

Total cost of ownership in 2030 and 2050 for each of the five scenarios Source: SULTAN
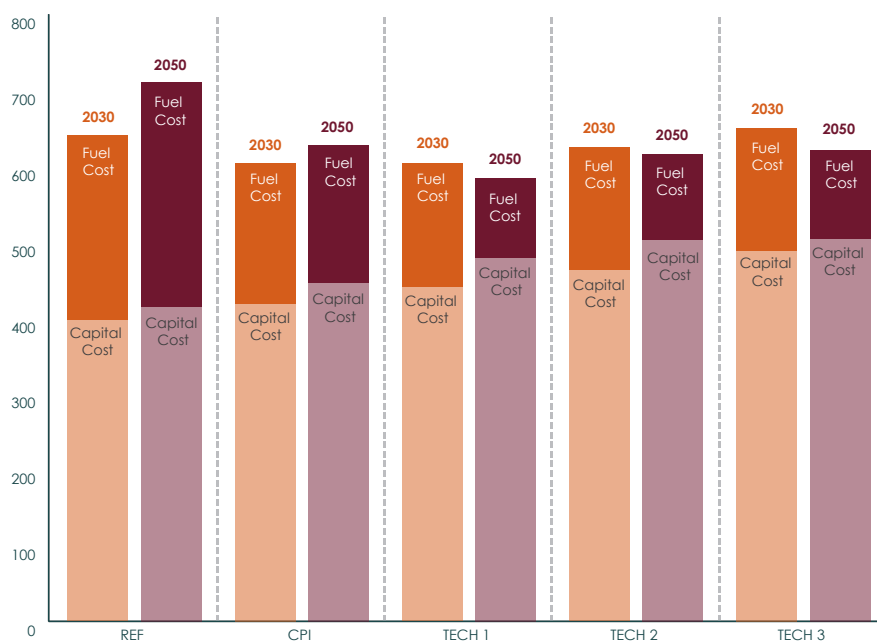
Europeans spend around €353 billion each year on cars and vans (including tax, and €269 billion excluding tax). Given the complexity of the vehicle supply chain, it is difficult to precisely ascertain the value that remains in Europe. However, the fact that suppliers are usually located in close proximity to auto manufacturers indicates that much of the first tier of suppliers is based in Europe. And although non-European brands have a significant share of the market, their cars are predominantly produced in Europe:

- Ford has production and/or R&D facilities in Spain, Belgium (due to close), the UK, Germany, Romania, Slovakia, Portugal, and France.

- Nissan has facilities in Spain, and the UK.

- Toyota has facilities in Belgium, France, the UK, Portugal, and the Czech Republic (a joint venture with Peugeot Citroen).

- Kia has an R&D centre in Germany and a production plant in Slovakia.

- Hyundai has an R&D centre in Germany.

Moreover, imports of vehicles into the EU account for less than 20 per cent of total sales. European brands accounted for around two-thirds of the European vehicle market in 2011. Slow economic growth in the Eurozone has, however, reduced total sales in the European market in recent years.

This recent decline gives greater importance to the role of export markets, not only for finished vehicles, but also for vehicle designs which are then produced in other world regions to serve their markets (in the same way that Japanese and South Korean designs are produced in Europe for the European market).

The total cost of vehicle ownership covers the full costs of a vehicle to a consumer over its lifetime:

- The capital cost (the upfront cost of the vehicle)

- The fuel cost

- The insurance and maintenance costs

Although maintenance costs could fall slightly as a result of a shift to potentially simpler battery electric vehicles, the cost changes are expected to be small.

Fig. 9.4

Diagram relating components of the cost of vehicle ownership to EU economy

BEFORE TECHNOLOGY INNOVATION

SPENDING ON EVERYTHING ELSE

All goods & Services

Economic production

Value in EU production

Value in imports

TOTAL COST OF VEHICLE OWNERSHIP

Capital Cost

Fuel Cost

Motor vehicles supply chain

Petrol diesel supply chains

EU value in vehicles

Import value in vehicles

EU value in fuel

Import value in fuel

AFTER TECHNOLOGY INNOVATION

SPENDING ON EVERYTHING ELSE

All goods & Services

Economic production increases

Value in EU production increases

Value in imports increases

TOTAL COST OF VEHICLE OWNERSHIP

Capital Cost

Fuel Cost

Motor vehicles supply chain

Petrol diesel supply chains

EU value in vehicles rises

Import value in vehicles rises

EU value in fuel falls

Import value in fuel falls

The key components are the capital cost and the associated fuel cost. These two components are interrelated but have different characteristics in terms of their impact on the economy.

The capital cost is related to sales of new vehicles. Cars are, on average, replaced every 12 years. By contrast, the fuel cost is inextricably linked to the stock characteristics of the fleet and can only change gradually, since only around one in twelve of vehicles are replaced each year.

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 EU 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, since it is assumed that the policy mechanism used to push more low-carbon vehicles into the market is an EU-wide fuel-efficiency or CO_2 standard.

Given these assumptions, higher costs have negative impacts on household real incomes and consumer spending. However, the overall costs to the economy are small. This is because even though car manufacturers (and purchasers of vehicles) face higher costs, a substantial share of these costs is in the form of value to European producers and the motor vehicle supply chain. For example, producers that supply fuel-efficient start-stop mechanisms would benefit from an increase in sales, due to an increase in demand for their products.

In this sense, the money remains in the European economy. Generally, the costs increase over time, in line with the number of new purchases of efficient vehicles.

Table 9.1

Fuel cost, total cost, capital cost, investment in hydrogen and electricity infrastructure, GDP and Jobs. All scenario results are relative to the Reference scenario
Source:E3ME

(2010 bn €)	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
	REF		CPI		TECH 1		TECH 2		TECH 3	
Capital cost EU car and van fleet (excl tax)	396,54	414,63	21,87	31,32	44,71	64,07	67,24	87,61	92,42	90,24
Fuel cost (excl tax, duties)	243,74	295,96	-58,45	-114,57	-80,41	-191,46	-82,37	-183,22	-82,77	-179,90
Capital and fuel cost EU car and van fleet (excl tax)	640,28	603,69	-36,58	-83,25	-35,70	-127,39	-15,13	-95,61	9,65	-89,66
Infrastructure investment	0,00	0,01	0,01	0,02	0,00	0,00	9,96	57,39	25,77	83,59
Employment (m)	229,98	217,68	0,50	1,38	0,66	1,95	0,85	2,14	1,08	2,35
GDP	17381,30	17556,36	36,74	168,22	40,67	223,36	53,04	264,13	72,49	293,09

By 2050, vehicle costs in the Tech 1 scenario are roughly 15 per cent higher than in the Reference scenario. By contrast, reducing fuel consumption in vehicles has a positive impact on the wider economy, which accumulates in two ways.

Firstly, there is a direct benefit to GDP from reduced imports of oil, which improves the trade balance and boosts GDP. Secondly, there are indirect benefits to households and businesses, as lower business costs are passed on in the form of lower prices.

To give an example, a plumber whose fuel costs are now cheaper can potentially pass on his cost savings in order to compete for more customers. For households this means an increase in real incomes, leading to increased household spending. For some businesses, this also gives a boost to competitiveness against foreign firms as distribution and travel costs fall.

The benefits of the more efficient vehicles accumulate gradually over time as the vehicle stock improves.

The macroeconomic impact of a shift to low-carbon vehicles can be characterised as the combination of four separate impacts:

1. The impact of lower total running costs of Europe's vehicle fleet

2. The impact of the changing composition of the cost of running Europe's vehicle fleet from a high proportion of fuel costs towards a higher proportion of capital costs

3. The impact of changing the fuel mix consumed by Europe's vehicle fleet from petrol and diesel to electricity and hydrogen

4. The impact of the infrastructure spending (and its associated financing) required to support the transition to EVs and FCEVs

The Tech 1 scenario is characterised by greater efficiency in petrol and diesel vehicles as well as an increasing proportion of hybrids. It therefore illustrates the first two impacts clearly. Fig. 9.3 shows the total cost of ownership at an EU-wide level.

Table 9.2

Table of macroeconomic indicators (GDP, Real Income, Consumer Spending, Investment, Government Spending, Net Trade, Consumer Prices) (The data in the scenarios columns is absolute difference from REF) Source:E3ME

(2010 bn €)	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
	REF		CPI		TECH 1		TECH 2		TECH 3	
GDP (2010 bn euro)	17519,62	25604,52	36,74	168,22	40,67	223,36	53,04	264,13	72,49	293,09
Consumption (2010 bn euro)	9107,77	13311,15	17,26	93,64	17,99	116,80	18,77	99,74	20,62	104,89
Investment (2010 bn euro)	4020,07	5831,80	7,78	34,97	9,73	48,12	22,11	107,87	40,64	135,14
ExtraEUExports (2010 bn euro)	4195,71	8082,89	1,66	7,57	1,82	10,57	1,02	-11,17	-0,14	-25,54
ExtraEU Imports (2010 bn euro)	3971,21	8052,98	2,07	26,47	3,34	35,23	7,15	44,18	12,40	50,80
Real income (2010 bn euro)	13678,02	17945,80	18,93	83,92	17,19	100,18	12,64	57,66	7,91	45,34
Consumer prices 2010=1	1,7	2,5	-0,1%	-0,3%	0,0%	-0,3%	0,2%	0,3%	0,3%	0,6%
Employment (m)	229,98	217,68	0,50	1,38	0,66	1,95	0,85	2,14	1,08	2,35

By translating this logic to the Tech1 scenario in 2050, it is possible to identify how the economic benefits arise. In the Tech 1 scenario, the capital cost of Europe's fleet of cars and vans increases by €64 billion by 2050 (excluding taxes) compared to the Reference scenario, causing consumers and businesses to switch €64 billion of spending towards vehicles and away from other goods and services, or in the case of businesses, profit margins might also be squeezed.

However, this added cost does not fully translate to a €64 billion reduction in GDP. On the one hand, real incomes are reduced by increasing prices, but on the other hand there is slightly more European value added for each € billion spent on motor vehicles than if the same € billion was spent elsewhere in the economy, on average.

As a result of this, the imposition of €64 billion of additional costs on consumers and businesses only results in a €51 billion reduction in GDP after second order multiplier effects.

The total fuel costs for running Europe's fleet of cars and vans decreases by €323 billion by 2050 (including tax). This is split between €191 billion of avoided spending on fuel and a €132 billion reduction in government receipts from fuel taxes, fuel duties and VAT. Of the €191 billion of avoided spending on fuel, part of the value is within the refining, distribution and retail sectors, leaving approximately €140 billion of avoided spending on imported crude oil or oil products. Given that domestically produced oil will primarily be consumed in Europe, it is assumed that avoided spending on oil will largely displace imports.

The €323 billion reduction in gross fuel bills affects GDP in so far as consumers retain that money and are able to spend it on other goods and services. Companies would be able to take advantage of lower operating costs by increasing other forms of spending.

A reasonable proportion of this increased consumer spending leaves the economy in paying for imports but a significant proportion of goods and services are provided domestically.

Fig. 9.5

Tech 1: Net employment impact, compared to baseline, in main economic sectors in 2030, 2050
Source:E3ME

Totals:
2030 – 659,330
2050 – 1,950,230
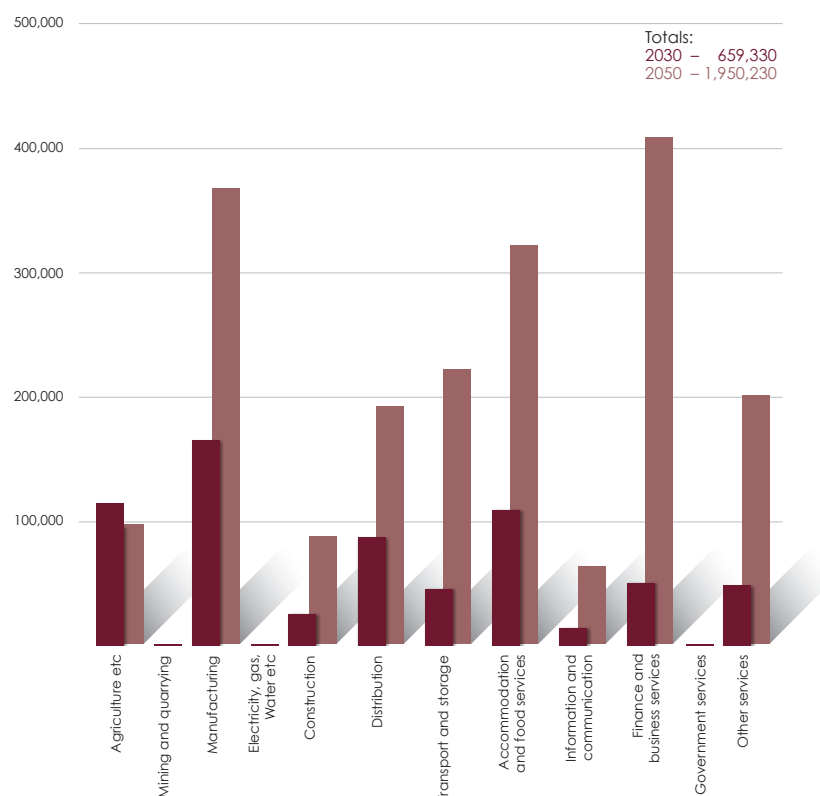
The net effect of reduced expenditure on petrol and diesel and increased expenditure on vehicles translates to €222 billion of additional GDP in Europe after second-order multiplier effects.

Furthermore, consumers can, in theory, enjoy a higher standard of living, which is not measured by GDP, as they are able to spend their net savings on other items as a result of lower fleet running costs.

The transition to spend more on vehicles, less on fuel, and more in other areas of the economy, also changes the sectoral composition of the economy, leading to a substantial increase in European employment of 1.95 million net additional jobs in the Tech 1 scenario (Fig. 9.5). In the CPI scenario, jobs increase by 1.38 million overall, while GDP increases by €167 billion.

The Tech 2 and Tech 3 scenarios are much more difficult to explain in the same way, because all four factors combine:

1. The impact of lower total running costs of Europe's vehicle fleet

2. The impact of the changing composition of the cost of running Europe's vehicle fleet from a high proportion of fuel costs towards a higher proportion of capital costs

3. The impact of changing the fuel mix consumed by Europe's vehicle fleet from petrol and diesel to electricity and hydrogen

4. The impact of the infrastructure spending (and its associated financing) required to support the transition to EVs and FCEVs

While it is possible to decompose the impact of lower fuel costs, on the one hand, and higher capital costs on the other (as described above); it is not possible to isolate the impact of lower fuel costs against the impact of a changing fuel mix as the two factors are dependent on one another (the fuel mix defines the cost). Moreover, the impact of the infrastructure is tied into the deployment of PHEV, EV and FCEVs and it also affects the fuel cost.

The impact of fuel switching (in isolation), is however, likely to have a positive impact on the European economy. First, it allows greater vehicle efficiency(Fig. 11.2), but more importantly the production of electricity and hydrogen is predominantly a domestic supply chain. Electricity is 80 per cent sourced from renewable generation technologies in all the scenarios[4]. Moreover, in each scenario, hydrogen is produced using a combination of centralised and decentralised electrolysis and so the supply chain is assumed to be European.

By contrast, crude oil is predominantly imported, and so the fuel switching represents a transition away from imported fuels. Set against the likely positive impact of fuel switching is the fact that electricity and hydrogen prices are expensive, and increasingly expensive given the 80 per cent renewable electricity grid by 2050 (as discussed in Chapter 8).

Infrastructure investment also has a positive impact on GDP. The positive impact arises because infrastructure projects are inherently domestic and require relatively high labour input in the supply chain. As a result, increasing infrastructure investment diverts expenditure away from items with higher import content.

However, increasing infrastructure investment will reduce the overall attractiveness of running EVs and FCEVs as it will need to be paid for. So, while the macroeconomic results are positive, the microeconomic impact for each consumer and business choosing whether to switch from an ICE vehicle might be negative (since each consumer only sees the cost of the infrastructure investment in the form of higher prices and not the related macroeconomic benefit that accrues in the supply chain). The consumer decision is also influenced by the borrowing rate available to them. At a 10 per cent borrowing rate, Total Costs of Ownership for some vehicles remains above current total cost of ownership until post-2025 (Fig. 6.6).

These two impacts, combined with the impacts of a transition to a vehicle stock with a higher capital cost and lower fuel-cost component, explain the overall improvement in GDP in the Tech 2 and Tech 3 scenarios.

They also explain the relative performance of Tech 3 compared to Tech 2. Employment increases across the scenarios; in part as a result of increased economic activity (GDP), but also because of a shift towards activities with more jobs associated with them. (Fig. 9.6)

Three trends prevail in the Tech scenarios:

• The reduction in total cost of ownership that allows consumers to spend their incomes on other goods and services is typically spent on leisure activities, or consumer services that are inherently labour intensive.

• The additional stimulus to the motor vehicles sector increases employment throughout the associated manufacturing supply chain.

• The expenditure on supporting infrastructure stimulates demand for construction activity which is also fairly labour-intensive.

Fig. 9.6

Tech 3: Net employment impact, compared to baseline, in main economic sectors in 2030, 2050
Source:E3ME

Totals:
2030 − 1,083,250
2050 − 2,349,730
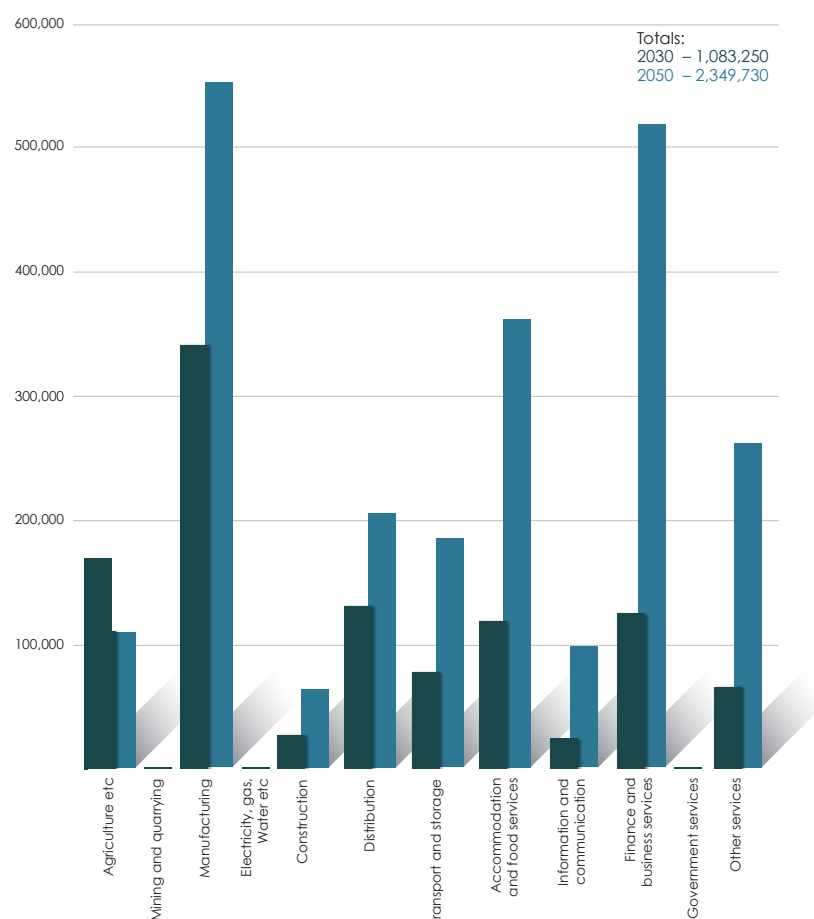
Overall, manufacturing sees the largest increase in employment in the Tech scenarios (370,000-550,000 FTE jobs) (Fig. 9.6),

However, since the deployment generates a general increase in European GDP, employment increases are fairly even across the economy, with an average increase of 0.9-1.1 per cent which is equivalent to around 2-2.3 million jobs.

A major concern to national governments, especially in the current economic climate, is the lost tax revenue that results from the deployment of more efficient vehicles, since petrol and diesel consumption is heavily taxed.

These scenarios are government-revenue-neutral and VAT has been increased (on a country-by-country basis) to meet the lost receipts from excise duties.

However, as the economy improves (relative to the Reference scenario) the modelling analysis suggests that the increased economic activity generates enough additional tax revenue to largely compensate for the lost excise tax revenues.

The magnitude of the results is contingent on a number of factors, and in particular:

• Projections of fossil fuel prices
• The vehicle technology costs that are realised
• The associated infrastructure costs

However, as discussed in Chapters 6-8 of this report, the modelling suggests that economic benefits will arise even if fossil fuel prices return to the lower-case levels projected by the IEA, or if the technology costs are at the upper end of the current range of estimates.

By contrast, if fossil fuel prices turn out to be nearer the IEA's higher estimate and technology costs are achieved towards the lower end of the estimated range, the economic benefits of the Tech scenarios will be even greater.

Fig. 9.7

Net employment impact in the four scenarios as compared to the Reference scenario, both in 2030 and in 2050
Source:E3ME

CPI
2030 = 500,800 net additional jobs
2050 = 1.39 mln net additional jobs

Tech 1
2030 = 660,000 net additional jobs
2050 = 1.95 mln net additional jobs

Tech 2
2030 = 850,000 net additional jobs
2050 = 2.14 mln net additional jobs

Tech 3
2030 = 1.10 mln net additional jobs
2050 = 2,35 mln net additional jobs
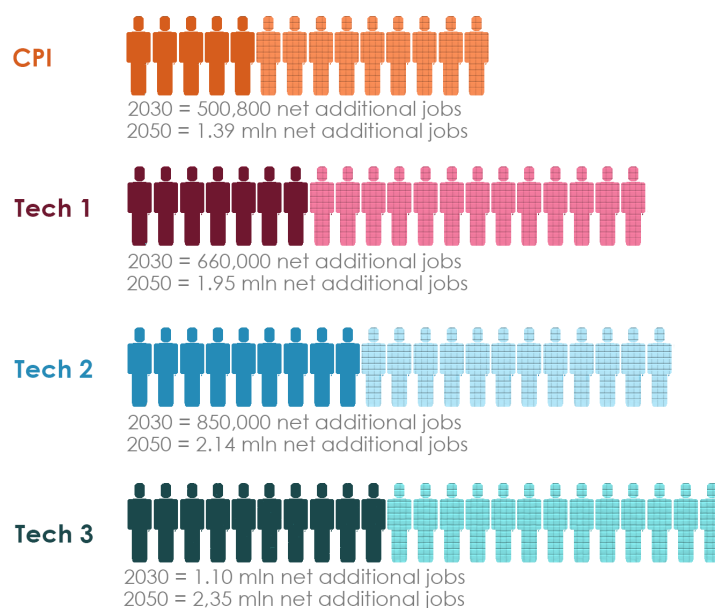
10 Skills

This chapter examines the implications for the skills needed in the European workforce as a consequence of the shift towards advanced hybrids, battery electric vehicles and hydrogen fuel cell vehicles.

Many of the skills required for the development of advanced vehicles are the same as needed for the manufacture and maintenance of conventionally-powered vehicles. They include such skills as the managerial capacity to plan and organise production efficiently, often across a number of countries; the capacity to produce attractive designs that are also aerodynamically efficient; the ability to market the vehicles so that their sales are maximised.

There are, however, a number of new skills that will come to the fore as various features of the technologies develop, related in particular to batteries, new materials and the production process. The search for ways of speeding the recharging of batteries and extending their range is likely to intensify.

There will be more research into new materials to reduce the weight of vehicles. And there will be changes in the way the production process is organised, not least because the dangers of working with high-voltage electricity might well give an added reason for increased automation. Such developments are possible only if particular skills are available. Specifically, there will be a need for high-level research chemists to investigate new substances to use in batteries, or ways of making existing batteries more powerful and efficient.

There will also be a need for materials scientists, to help in the quest for lighter materials; and, more generally, engineers in various disciplines will be needed to incorporate the results of research in vehicles and components, including:

- Chemical engineers to develop new batteries; to improve existing battery technology; and to design the equipment and processes needed for manufacturing batteries

- Electrical engineers to design, develop, test and supervise the manufacture of electrical equipment and components, and to design the electrical circuitry to charge batteries and distribute electricity from batteries to the motor

- Industrial engineers to determine the most efficient and cost-effective ways of combining the various factors of production: labour, machinery and materials

- Materials engineers to develop and test new materials

- Mechanical engineers to design and develop tools and components for use in the manufacture and repair of vehicles

- Computer analysts to design the software for controlling the vehicles, especially the systems for the on-board computers that distribute the appropriate amount of electricity to the powertrain.

All the above occupations require people with at least tertiary level qualifications – i.e. university degrees or the equivalent. For tasks involving research, the need is for people with postgraduate qualifications.

Many of the workers involved in the actual manufacture of electric vehicles also require a special set of skills that differ in some degree from those for the production of conventional vehicles, since the process is more complex. Many of these special skills are required for the manufacture of vehicle charging stations, which are, in any case, likely to be a major source of additional jobs as the take-up of electric vehicles becomes more widespread.

The skills concerned include those for the assembly of electric motors, computers, electronic control devices and sensing equipment, which in practice means operating some automated control systems to put the various components together. They also include the higher-level skills needed by the operators of computer-controlled machine tools used in setting up and maintaining the machines for various automated operations.

Machine tool operators, like mechanics of various types, need to have completed a formal vocational training programme such as an apprenticeship, focusing on working with electrical and electronic systems.
The number of workers required in these areas, as well as their availability, will vary between countries and regions.

Auto sector employment in Europe

The motor vehicles industry, narrowly defined as in the standard NACE classification[1], accounted directly for around 1.5 per cent of total employment in Europe[2] or around 3.1 million people in 2012. This classification includes vehicle manufacture but only some of the components; for example it does not include the production of electric motors, batteries, lighting equipment or tyres. Nor does it cover the people who are employed in the sale, maintenance and repair of motor vehicles, around 4 million overall across Europe. When all suppliers are included, it is likely that overall at least 10 million people across Europe depend directly on the industry for their jobs, and many more depend indirectly.

Around 40 per cent of employment in the motor vehicles industry (narrowly defined) in Europe is in Germany, over five times the share in any other country (Fig. 10.1). This share has not changed much over the past 10-20 years, even though production (particularly in vehicle assembly and the more labour-intensive activities) has shifted from Western Europe to Central and Eastern Europe.

This eastward movement accelerated during the economic crisis with the result that the largest job losses have been seen in Western European countries other than Germany.

Fig. 10.1

EU distribution of auto industry (NACE 29) employment in 2012. Source: Eurostat
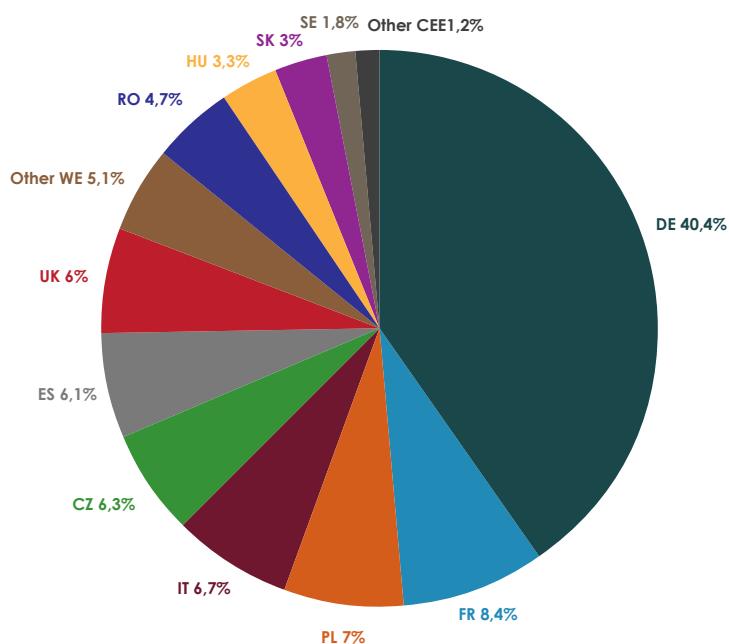
Therefore, whereas the motor vehicles industry accounts for over 3 per cent of total employment in Germany, in other Western European countries, it accounts for at most just over 1 per cent (in Spain and Sweden). The industry is a more important employer in Central and Eastern Europe, accounting for 4 per cent of employment in Slovakia and the Czech Republic, for example.

The composition of employment – i.e. the division between different jobs or occupations – varies markedly between countries, both within Western Europe and between Western Europe on the one hand and Central and Eastern Europe on the other. These differences reflect the move within the EU of the more labour-intensive activities from higher-wage to lower-wage economies.

Regional distribution of professions

Core activities, such as R&D and design, tend to be located in the countries where the major car manufacturers are based, while many other activities have been outsourced to countries where costs are lower. In Europe as a whole,

just over 7 per cent of those employed in the motor vehicles industry are engineers (Fig.10.2) and the same proportion are engineering technicians (i.e. one level down from engineers). In Germany, the figures are higher, at 10 per cent and 9 per cent respectively. By contrast, in Spain and most Central and Eastern European countries, engineers account for just 3-4 per cent and in Italy, for even less.

'Other professionals' – software developers, systems analysts, chemists, accountants, economists and marketing experts – also account for a much larger share of the workforce in the industry in Germany than in other countries, and a larger share in most Western European countries (except Italy) than in Central and Eastern European ones.

Overall, engineers and other professionals have on average a share of just over 20 per cent in motor vehicles employment in Europe, but with a range from almost 30 per cent in Germany to under 10 per cent in Italy, Hungary and Slovakia.
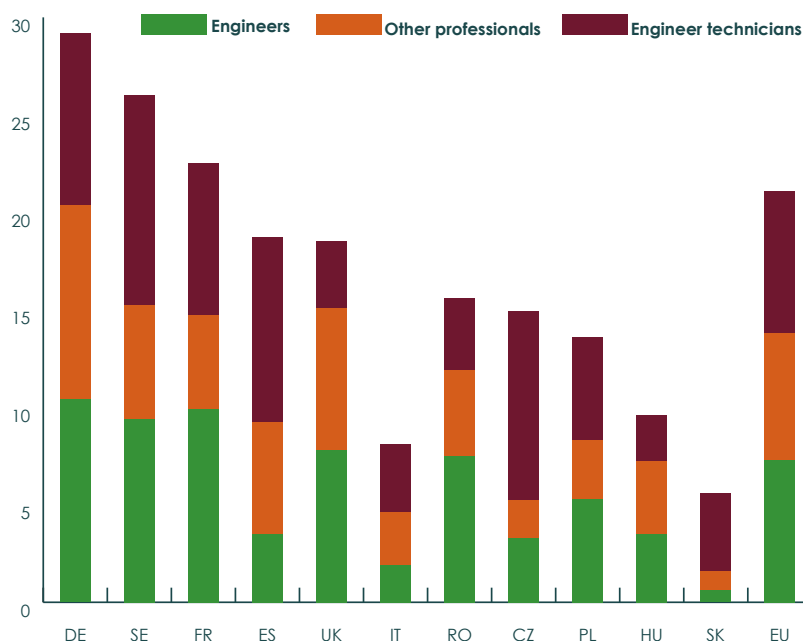
Jobs on the shop-floor

The other major difference between countries lies in the employment shares of skilled manual workers as opposed to production-line workers with lower-level skills (Fig. 10.3).

In Europe as a whole, tool-makers and mechanics (including electrical mechanics) account for 18 per cent of the motor vehicles workforce, but in Germany, the share of almost 24 per cent is well above the average, while in Spain, France and Central and Eastern Europe the share is lower than 15 per cent.

Conversely, lower-skilled professions, such as assemblers and machine operators, account for 21 per cent of the total motor vehicles workforce in Europe, but only 10 per cent in Germany, less than in any other Western European country and much less than in Spain and Central and Eastern Europe, where the figure is 30 per cent or more.

These differences in the structure of the workforce mean that both the higher-level professional jobs – for engineers, system architects, etc – and the more skilled manual jobs are even more concentrated in Germany than jobs as a whole.

To be precise, some 60 per cent of engineers and other professionals employed in the industry in Europe are based in Germany, well over twice the number in other Western European countries taken together, and five times the number in Central and Eastern European countries taken together.

In addition, well over half of toolmakers and mechanics in this industry in Europe are also based in Germany, again over twice the number in other Western European countries taken together.

By contrast, Central and Eastern European countries account for around 42 per cent of all assembly-line workers in the industry, much more than in Germany (24 per cent) or in the rest of Western Europe (34 per cent).

Fig. 10.3

Share of different professions on the auto industry shop floor (2012). Source: Eurostat

Legend: Tool-makers, Mechanics, Electrical mechanics, Assemblers + machine operators
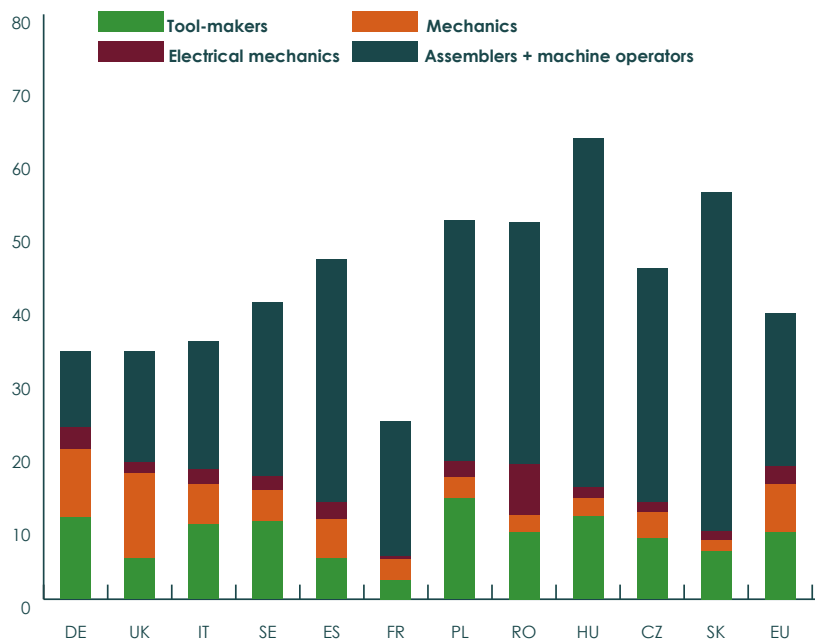
Graduate skills sets

New graduates entering the labour market are an essential source of the skills for the successful development of vehicle technology. Over the past decade, there has been a pronounced upward trend in the number of young people graduating from university in Europe. In 2010 (the latest year for which a full set of data is available), the number of people graduating from university in the EU amounted to just over 14 per cent of the 20-24 age-group[3], up from 9 per cent in 2000 and just ahead of the percentage in the United States.

Of the total number graduating in 2010, around 8 per cent (or just over 1 per cent of the whole 20-24 age-group) had specialised in engineering. This is almost twice the proportion of the same age-group in the US, but nearly one-third less than the proportion in Japan.

While there is free movement of labour for the most part within the EU[4], it is still the case that the great majority of young people continue to live and work in the country in which they were born.

Because there is not yet really a European labour market, the pool of new graduates available for companies to recruit remains largely national. Nevertheless, things are gradually changing and increasing numbers of young people are moving to other countries to take up jobs. For the most part, therefore, the important factor is still the number of young people graduating from university with relevant qualifications in each country.

Growth between 2000 and 2010 in the proportion of graduates with engineering degrees was especially strong in Romania, Slovakia and most other Central and Eastern European countries; while in Western Europe there was strong growth in Finland, Austria, Spain and Germany(Fig. 10.4). By contrast, the shares in the Netherlands and Italy were comparatively small in 2000 and shrank further by 2010.

The proportion of university graduates in Europe with degrees in science, maths or computing is slightly higher than the proportion with degrees in engineering, at just over 9 per cent in 2010. In this group of subjects too the proportion of graduates has risen since 2000. Moreover, the proportion is higher than in either the US or Japan.

Fig. 10.4

University graduates with a degree or equivalent in engineering (per cent of 20-24 age-group))
Source: Eurostat
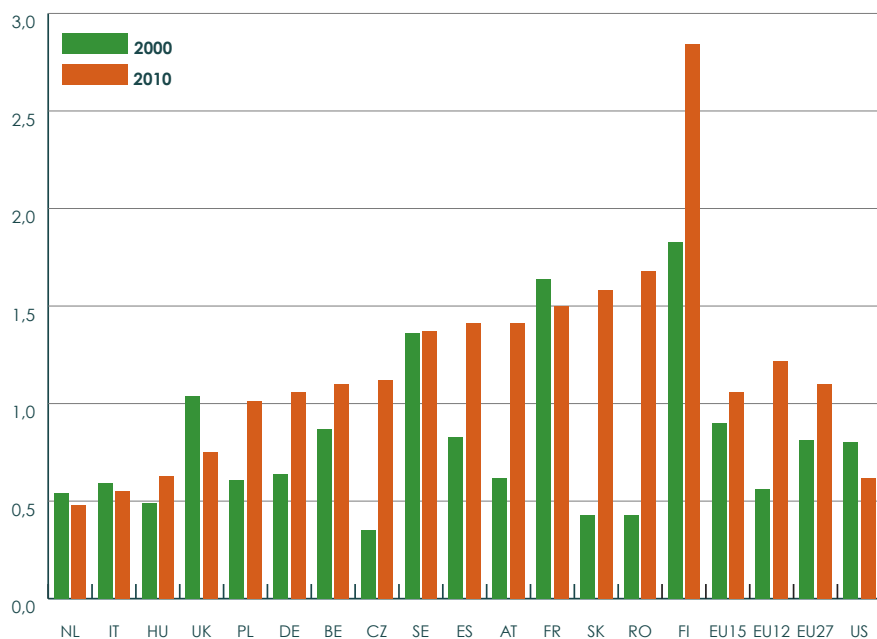
Just as with engineering, there was notably strong growth in the share of science, maths or computing graduates in the car-producing countries of Central and Eastern European, taking Poland, Slovakia and the Czech Republic from below the EU 15 average in 2000 to above the EU 27 average in 2010. Germany also saw strong growth. France and the UK, however, continue to lead, despite a decline in relative numbers during the decade. Italy again has the smallest proportion – well below half the EU average – reflecting the low level of education of much of the Italian work force, which is a major structural weakness of the economy.

Postgraduate skill sets

While the number of young people graduating with relevant qualifications is important for the future prospects of the motor vehicle industry, the proportion completing postgraduate degree programmes is even more important for the development of new vehicle technologies.

The number of people completing postgraduate programmes in engineering in the EU in 2010 amounted to some 18,000, or around 15 per cent of the total obtaining postgraduate degrees. This number is again above the figure in the US, as a result of a much bigger increase over the 10 years 2000-2010 (Fig. 10.5) and is much the same as in Japan.

Once more, the proportion is highest in Finland and Sweden and remained relatively unchanged over the decade. In Germany, the figure was around the EU average in 2010 after many years in which it exceeded the EU average. As a result, there are more people with advanced qualifications in the labour market – and perhaps doing research – than in most other countries.

By contrast, the proportion in Italy rose markedly over the 10 years to well above the EU average, as it did in the Czech Republic, Slovakia and Romania, all countries where the motor vehicle industry is important. On the other hand, the proportion remained well below the EU average in France and Spain, as well as in Poland and Hungary.

Fig. 10.5

Completion of postgraduate programmes in engineering (per 1,000 in the age group 25-29). Source: Eurostat
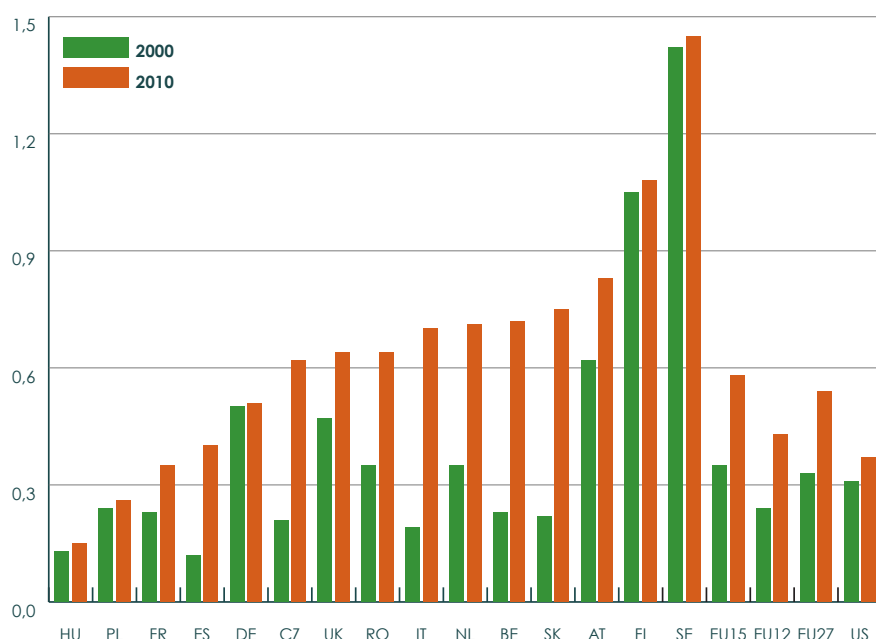
Many more people complete postgraduate programmes in science, maths and computing each year than in engineering – just over 32,000 in the EU in 2010, well over a quarter of all those obtaining postgraduate degrees, and much higher in relative terms than in the US or Japan.

The highest number is in Germany, followed by France, Sweden and the UK, well above Spain and Italy and much higher than in the Central and Eastern European countries, apart from the Czech Republic. Although the relative growth in Germany was less than in most other car-producing countries, the level remained high over the decade, resulting in a large pool of talent.

As a result, Germany – and to a lesser extent Sweden and France – seem to have relatively good access to scientists with the skills for R&D in vehicle technology. However, data is limited on how this is broken down to specific disciplines, such as chemistry, electrical engineering and systems analysis.

Whether the potential availability of researchers will be turned into reality depends on a number of factors, not least the industry's ability to attract top scientists given the competing demands for their services. Indeed, prospective skill shortages in the motor vehicle industry are likely to arise as much from competition from other sectors, which might offer a more certain future and higher salaries, as from an overall scarcity of skills.

The implications for workers

Most of the people employed in the motor vehicle industry, especially outside Germany, are not highly trained. Most of them do not have university degrees, and the tasks that they perform can to a large extent be taught on-the-job. While many of the jobs involved in the manufacture of low-carbon vehicles are the same as for conventional cars, there are also many that differ, not least because of the risk of exposure to high voltage electricity. Although training will be required for people on the shop floor to be able to perform the new jobs, it is likely this can be largely provided within the industry without too much difficulty.

Fig. 10.6

Proportion of mechanics and toolmakers and assembly line workers in the auto industry aged 55 and over in 2012 (per cent of each occupational group) Source: Eurostat
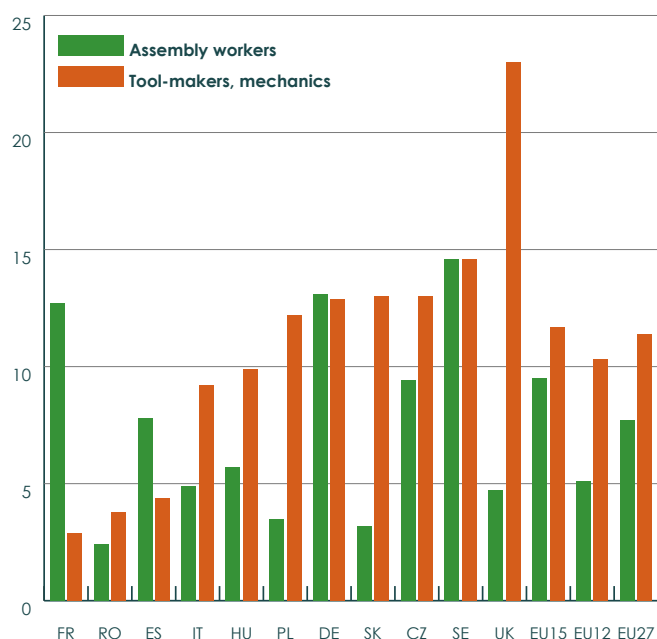
This would suggest that the implications are relatively minor. But things are not quite as simple as this. First, there is no guarantee that the new jobs created by the new technology will be located in the same firms or even in the same locality.

While some companies may be able to shift manufacture to new or modified production lines, others will not be able to and may be forced out of business. This would especially affect companies producing conventional auto components that face declining demand.

Moreover, the development of new technologies opens the way for new entrants to come into the industry. These will not necessarily take on workers already employed in the sector.

Secondly, some of the existing work force might have difficulty in learning the new skills required. This may particularly be the case if they lack the educational background to absorb new know-how.

Equally, companies might be reluctant to provide extensive training to older workers nearing retirement age, who would have only a few years to put their new skills to productive use. It is hard to assess the extent of disruption to the existing work force as a result of new technology or how far current workers will be able to keep their jobs.

Much depends on the rate of development of advanced vehicles and the amount of time that companies have to retrain their workers, or to recruit and train new people.

Given the rate of growth of non-conventional vehicles envisaged in the present study, there ought not to be major problems in general, though there may be difficulties in specific activities or particular locations.

Workers nearing retirement

Only a small proportion of current EU mechanics and toolmakers are nearing retirement age, though the situation varies between countries. Much the same is true of assembly-line workers. Just over 11 per cent of those working as mechanics and tool-makers were aged 55 or over in 2012 (Fig. 10.6).

If the normal retirement age is 65, only slightly more than 1 per cent will retire each year on average over the next 10 years. This ought not to pose major replacement problems for companies in general.

There might be more problems for the UK, where 23 per cent of mechanics and toolmakers are 55 or over, and to a lesser extent Sweden, where the proportion is close to 15 per cent.

The number of assembly-line workers aged 55 or over is even smaller, averaging less than 8 per cent of the total employed by the industry in the EU. This reflects the very small number of such workers in this age group in the Central and Eastern European countries – only 5 per cent on average – which results from the recent growth of the industry in the region and the fact that relatively few of those recruited were in older age groups.

Workers with low education

Most of the people below 55 employed as mechanics or toolmakers in the motor vehicle industry have at least upper secondary level qualifications. Accordingly, they are likely to have the basis for picking up new skills or learning new tasks relatively readily.

In the EU as a whole, about 15 per cent have no educational qualifications beyond basic schooling. In France, however, the proportion is almost a third (Fig. 10.7). In Italy, it is just under a half. This does not necessarily mean that the work force in these two countries is any less skilled than in others, but it does mean that they have less formal training, which might imply that training existing workers to perform new tasks might well be more problematic.

Relatively few electrical mechanics have no qualifications beyond basic schooling, with the exception of Spain where the proportion was 40 per cent in 2012.

The figure was similar in Italy and reached 25 per cent in France. In these three countries, therefore, retraining the existing work force could pose more problems than elsewhere. Retraining assembly line workers might be less demanding in the sense that the tasks to be performed are more straight-forward, but it is still likely to be easier if the workers concerned are better educated.

In most of the car-producing countries in Europe, the large majority of such workers have completed at least a formal vocational training programme after compulsory schooling.

This is not the case in Spain, where almost half of them have only basic schooling, and in Italy, where the proportion is close to 60 per cent. In both France and the UK, the proportion with no education beyond compulsory schooling also exceeded the EU average.

Fig. 10.7

Mechanics and toolmakers employed in the motor vehicles industry with no education beyond compulsory schooling, 2012 (per cent total of each group employed in the industry). Source: Eurostat
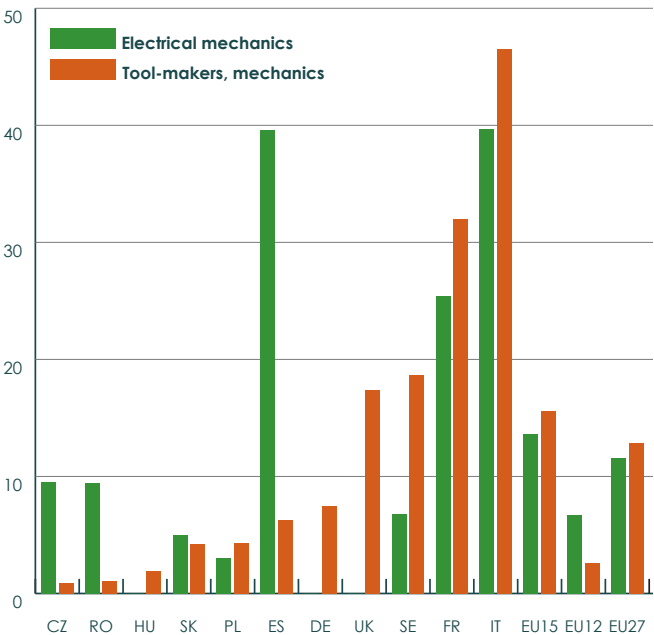
Industry's view on skills

Members of the Working Group were interviewed to obtain a more informed view of the likely availability of the skills for the development of advanced vehicles. All of the companies are facing shortages of particular skills, despite the depressed nature of the car market in many parts of Europe. For automakers, skill shortages are generic to the industry in the sense that all of the main car manufacturers in Europe are looking to recruit people with similar skills.

The economic crisis hit the auto industry especially hard and is thought to have worsened recruitment problems. Falling car sales reduced the attractiveness of the industry and caused people to move into other sectors, such as aerospace and even banking. Engineers with a few years of experience have been particularly affected. While, therefore, it is possible to find recent graduates with suitable engineering qualifications, there is currently a particular shortage of engineers in mid-career who offer experience, technical ability, and sufficient years in front of them to justify in-house training.

One significant emerging problem is recruiting engineers for mechatronics -- a fusion of mechanical, electrical, electronic and control engineering. A recent study by AEA[5] for the European Commission highlighted the difficulties auto parts suppliers are already facing with finding engineers capable of thinking creatively about mechatronics. In future, this discipline will become increasingly complex, involving information processing, strategic control systems and the use of electric actuators.

For the battery manufacturers, skill shortages stem in part from the failure of some EU universities to provide teaching and research opportunities in the field of lithium ion technology.

One company identified a particular shortage in the area of computer software and systems architecture, required for the development of larger power units and battery systems. The sector faces fierce competition from the aerospace industry for people with the software and system architecture expertise they need.

As a result of skills shortages, both auto manufacturers and battery makers are working with universities to ensure tuition programmes are more closely tailored to their needs. Another approach is to target school-leavers to encourage them to pursue suitable study paths and to enter appropriate training programmes.

Battery manufacturers involved in the project are currently cooperating with car manufacturers to advise universities on how to improve programmes for electro-engineering and mechanical engineering.

This shortage of skills has also led some companies to develop graduate programmes to train new recruits in the relevant fields, whereas previously they relied more on recruiting people with a few years of experience. However, training programmes come at a cost and hiring experienced people who already have the requisite skills is an alternative, even though it might mean paying higher salaries.

Both battery-makers and auto companies are focusing on finding skilled workers in Central and Eastern Europe, but are also looking further afield to India and China. Southern European countries with high levels of youth unemployment, such as Spain, have also been identified as a potential source of skilled graduates.

All the manufacturers agreed that tackling skill shortages is a joint responsibility between governments and companies, though ultimately it falls to companies to respond to the prevailing situation.

11 Environment and health

Although the focus of this research is on the economic impacts of a cleaner European vehicle stock, there are also environmental benefits under each of the four scenarios.

This chapter discusses the relative environmental benefits of each of the scenarios, taking into account not just tailpipe GHG emissions, but also the CO_2 emissions generated by electricity and hydrogen production, as well as tailpipe NOx emissions and particulates.

Since the Tech 2 and Tech 3 scenarios include, to varying degrees, a shift from petrol and diesel to electric vehicles (whether PHEVs or BEVs) or to vehicles powered by hydrogen fuel-cells, it is necessary to consider emissions from the future electricity and hydrogen supply chains. As explained in the discussion of fuel costs in Chapter 8, the methods of electricity generation in these two scenarios are compatible with 80 per cent renewable electricity by 2050, as explored in the European Commission's "Energy Roadmap 2050" and as proposed in the European Climate Foundation's "Roadmap 2050".

The remaining 20 per cent is supplied by a combination of nuclear power and carbon capture and storage technologies. This vision for Europe's future electricity grid presupposes high levels of interconnectivity across Europe and therefore requires relatively less back-up gas capacity than is often assumed.

Over time, the switch to these methods of electricity generation brings about a substantial reduction in the CO_2 intensity of electricity generation (Fig. 11.1). By 2050, only a tiny residual amount of power generation emits CO_2. The emissions intensity of power generation falls to just under 60 g CO_2/kWh by 2030 and 10 g CO_2/KWh by 2050, a 97 per cent reduction in total from the level of around 340 g CO_2/KWh in 2011.

As a result, electricity consumed by PHEVs and BEVs in 2050 is effectively zero-carbon and is very low-carbon by 2030. In comparison, the CO_2 intensity of hydrogen production is expected to drop from around 425 g CO_2/kWh in 2011 to just over 78 g CO_2/kWh by 2030 and 13.5 g CO_2/kWh by 2050.

Fig. 11.1

Assumed CO_2 intensity of electricity and hydrogen to 2050 (tCO_2/KWh)
Source: E3ME
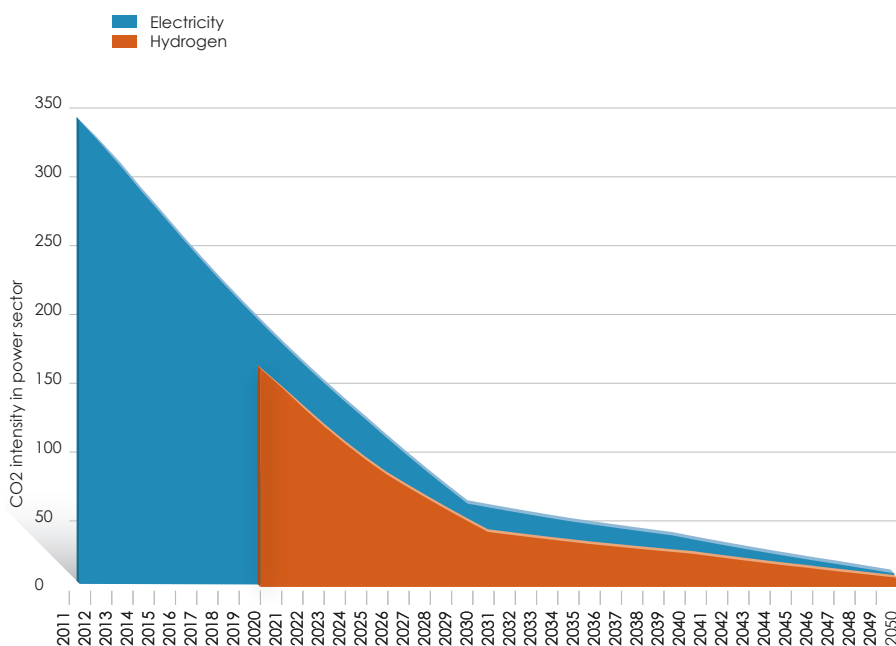
Hydrogen is produced through electrolysis, split between centralised electrolysis (using electricity from large onshore wind sites) and decentralised electrolysis in large production facilities, using electricity from the grid. The decentralised hydrogen that is produced from grid electricity has CO_2 intensity of around 35 per cent higher than electricity because of efficiency losses.

A comparison with the carbon intensity of petrol is instructive. At present, petrol has a lower carbon intensity than electricity, around 240 g CO_2/kWh in 2011 compared to 340 g CO_2/KWh, and thus petrol appears to be a cleaner fuel.

However, it is definitely not cleaner than projected electricity in the near future. Furthermore, in order to make a complete comparison between petrol and electricity or hydrogen, it is important to consider not only the generation of the energy, but also how efficiently it is used in the vehicle.

The electric powertrains used in BEVs (and also in PHEVs and hydrogen FCEVs) are considerably more efficient than those in conventional petrol and diesel ICE vehicles, because they suffer far smaller losses in the conversion of supplied energy into motive power (Fig. 11.2). This means the carbon intensity per km driven is also much lower for BEVs, PHEVs and vehicles powered by hydrogen fuel cells than it is for comparable ICEVs.

The tailpipe emissions of GHGs are substantially different between scenarios. In the Tech 3 scenario, annual tailpipe GHG CO_2 emissions from Europe's car and van stock have been reduced by 97 per cent by 2050, compared to 2010 (Fig. 11.3).

This far exceeds the goal of 60 per cent GHG emissions reduction in 2050 for transport as a whole proposed in the European Commission's Transport White Paper. However, there are fewer (and/or less cost-effective) technological options to reduce emissions from other parts of the transport sector. These options will also take much longer to work their way into the fleet (e.g. for aircraft, trains and ships).

Fig. 11.2

Comparison of energy losses in ICEVs and BEVs
Source: AEA

~64%
Diesel engine

~9%
Fuel production

Diesel Vehicle
Energy Input 100%

~7%
Mechanical drivetrain

~15-20%
Useful work

~36%
Power generation

~8%
Fuel production

~5%
Elec. transmission

~6%
Battery

~4%
Electric motor

~4%
Mechanical drivetrain

Electric Vehicle
Energy Input 100%

~40%
Useful work
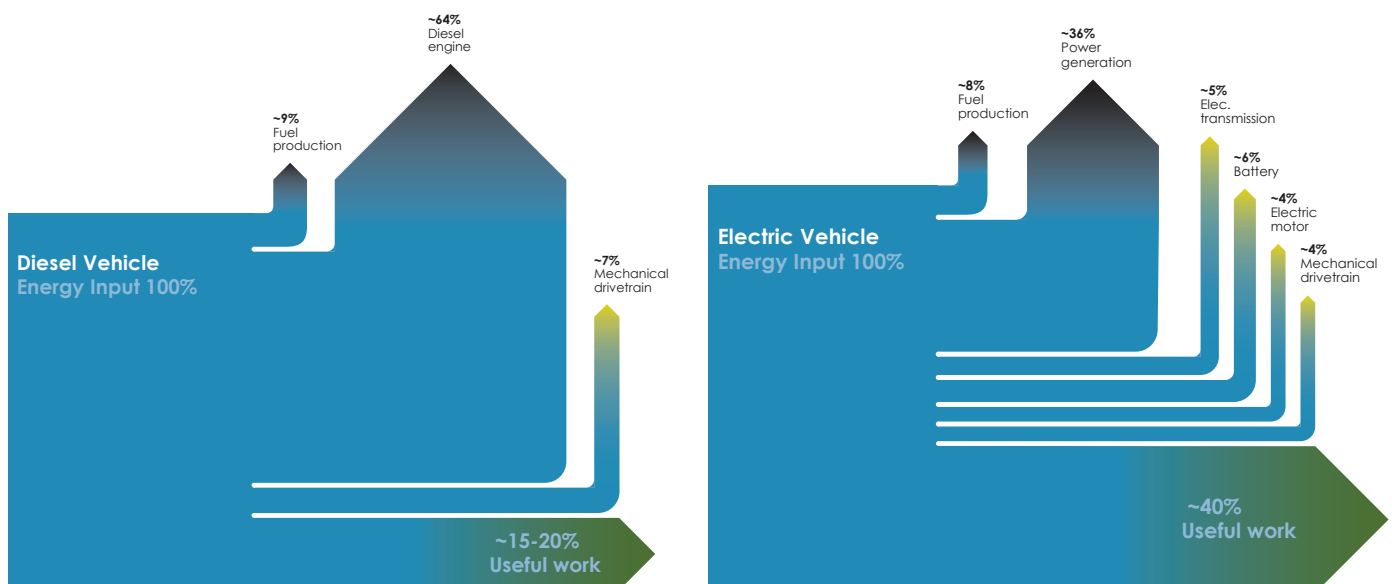
This means that reductions in emissions from cars and vans beyond the 60 per cent target will be particularly important, as has been demonstrated in previous modelling analysis for the European Commission, including the project "EU Transport GHG: Routes to 2050". Moreover, at these reduction levels, any rebound effect from the lower running costs would be unlikely to lead to much of an increase in emissions because the vehicles are efficient and the fuel sources are clean.

At the other end of the scale, the Reference scenario projects a reduction of just 2.5 per cent in GHG emissions as today's more efficient vehicles replace the entire stock, but increased vehicle ownership and use all but outweigh the improvements in efficiency.

The CPI scenario, which includes carbon efficiency improvements broadly in line with the proposed EU standards for 2020 and some more gradual improvements thereafter, projects reductions in tailpipe emissions of CO_2 of around 30 per cent by 2030 compared to 2011 and 40 per cent by 2050.

Because of the discrepancies between these projections and the targets in the EU's long-term strategy to decarbonise transport, more stringent standards would be necessary after 2020. The Tech 1 scenario projects the possible reductions in tailpipe emissions of GHGs resulting from efficiency improvements to ICEVs and HEVs, without switching to electricity (PHEVs and BEVs) and hydrogen powered vehicles (FCEVs). The projections show substantial reductions of 38 per cent in CO_2 emissions by 2030 and 64 per cent by 2050.

Overall, each of the three Tech scenarios projects emissions reductions that either reach or surpass the European Commission's current targets for decarbonisation of the transport sector as a whole. Only the widespread adoption of BEVs, PHEVs and FCEVs result in almost total decarbonisation, but substantial improvements can be made merely by raising efficiency standards and promoting the wider take-up of HEVs, similar to those on the road today.

Cars and vans also produce NOx and particulates: local air pollutants with harmful consequences for human health.

Fig. 11.3

Direct CO_2 emissions and avoided CO_2 emissions in the 4 scenarios in 2050
Source: SULTAN

Avoided emissions 2050

16.1   250.4   403.5   527.7   587.3

611.8   377.5   224.4   100.1   40.5

Direct emissions 2050

Ref   CPI   Tech 1   Tech 2   Tech 3
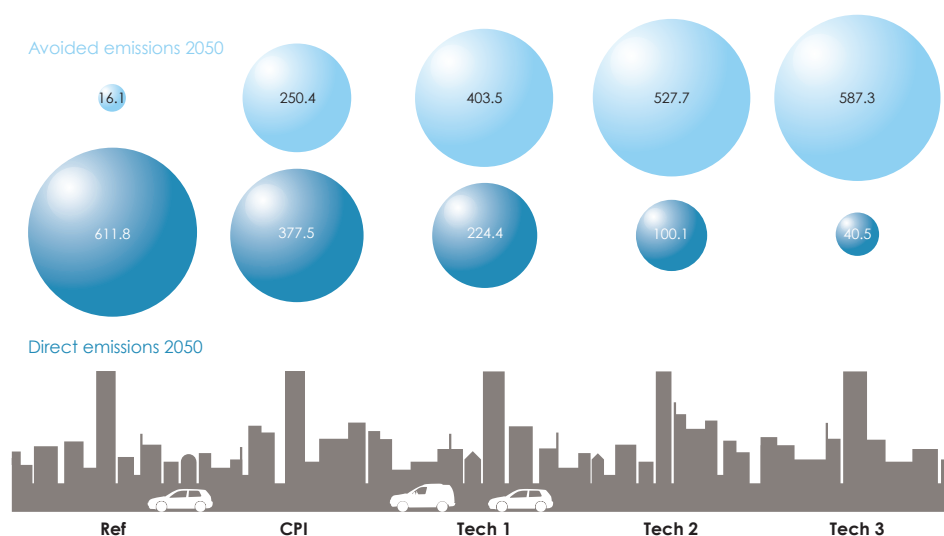
Current estimates are that around 1.35 m tonnes of NOx were emitted by cars and vans in Europe in 2010, and around 75,000 tonnes of particulates.

The potentially harmful effects of NOx 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 NOx is produced in the combustion of fossil fuels, each of the Tech scenarios projects a substantial reduction in tailpipe emissions of NOx as a result of the reduced use of these fuels. By 2050, the Tech 3 scenario projects a 97 per cent reduction in direct NOx emissions from cars and vans compared to 2010, since so little fossil fuel is consumed in this scenario. In short, decarbonisation would have the additional benefit of effectively eradicating direct NOx emissions from the vehicle tailpipe.

Under the CPI scenario, NOx emissions might fall by as much as 77 per cent (by 2050) as a result of implementing the existing Euro V and EuroVI air pollutant standards and the expected introduction of further more stringent standards in the future (Fig. 11.4). However, these reductions are much less certain than the reductions in the Tech 2 and Tech 3 scenarios, which include high levels of vehicles using hydrogen and electricity with zero tailpipe emissions. This is due to uncertainties with measuring real world emissions. Upstream emissions of NOx and other air pollutants would also be expected to be virtually eliminated by 2050 with the shift to electricity produced from renewables, nuclear and fossil power generation with carbon capture and storage.

Atmospheric particulate matter also affects human health, and is therefore also regulated in Europe and elsewhere in the world. Despite this, particulates are estimated to have been responsible for 370,000 premature deaths in Europe in 2005 . The European Environment Agency also estimates that 90-95 per cent of European urban dwellers were exposed to levels of PM2.5 above the guideline levels suggested by the World Health Organisation (WHO), while around 80 per cent were exposed to levels of PM10 beyond the WHO's recommended levels.

Fig. 11.4

Direct Nox emissions and avoided Nox emissions in the 4 scenarios in 2050
Source: SULTAN

Avoided emissions 2050

| 838.7 | 1044.2 | 1153.1 | 1259.0 | 1314.1 |

| 511.7 | 306.2 | 197.3 | 91.4 | 36.3 |

Direct emissions 2050

| Ref | CPI | Tech 1 | Tech 2 | Tech 3 |
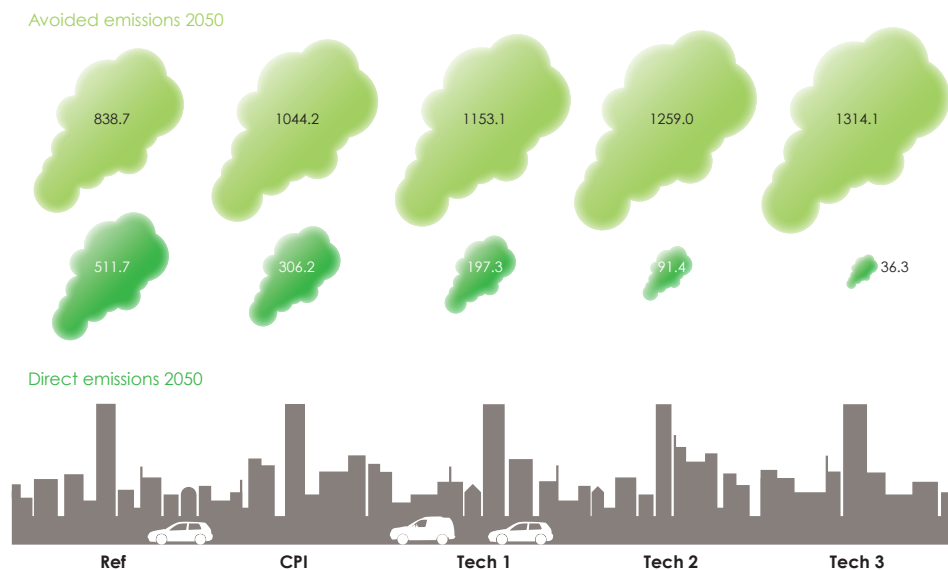
Particulates arise from, among other sources, burning petrol and diesel in the combustion process in vehicles. Consequently, another benefit of the reduction in the use of such fuels in the Tech 3 scenario is a considerable reduction in the emissions of particulates from tailpipes (Fig. 11.5).

The Tech 2, and to a lesser extent, the Tech 1 scenarios also show fairly substantial reductions by 2050 compared to 2010. By contrast, the Reference scenario projects a fall of around 29 per cent in particulate emissions compared to today's levels.

The reduction of these two local air pollutants, NOx and particulates, could yield considerable health benefits and thereby reduce long-term spending on health (or free the savings to be spent on other healthcare issues). The European Environment Agency estimates that local air pollutants from NOx and particulates from road transport have an economic cost of around €100 billion arising from sick days and health costs.

Around half of this is estimated to be caused by pollutants from heavy-duty vehicles, while the other half comes from all other forms of road transport.

Therefore, the three Tech scenarios would probably yield substantial environmental benefits, not just with respect to global issues of climate change mitigation, but also in relation to local issues of air quality and human health. These more tangible outcomes of improved air quality will be particularly noticeable in the major urban conurbations in which Europeans increasingly reside.

The conclusion to be drawn from the Tech scenarios is that, alongside decarbonisation of the power sector, decarbonisation of light-duty vehicles would represent a major step towards decarbonisation of Europe's economy. Globally, the environmental implications are even more far-reaching, especially if vehicles and vehicle designs were to be exported to other (fast-growing) world regions such as China, India and Latin America.

Fig. 11.5

Direct particulate emissions and avoided particulate emissions in the 4 scenarios in 2050
Source: SULTAN

Avoided emissions 2050

| 21.6 | 42.5 | 55.0 | 65.9 | 71.3 |

| 53.3 | 32.4 | 19.8 | 9.0 | 3.6 |

Direct emissions 2050

| Ref | CPI | Tech 1 | Tech 2 | Tech 3 |
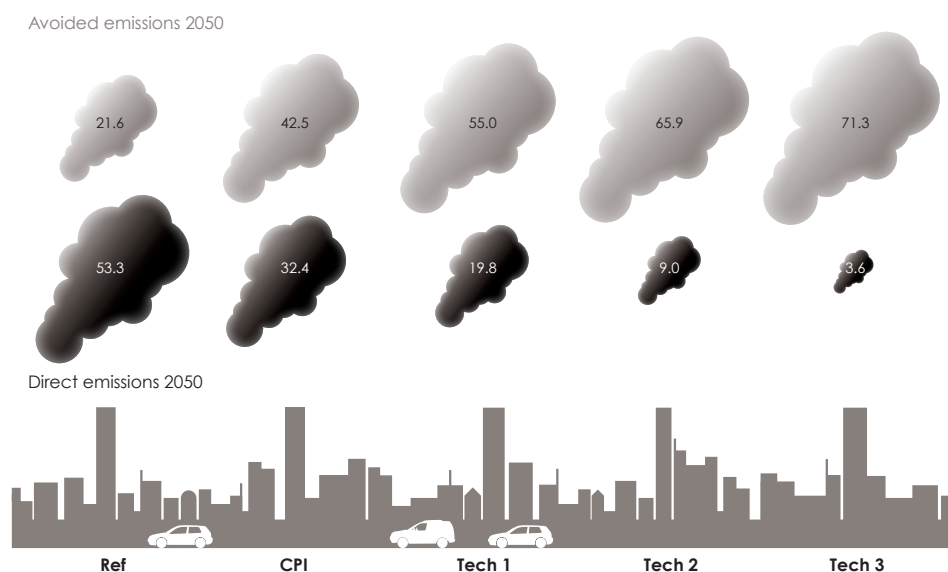
12 Synergies between transport and power systems

This chapter examines the impacts on the electricity grid that might arise as a result of charging large numbers of EVs, both the challenges and potential synergies

To maintain the supply of electricity (voltage and frequency) to the required standard, Transmission System Operators (TSOs) provide a range of support services to deal with supply/demand imbalances, either caused by variability (expected change) or uncertainty (unexpected change) in the system. The duration of these events can vary, for example:

- a contingency event such as a large generator suddenly going off-line would require near-instantaneous frequency stabilisation followed by other services to bring frequency back to an acceptable level.

- where wind energy output is dropping over the course of a few hours while energy demand is increasing; the higher ramp rate of demand requires sufficiently flexible energy resources to restablise frequency.

- when too much energy is being generated (e.g. from inflexible conventional generation plus non-dispatchable renewables) which requires output to be constrained, or load to be increased to match supply.

Electric vehicles (EVs) could have negative impacts on the future grid, for example if EV charging results in a new peak in demand, then the grid may need significant investment in generation, transmission and distribution to accommodate this. There is also a high risk that transformers on distribution networks become overloaded if too many EVs charge simultaneously on the same circuit. However, EVs could also provide services to the grid.

Whether over short or long timescales, balancing supply and demand can involve changes in generation output (to increase/decrease supply), or changes to demand. Both approaches are used to maintain reliability and to help match supply with demand.

These services are procured from participants in the energy market (who may be generators but also those providing demand response (DR)

services). An example of a DR service is a large industrial process which can be interrupted at short notice. A sufficiently large fleet of EVs represents a significant aggregated electricity load.

As the charging energy is being stored in the vehicle's batteries (rather than being used immediately) there is scope for modifying this charging process should this prove beneficial to the grid.

With additional hardware, there is the potential in the longer term (if technical and economic barriers are overcome) for this distributed store of energy to provide power back to the grid[1] at appropriate times. But due to challenges around technology and current expectations of the business case, this has not been modelled.

This chapter identifies the value that could be generated by the stock of EVs through providing grid support services. It uses EV deployment assumptions from the Tech 2 scenario, the less ambitious of the two scenarios that include EVs. It also assumes a high rate of deployment of renewable electricity (RES), raising to 80 per cent by energy in 2050. Of this, wind delivers 30 per cent of energy, while non-dispatchable renewables deliver 53 per cent of energy.

A set of potential services to the power grid is examined, and those that are most relevant to EVs are shortlisted. The future growth in demand for these services is projected, and assessed against the potential for EVs to supply these services. The overall value in the EU is determined, and the macroeconomic impact is assessed.

The value of these services is assessed at a relatively high level. Data on the national (aggregate) demand for grid services is identified, and data in the literature, as well as predictions by system operators, are used to estimate the future level of demand in response to the high RES penetration.

Therefore, the data should be interpreted not as a prediction but as an indication of the potential, acknowledging a high level of uncertainty. For transparency, the approach does not attempt to reproduce conditions that pertain to separate countries in the EU; instead, data which represents the European system in 2050 is used (consistent with the ECF 2050 Roadmap).

Grid balancing: response and reserve

System operators procure a broad range of services to maintain quality and reliability of grid supply. The terms used for these services (and indeed the specifications of these services) vary between System Operators. A map of the services and how they interact is shown in Fig.12.1.

In different countries, similar terms are used for different services. For example, US utilities identify the "operating reserves market" which includes reserves for regulating frequency, as well as for example contingency reserves.

In the UK, "frequency response" is the term used for services for regulating frequency, while "reserve services" is the term used for the services dealing with unforeseen demand increase and/ or loss of generation.

For the purposes of this study, a simple delineation is used:

- Response (primary response) is the set of services called upon to maintain frequency, either following an unexpected event, or in the normal course of balancing supply and demand. The services need to respond quickly and are characterised as acting over seconds to minutes.

- Reserve is the set of services used to manage longer term imbalances (for example, shutting down industrial processes if supply is decreasing. Reserve is typically provided over a period of minutes to hours.

Fig. 12.1

Operating reserves
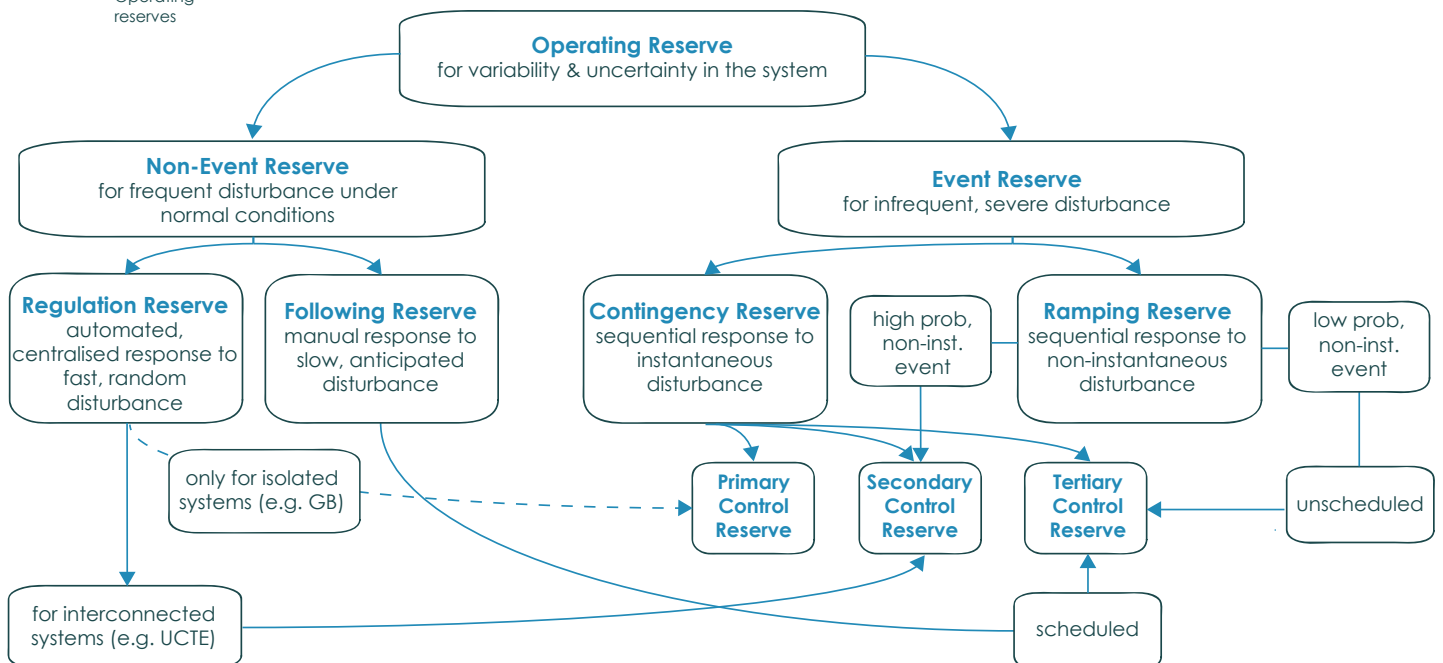
Fig. 12.2 and 12.3 illustrate response and reserve services, on a typical historical daily load profile (the profile may change in the future). Frequency response is required constantly, but is in greater demand when the underlying energy demand is low, and when any variation has the largest impact (Fig.12.2).

Typically frequency response services are called to respond very quickly (e.g within 4 seconds of a signal being received). Demand management can be used to provide frequency response; by turning up or down, load is altered and frequency adjusted.

Currently, for an electricity network the daily demand for reserve services is flatter compared with the daily demand for response services (as shown for the UK Grid in Fig. 12.4, although there tends to be an increase when load is higher, on the "shoulders" of the load (when it is increasing or decreasing).

Reserve may be used to settle any residual imbalances in supply/demand following "gate closure" (when contracts to supply are fixed); and to make up for shortfall following contingencies (such as a generator outage).

Fig. 12.2

Response and reserve services

Power (MW)

Timescale is fraction of a second

Response
- Frequency regulation
- Short duration (seconds to minutes)
- Response provided within a region
- Max. requirement overnight when load is low

Time (24 hours)
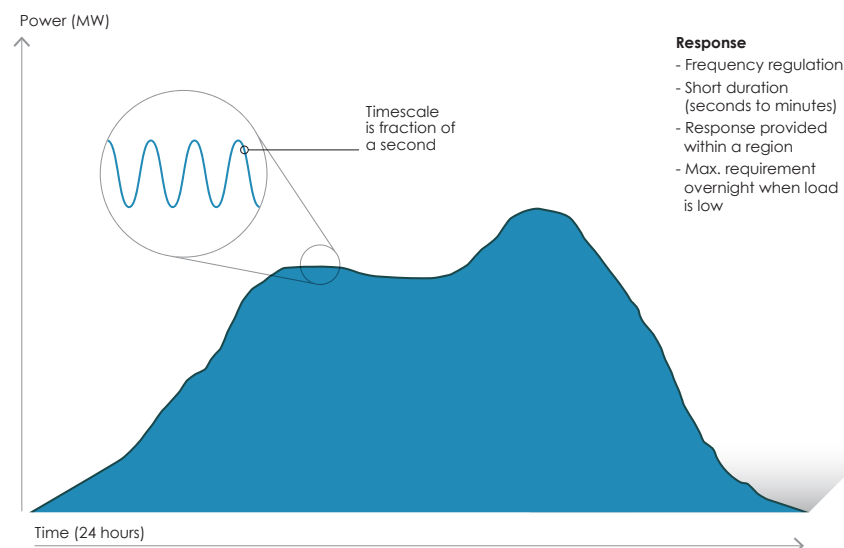
Fig. 12.3

Reserve services

Power (MW)

Timescale is minutes/hours

Demand

Generation

Reserve

Reserve
- Load support
- Longer duration (seconds to minutes)
- Can be provided between interconnected regions

Time (24 hours)
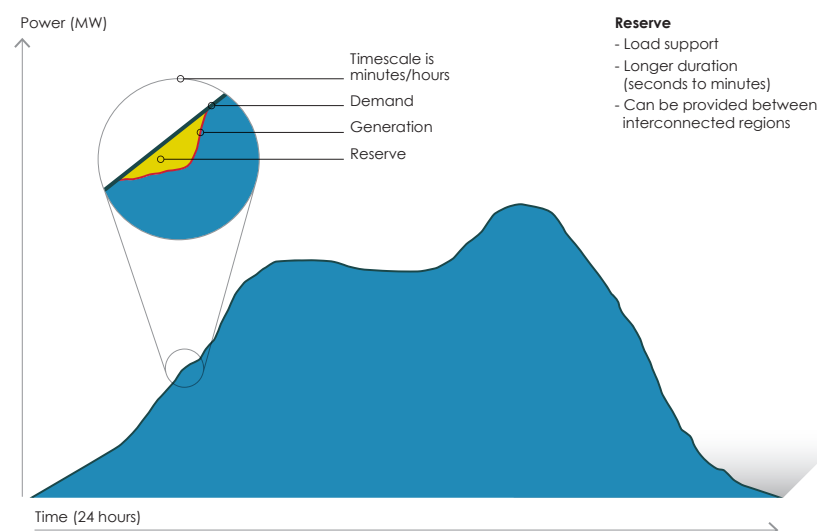
Reserve services could be provided either by generators or by any end users that are able to interrupt or adjust their demand. It should be noted that these diurnal patterns are based on grids with relatively low RES penetration. In an 80 per cent RES scenario, response and reserve will need to manage net load (ie including RES generation) and so the need for such services may be expected to change.

In both cases, these services are procured on an availability and a utilisation basis. This means that the system pays for the capability to supply services (e.g per MW of capacity for each hour available), as well as the utilisation of these services (per MWh). The high value placed on capacity is important in the EV context: it means an EV fleet could be paid to provide these services, which would in turn imply that the load profiles actually realised by its batteries differ from those without the service which might result in a negative utility from the users point of view.

But if the EVs were utilised only infrequently, the provision of the services could have little discernable impact on the driver.

Peak avoidance and reduced curtailment

Aside from the services that support the power quality dimension of reliability, a large fleet of electric vehicles could have other positive impacts on the network.

If the charging profile of EVs correlates with the underlying electricity demand profile, then charging events will result in a larger peak electricity demand. This could significantly impact the whole network, necessitating an increase in the need for generation capacity, transmission network capacity and distribution network capacity and potentially adding significant cost.

Fig. 12.4

Daily profile of response and reserve services (For the UK, summer 2010)
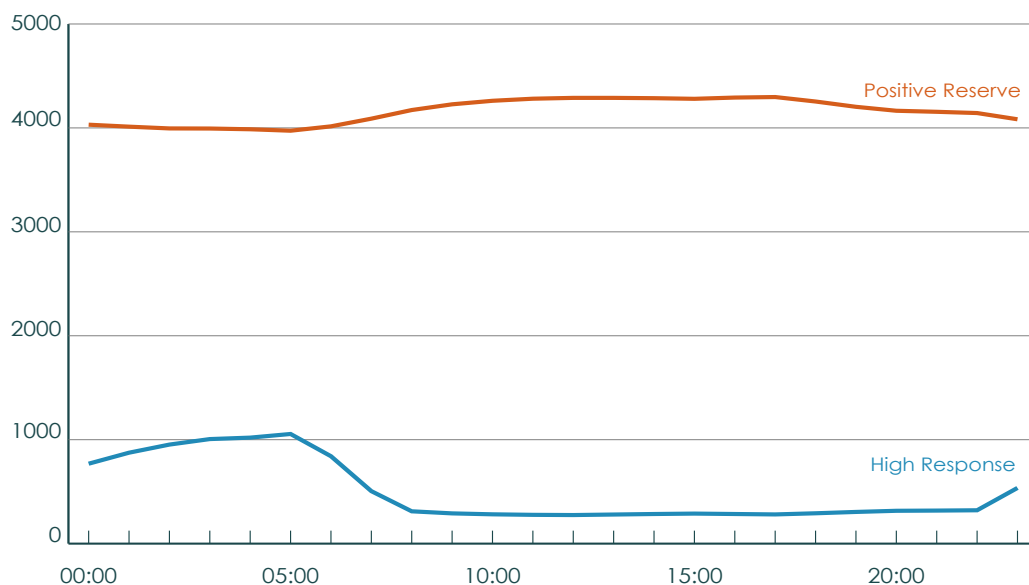
There is a clear correlation between vehicles arriving at home (potentially to recharge), and a daily increase in electricity loads, so this issue is important to address to avoid significant exta cost to the energy system. However, delaying or advancing the period of time during which loads come onto the network can prevent any increase in peaks and is known as 'load shifting' under the umbrella term Demand Side Management (DSM) as illustrated below in Fig.12.5.

Wind and photovoltaic renewable energy generators are not dispatchable – they cannot be turned up to meet the demands of the grid, and turning these resources off, know as curtailment, is a waste of energy.

The introduction of significant renewable capacity on networks is likely to result in periods of excess renewable (RES) generation, which either has to be used, stored or curtailed. Curtailment represents a loss of RES generation and adversely affects economics and CO_2 benefits. By using DSM to move EV charging events into a period of high RES output, more of this clean energy can be used.

It is important to acknowledge that this is subject to sufficiency of transmission and distribution capacity, network stability criteria, and the appropriate regulatory regime. An illustration of the principle of curtailment reduction through DSM is shown in Fig.12.6. Note that real demands and RES generation profiles will change over time, and the call on response and reserve services will change also (a representation of the future increased demand for these services has been included in the modelling).

EV services to the grid

As noted previously, grid services can be provided by varying generation, or by varying demand. In the context of EVs connected to the grid we identify two types of service:

- "One-way" services are those arising through varying demand (charging), also known as Grid-2-Vehicle, or G-2-V.

- "Two way" services are those arising through generation of electricity by the vehicle to be fed back to the grid, or building. These are also known as Vehicle-2-Grid, or V-2-G, and V-2-Building, or V-2-B.

Fig. 12.5

4 Demand side management (DSM) is a technique which can be used to attenuate peak demands and move loads in time

Power (MW)

Load Shifting
- Avoiding peaks in net demand (i.e. demand of RES output)
- Avoid generation and transmission investments

Net demand peak avoided

Demand

RES generation

Time (24 hours)
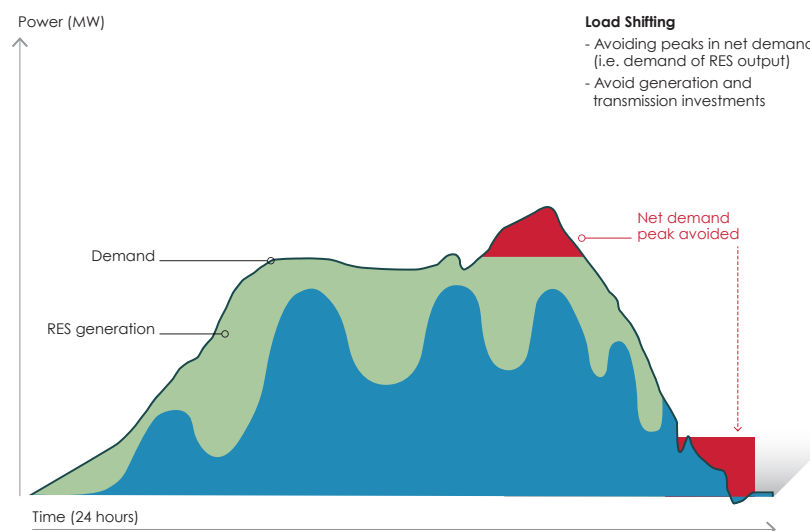
In both cases, the impact of a large EV fleet could be significant:100 Million EVs connected at charging rate of 2kW has the technical potential to deliver 200GW of demand response (nearly 10 per cent of generation capacity in 2050) at very little additional cost.

While discharging electricity from EVs into the grid seems attractive at this scale, there are significant barriers. EVs would need to be equipped with grid-tied inverters (representing a significant additional cost). Also, the additional cycling of EV batteries would reduce their longevity – a significant concern for the current generation of automotive battery technologies.

There are times when electricity prices are very high – sufficient to make "generation" from EVs financially attractive at these times. However these are infrequent events and the resulting load factor on the equipment is low, making economic operation on an annual basis, very challenging indeed.

While acknowledging that battery degradation rates should improve; that flexibility might be more highly valued in future markets with increasing variable RES; and that more innovative

approaches to two-way service provision may arise (EVs could use the inverters in home PV systems); two way services have been excluded from this analysis.

A concept being explored by some automotive manufactures is Vehicle to-Home/Building. This is where the EV provides services, not to the grid, but to the building to which it is connected. This could include the generation of electricity at times of high cost but might also include providing uninterruptable power supply and back-up power. It is certainly the case that in areas where a grid extension is costly, or where the network is weak and unreliable, a customer could place a high value on a V-2-B service.

For this report, it is not thought that V-2-B services would attract high value in EU countries, and these are not explored further here. It is, however, worth noting that buildings, e.g. work places, might in effect become aggregators of EVs for RES curtailment reduction as they would encourage charging when electricity prices are low.

Fig. 12.6

Reduced RES curtailment via demand side management (DSM). A predicted excess in RES output could be accommodated by delaying charging to coincide .7

Power (MW)

Reduce curtailment
- Add demand during periods of high RES output

Excess RES

Demand

Vehicle charging

Time (24 hours)
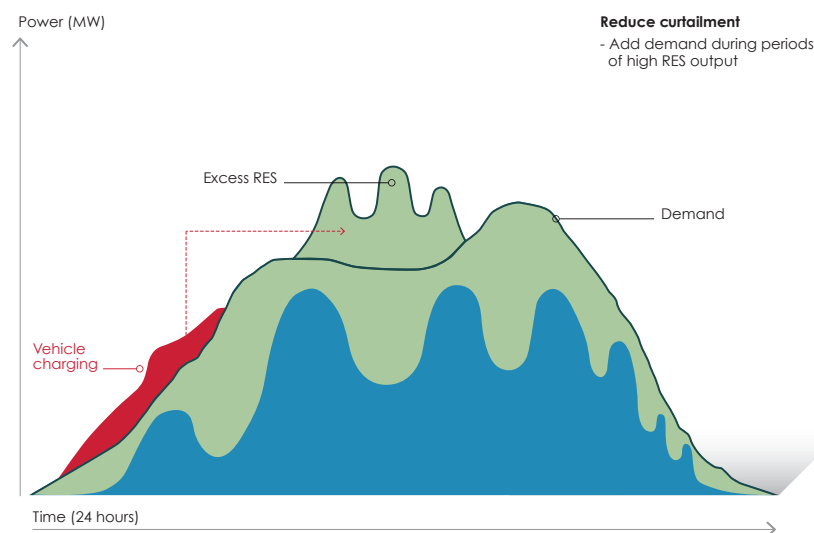
Availability of EVs to supply response and reserve

As EVs can only provide grid support services when stationary and charging, only a proportion of the fleet may be able to provide such services at any point in time. A model of vehicle arrival and departures was developed to identify the level of charging capacity on the network at each hour. This is related to the cumulative arrival and departure patterns, the charging rate, and the amount of charge required by each vehicle.

Fig.12.7 shows the percentage of daily car movements, per hour and by destination. It shows the significant movement of vehicles away from the home during the morning rush hour, peaking at 9am, and the reverse during the evening period, peaking at 6pm. Fig. 12.8 shows the demand that would arise for home-charging if the daily charge event occurs immediately after the last journey of the day is completed (blue areas).

Vehicle charging events are distributed through the day over some 20 hours but he peak at 6 pm is ca. 25GW in 2030, rising to 90GW (in 2050). The peak becomes narrower over time – this is due to vehicles improving in efficiency and requiring less charging duration for the same daily mileage. This graph does indicate potential issues with EV charging on the low voltage (distribution) network, however an analysis of this is out of scope.

The graph also provides an example of what would happen if the home-charging load were shifted from day to early hours of the morning, and concentrated over a much shorter timeframe of 9 hours, to provide a more sustained level of demand (red areas).

It can be seen that for a 4-6 hour window, approximately the same level of demand capacity can be provided, as occurs at the unmodified peak. Charging at 18h (blue) would likely increase peak gross demand but charging at night (red) would not.

Share of EU car journeys by destination: typical weekday (based on GB travel patterns)
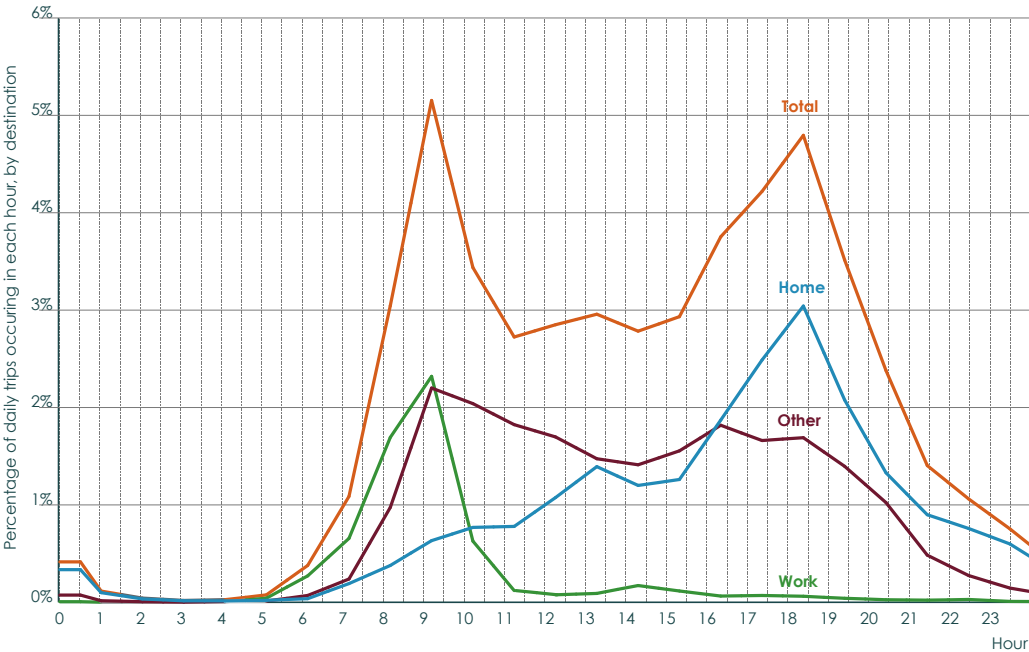
This is an illustration of what could be achieved with Demand Management of EV charging but is not intended as an illustration of best practice.

In this case, the objective is to remove an evening peak in EV charging demand, which coincides with a peak in general demand. In a high RES future, the same quantity of charging energy could be moved to the overnight period as shown, or could be used to provide another service (for example, charging around midday during periods of high RES (solar) output, such as would occur in the south of Europe.

This sustained level of charge is used as the aggregate level of response and reserve capacity offered to the system by EV charging. By operating overnight, this modified profile may correlate well with the requirement for response (which is highest overnight). However, it is clear that reserve services could only be maintained at this level for a proportion of the day. The system operator would require other providers of response outside this period, during times in which EVs are on the road and therefore unavailable to provide services to the grid.

Demand for grid balancing services with high RES penetration

In this study, an 80 per cent penetration of RES on the electricity network by 2050 fundamentally alters the need for response and reserve. This section is focused on estimating the change in demand for response and reserve, over the period to 2050, resulting from significant RES deployment.

There are a number of data sources which identify the impact of wind energy on grid services. All agree that variability and uncertainty will increase in the future with significant wind deployment. Their focus is on wind, rather than on RES generally because forecasting wind output is very difficult, due to the cubic relationship between wind speed and power output, which means that unexpected wind ramping effects can be very large. Hence this study uses the available data on system reliability in relation to wind deployment, acknowledging that while wind may be dominant, it will not be the only RES to impact on system reliability.

Fig. 12.8

Daily EV charging profiles out to 2050: unmodified, and with DSM
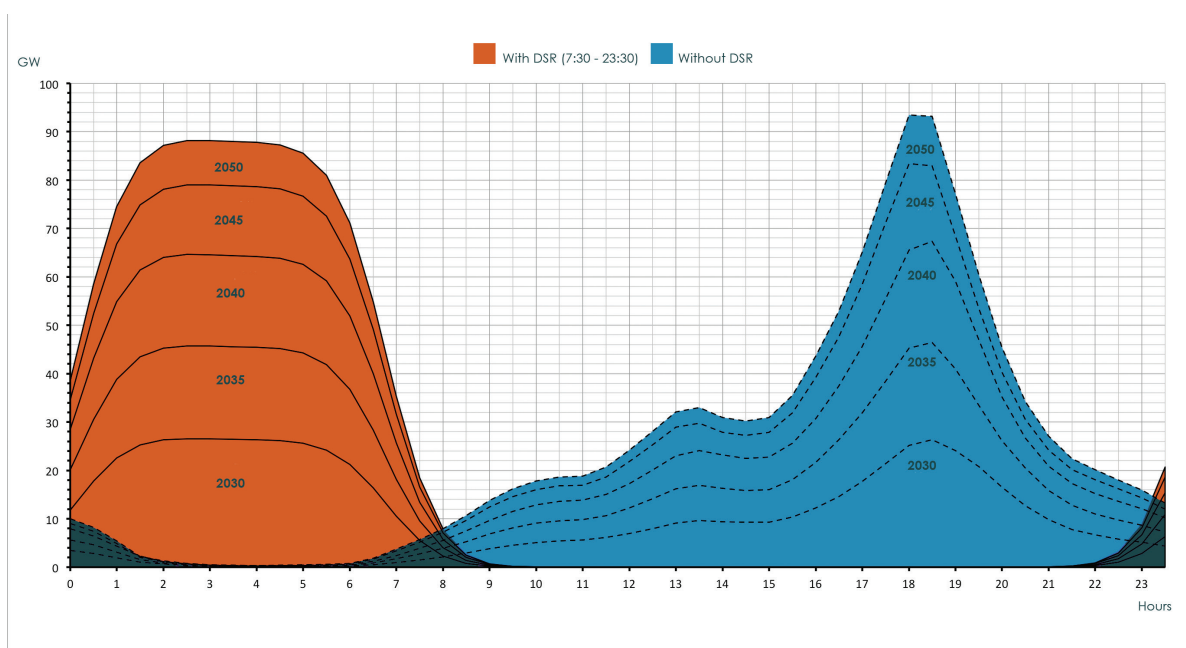
It is acknowledged that the system impacts studied in the literature are specific to each system. The level of interconnectedness of a network; the geographic and therefore temporal distribution of wind; and the accuracy of forecasting, can determine the level of impact in each case. A detailed assessment is outside the scope of this study.

Impact of wind on response

Inherent in thermal power generation is a certain level of inertia. For a short period of time, this allows generators to support the system frequency following an outage somewhere on the system.

Currently, most wind turbines do not contribute to system inertia. However in countries where wind penetration is already high, system operators are imposing requirements for emulated governor and inertial responses on turbines to provide power tracking and frequency regulation services.

Therefore, and while noting some exceptions, most of the literature is in agreement that a significant increase in wind energy will not require a significant increase in response.

Also, there is general agreement that significant wind penetration does not imply an increase in contingency requirements, as the wide geographical distribution of wind power means that a wind farm outage is never larger than the existing single outage of a power station.

This is supported by data from the UK National Grid which shows no increase in response requirements arising from wind penetration. For this study, the demand for response in the EU is increased from 4.5 GW currently, to about 7 GW in 2050[1] (this correlates well with the near doubling of generation capacity on the network over this time).

Fig. 12.9

Ratio of Short Term Operating Reserve to wind capacity (for the UK)
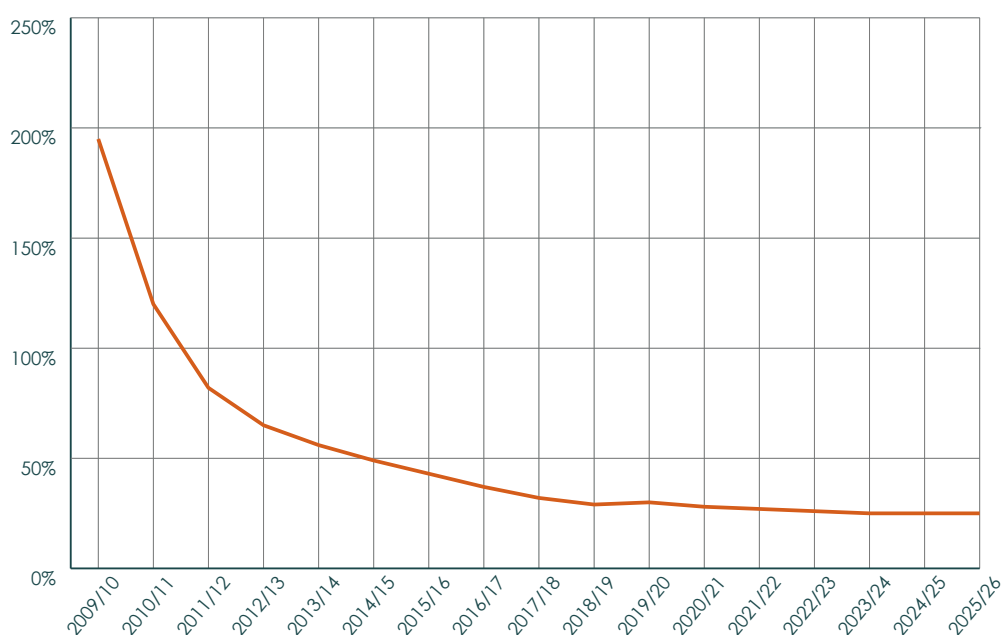
Impact of wind on reserve

In contrast to response, wind is expected to require a significant increase in reserve services. This is because the ramp rate of wind may be significant e.g. if load is increasing just as wind is ramping down. Also the difficulty in predicting wind output accurately means that greater reserves need to be held.

The UK National Grid has published its expectations for reserve (positive reserve / Short Term Operating Reserve (STOR)) out to 2025 and the data is shown in Fig.12.9, as a percentage of STOR to Wind capacity on the network. Initially, reserve levels are set by the demands on the (primarily) thermal generator network, and not by the wind level. As wind penetration increases, the reserve requirement is increasingly correlated with wind penetration, and in 2025 it settles towards 25 per cent of the wind capacity.

This data is specific to the UK and the ramp rate of wind across the UK network is likely to have a larger proportional impact than an equivalent level of wind penetration in the mainland European UTCE/ENSO-E region. In the latter, the impact is lessened by the greater geographic (and hence temporal) distribution of wind capacity and output, combined with an integrated network. Nevertheless the UK data serves as a useful indication of the growth of necessary reserve with the deployment of renewables.

Using this ratio, the level of demand for reserve can be estimated through time, and in 2050 is about 150 GW (for 600 GW of wind). A supporting data point is from the European Climate Foundation's "Roadmap 2050", which predicted a maximum reserve requirement of across Europe of 183 GW.

This can be compared to the maximum EV supply rate of about 90 GW, indicating that EVs are not expected to saturate the market for reserve.

The need for response and reserve services is greater in countries such as the UK and Ireland, which are not well connected to the larger ENSO-E system in mainland Europe. It is acknowledged that initially, each country will have unique requirements, but the EV fleet will be small and any impact very limited.

In the longer term, when an EV fleet could have more significant impact, all countries will need to have high RES capacity[2] and the European system is expected to be much more interconnected with significant additional transmission capacity. This supports our approach of treating the EU as a single entity for this high level study.

Avoiding creating new demand peaks

As stated above, that the EV fleet in 2050 could represent 90 GW of charging demand, at the peak time of around 6 pm. This is a significant level of demand, representing nearly 5 per cent of EU generation capacity in 2050. If this demand (net of RES output) were to coincide with the baseline consumption in electricity, then a new generation peak would arise, with significant cost implications on generation, transmission and distribution infrastructures.

The correlation is shown in Fig.12.10, using the assumption that charging were to happen immediately after the last trip of the day. The graph shows an EV peak load at 6 pm, close to a peak in general demand at 7-8 pm. The baseline peak demand of about 520 GW is increased to nearly 590 GW at these times. While renewable technologies could be generating at these times, the system must maintain reliability if they are not generating. This could be a significant and costly issue and EV charging should be managed to avoid this situation.

Fig.12.10 shows the effect of demand management techniques to delay the charging load to the overnight period, away from the peaks. This could be very successful in eliminating new peaks. This effect could be achieved very simply by having a limited time delay on all EV chargers. The impact on drivers should be minimal – an overnight charging window is large enough to accommodate a delay while ensuring that all vehicles are still fully charged when required the next day.

Some drivers might wish to have an override button to charge vehicles immediately when plugged-in. Careful design of appropriate tariffs, reflecting the impact on distribution, transmission and generation assets might be used to discourage peak time charging. Load control and time-of-use tariffs will be facilitated by the upcoming roll out of smart meters (current in some EU countries).

Reducing curtailment

At a certain point in any network, an increase in RES capacity cannot be accommodated fully and some RES output may need to be constrained. As RES capacity increases, more output will be constrained and returns on investment deteriorate. Such an effect arises earliest in weaker grids (for example, a study on the Irish system determined that beyond 8GW of wind, all additional RES generation would have to be constrained off completely). A study by Imperial college suggested that 40 per cent of wind output in the UK could be constrained by 2030. Reducing curtailment is valuable in reducing CO_2 emissions, as well as improving the economics of RES investments.
Curtailment can be reduced by:

- increasing transmission capacity (shifting generation to a market with greater load)

- adding energy storage (in effect, an additional load at times of high generation)

- using demand side management (DSM - moving load into a period of high RES generation to match supply and demand)

Fig. 12.10

Avoiding new demand peaks through demand side response (DSR) management of EV loads
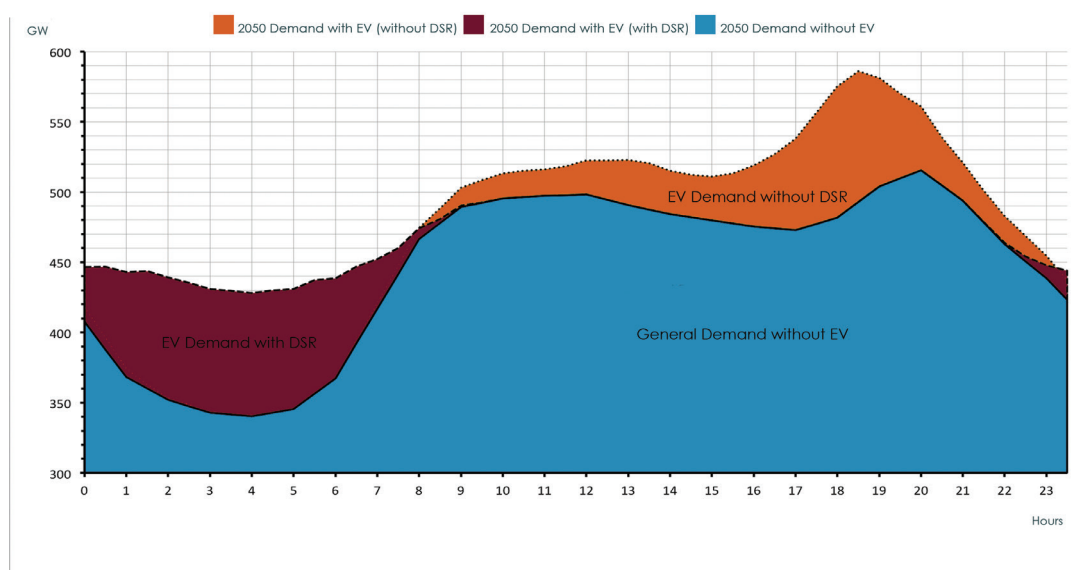
Benefits arise at a number of levels in the system. By permitting greater TWh of RES on the system, there are significant opex savings (avoided TWh of thermal plant). Storage devices in appropriate locations work to reduce peaks and fill troughs, thus providing savings on network investments. An EV fleet can act as an energy store, using DSM techniques to move the charging load to correlate with RES output.

Determining the benefits arising from the introduction of a unit of storage on a network is highly location specific. The benefit is greatest for networks with high RES penetration, but the value decreases if the network is optimised (i.e. transmission capacity is increased). Also the value of storage is highest with the first unit, but diminishes thereafter.

A starting point for this work is the ECF's Roadmap 2050 study, which showed that an optimised transmission network in Europe would result in RES curtailment at 3-4 per cent of output, even with about 80 per cent RES on the system by 2050.

An EV fleet could reduce curtailment further. A study by Imperial College of the value of storage on the UK network[13] was used to relate the level of storage (as a percentage of RES capacity) to the reduction in curtailed generation, using the 2050 constrained level as a starting point. The data is shown in Fig.12.11, which indicates that the initial units of storage have a greater impact on constrained generation.

It was shown above that the EV fleet in 2050 could provide 90GW of storage capacity, for an aggregated period of about 6 hours per day. Work by Imperial College suggests that short timescale storage durations (6 hours or less) are the most valuable in reducing curtailment[4]. However, storage in the Imperial College study was not constrained by other daily demands such as EVs would be. This might reduce the EV storage capacity through the day. On the other hand, if the whole EV fleet could be recruited when stationary, and if some charge was required by all, then short durations of higher power storage loads (up to 300 GW in theory) could be generated.

Fig. 12.11

Reduction in constrained RES generation, through deployment of storage
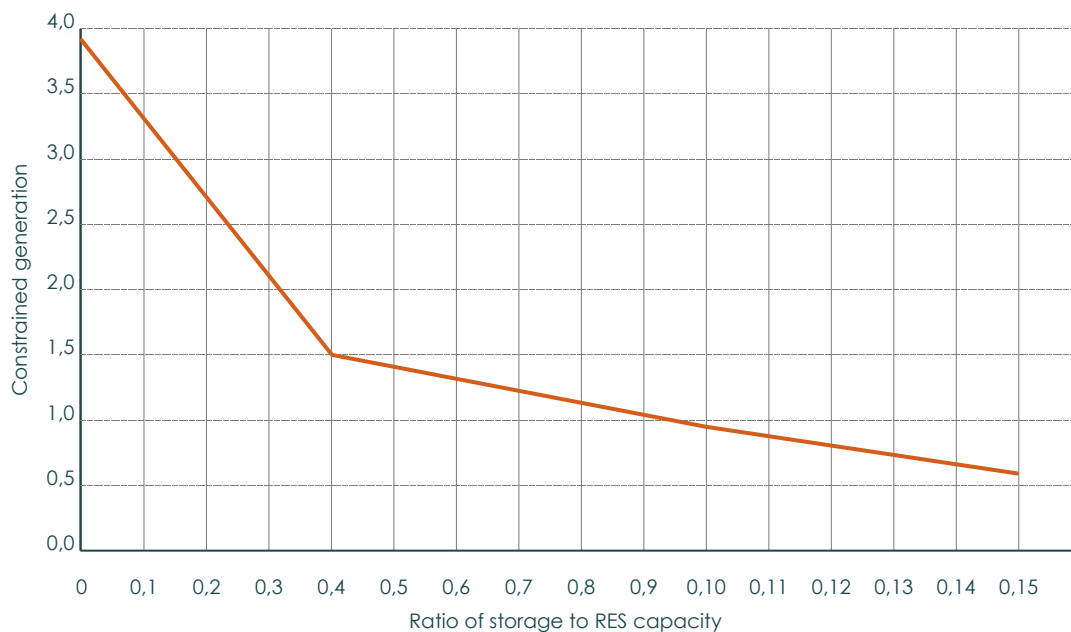
Using the above data, it is possible to link the EV related storage capacity and RES penetration to calculate the value of avoided curtailment. As a cross-check of this approach, assuming that each TWh of wind allowed on the system through this means is valued at the wholesale electricity cost, the value per unit of EV storage capacity coming out of this analysis is calculated at €90-110/kW. This is reasonably cautious, when compared against data in the Imperial College study. In that report, storage capacity is valued at £600/kW (or above) for the first unit, but the value does drop to between £100-200/kW when storage penetration is higher, and when other means of curtailment reduction is introduced (such as transmission capacity and DSM)[3].

Results: impact of EV services
Value generated by an EV fleet providing grid services

The three value streams identified above: provision of one-way response, one-way (secondary) reserve, and reduced curtailment, are combined in Fig.12.12 and Fig.12.13. Note that the future value of services is pegged to the cost of electricity in each year (which is expected to double over the period).

For response and reserve, the value of capacity and utilisation are based on historical data provided by the UK National Grid[17]. The effective reserve valuation is €41k/MW per annum. The effective response valuation is €66k/MW per annum (although this reduces over time per MW of total EV storage as the fleet grows in size and saturates the response requirement).

Of these services, by 2050, reserve and curtailment avoidance provide the greatest contribution, while frequency response provides relatively little. There is significant growth in the aggregate value of these services over time, with the growth of RES on the system being the main driving factor for this. This assessment indicates an annual value of €18 billion.

Fig. 12.13 shows the value streams per EV in the fleet. Initially, there is a fairly even balance in value between the three, but over time, the value of response per participant reduces significantly. This is because the fleet is capable of providing the level of response required in the EU (at least for some fraction of the day) and additional vehicles simply dilute the value per participant.

Fig. 12.12

Annual revenues from EVs providing grid services

- Reserve
- Frequency response
- Reduced curtailment
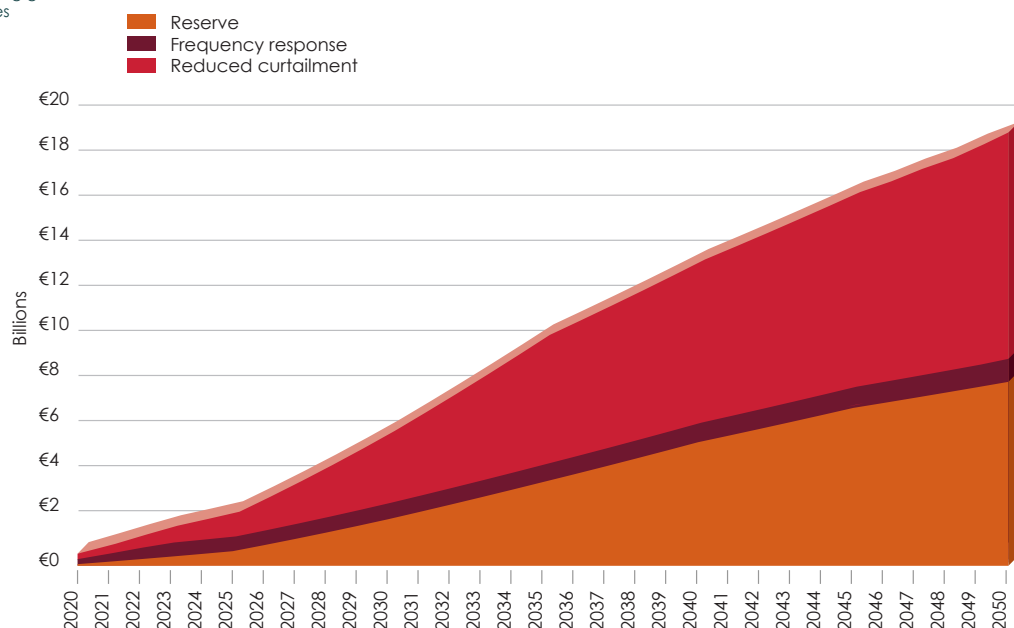
No attempt is made to model the potential impact the EV fleet could have to change the market value of these services. It should also be noted that in practice these services may not be 100 per cent additional; a vehicle providing reserve capacity may not be able to provide frequency response.

Nevertheless the data does provide an indication of the value generated. Based on an annual demand of 1,141 kWh/vehicle per year, and an electricity cost of €172.3/MWh (both 2050 numbers), the annual cost of electricity for an EV is about €196. This study suggests that the fuel cost of an EV could be halved if the grid benefits were fully monetised and passed on to EV owners, without additional costs.

Realising the benefits

As a minimum, to avoid the generation of new demand peaks, relatively inexpensive and passive measures could be deployed on EV chargers, for example a simple time delay (with user override) to move charging away from peak demand periods.

However this focuses on avoiding a new problem rather that ensuring a future EV fleet can provide useful grid services. The approach can be seen as an interim measure in the transition to aggregation and participation of EV DR in markets. To provide dynamic response or reserve may require more active solutions including smart grid technology.

With such a system, it is unlikely that all of the value generated by EVs will flow to the vehicle owner. This is because the service is provided (by the driver) at one point in the network but the value arises upstream, either at the system operator level, or at the generator. There would undoubtedly be a transaction cost for the linkage of these.

Also, each vehicle cannot provide meaningful services alone, and some form of aggregation will be necessary, to achieve a minimum level of capacity required to participate in electricity markets.

Fig. 12.13

Annual revenues, per EV in fleet.

Legend:
- Reserve
- Frequency response
- Reduced curtailment
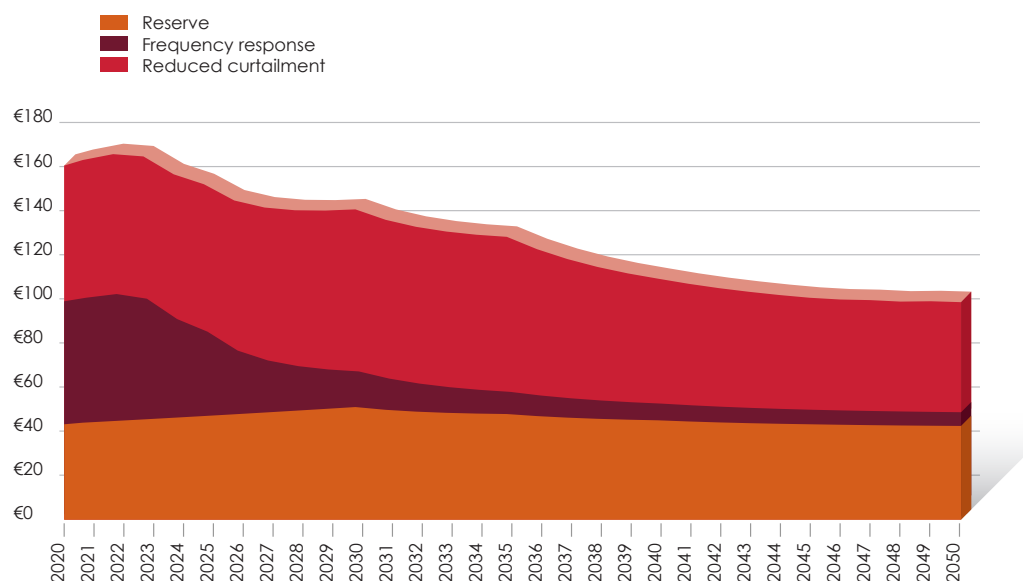
Pooling EV loads will result in transaction costs, but the ability for the aggregator to develop a successful business model depends on full access to competitive markets, for EV grid support services to be fairly and appropriately compensated by electricity markets or by the system operator. If markets fairly compensate flexible demand response, as is beginning to happen in the US (e.g. FERC Order 755), then the flexible demand response that EVs are capable of providing might have higher value in the future than modelled in this study.

The value that EVs can provide to the grid might also increase if technical barriers to two-way charging are overcome, and these services become economically feasible. At the same time, EVs will need to compete with other low-cost flexible demand side resources such as electric water heaters.

Currently, the demand side only represents a fraction of the response and reserve capacity in Europe, and most of these services are procured either through balancing market mechanism, or through regulated requirements on large generators.

It is likely that there will be some inertia amongst system operators in procuring a large percentage of vital services through such a novel mechanism as a distributed EV fleet. All participants will need to be confident that the fleet can maintain the desired level of service while not impacting excessively on driver satisfaction.

Market rules need to change to open up markets to demand response and to allow aggregation. Demand response (DR) needs to gradually establish itself in European markets and ideally keep pace with increasing shares of variable RES on the system.

Economic impacts of EVs providing grid services

If the grid services identified could be realised, it would clearly improve the macro-economics of electric vehicle deployment. Through the development of business models that can extract the value of response services, it is possible that owners of electric vehicles could capture a substantial part of the value service, either directly through an agreement with electricity suppliers, or through an intermediary business service that uses the value service to offset the battery cost to the vehicle owner.

Reduced curtailment would either lead to lower wholesale electricity prices (and so the value would be distributed across all electricity consumers), or by owners of batteries capturing the value directly, either through reduced electricity costs or a direct transfer payment from a utility provider (or intermediary).

Model-based analysis in E3ME suggests that value services would increase the GDP impact, but only by a small amount (less than 0.1 per cent by 2050).

13 Conclusions and limitations

This research highlights the economic co-benefits of decarbonising Europe's fleet of cars and vans. The principal macroeconomic impact comes about as a result of reducing European dependence on imported oil. As a result, more of European consumers' spending stimulates value that is retained within the European economy. By retaining value in Europe, rather than allowing it to leak abroad through payments for oil imports, a substantial number of jobs are generated.

The overall results are contingent on the assumed fuel costs and the assumed cost of the different technologies, relative to the efficiency gains that they deliver.

Forward-looking technology costs are inherently difficult to anticipate. The approach taken in this study was to generate a series of central technology cost assumptions that were then refined by a Working Group comprising industry representatives and other technology experts.

To 2030, the technology costs generated by this study are well-aligned with other studies, and perhaps even cautiously on the high side. To further ensure the robustness of the results, the economic analysis is tested against a range of alternative technology cost assumptions. Although higher technology costs yield worse results than lower technology costs, all of the results are positive for the economy.

Fuel cost assumptions were generated for each of the fuels considered. Crude oil prices were based on the most recent IEA World Energy Outlook, which assumes steadily rising real oil prices and it is assumed that existing tax regimes on petrol and diesel remain in place. The economic results are not overly sensitive to the crude oil price projections, although intuitively,

decarbonisation of Europe's car and van fleet has greater economic benefits in a future world of high oil prices, since even more leakage, in the form of payments for oil imports, is avoided.

Since the vehicle types in this analysis include electric and hydrogen fuel cell vehicles; price projections were developed for these fuels. Electricity prices reflect the vision for an 80 per cent renewable grid in 2050, as explored in the European Commission's "Energy Roadmap 2050" and as proposed in the European Climate Foundation's "Roadmap 2050". Price increases are therefore quite substantial. A further assumption is made that electricity sales to vehicles will include the same taxes and margins that are applied to household electricity sales.

Hydrogen prices broadly follow wholesale electricity prices, but also include an additional component to recover the production, distribution and retail costs. A further assumption is made to apply VAT to hydrogen sales. Ultra low-carbon electricity and hydrogen is relatively expensive for each unit of energy flowing into the vehicle, but this is more than offset by the high efficiency of these vehicles.

Without a transition towards more efficient cars and vans, total fuel costs will rise. As parts of Europe's economy grow, vehicle ownership is expected to rise and the total distance travelled is therefore expected to increase. Combined with increasing crude oil costs, our research estimates that the total fuel cost for Europe's car and van fleet could double by 2050. By stark contrast, fuel costs could be reduced by a third compared to today if potential efficiency gains are realised, despite increasing fuel prices and vehicle ownership.

Rebound effects are considered. The direct rebound effects could partly undermine the carbon reduction of a transition to low carbon cars and vans, but only if the future fleet continues to be powered by diesel and petrol, rather than a switch towards electricity and hydrogen. Equally, a direct rebound effect undermines the economic results, albeit only in part, as it leads to a smaller reduction in crude oil imports.

A particular concern of national governments is the loss of revenue from falling sales of petrol and diesel. The approach of the economic analysis was to maintain government balance sheet neutrality in real terms. The modelling suggests that although very small increases in VAT rates are required in the short term to maintain government revenues, in the longer term the stimulus to the economy generates enough income tax revenue, social security contributions and VAT receipts to outweigh the lost excise duty from falling petrol and diesel sales.

Infrastructure is required to support more advanced vehicles such as PHEVs, BEVs and FCEVs in the form of electrical charging points and hydrogen production, distribution and retail facilities. This is expensive, but generates substantial value to the economy. Large-scale deployment of electric vehicles could provide a value service to the electricity system. Batteries could generate value by reducing curtailment of excess renewable electricity, or by allowing the grid to balance short term operating reserves using batteries that are connected for charging. This value could be substantial.

The model-based analysis does not capture the potential for skills shortages to constrain or slow a transition to low carbon cars and vans. However, evidence on the skills and future skills of the European workforce suggests that this is unlikely to be a major constraint. Germany, in particular, would be well-placed for a transition, given its abundance of highly qualified engineers. Interviews with battery providers and vehicle manufacturers reveal that although there are current skills gaps in particular niches, such as software engineering, the problem is unlikely to worsen. Moreover, training partnerships that are being developed could start to bridge these gaps.

The transition to a low-carbon car and van fleet delivers other co-benefits to the environment. Local air pollutants such as NOx and particulate emissions would be substantially reduced. This would improve the health of European citizens, particularly those living in major urban conurbations.

Four scenarios of future vehicle deployment were assessed against a Reference scenario:

• Current Policy Initiatives (CPI)

• Tech 1 – deployment of more efficient ICEs and hybrids

• Tech 2 – deployment of more efficient ICEs, hybrids, plug-in hybrids, battery electric and fuel cell vehicles

• Tech 3 – the majority of sales after 2030 are plug-in hybrids, batter electric and fuel cell vehicles

Each of the scenarios delivers different impacts across a range of key indicators. Fig. 13.1 shows a comparison between three indicators. On the y-axis the aggregate impact to consumers is represented by the reduction in combined (Europe-wide) vehicle and fuel costs by 2050 compared to the Reference scenario.

On the x-axis, the impact on the wider economy is represented by the increase in total employment relative to the Reference scenario. The size of the point marked (the bubble), represents the scale of tail-pipe carbon emissions reductions relative to 2010.

The Current Policy Initiatives scenario delivers improvements across all three indicators relative to the Reference scenario, but is surpassed by all the more advanced Tech scenarios, across all three indicators.

The Tech 1 scenario is, arguably, better for individual consumers. The combination of vehicle costs and fuel costs are reduced by most in this scenario because it does not include the more costly advanced powertrains (for PHEVs, FCEVs and BEVs), while still delivering substantial reductions in fuel costs through improved efficiency. Realising this future seems relatively simple. There is no infrastructure requirement, and the vehicle stock envisaged, by 2030 at least, would simply have to match the technology in today's most efficient vehicles.

Moreover, consumers are likely to demand these higher performing vehicles in light of increasing fuel costs.

By comparison, the Tech 3 scenario is arguably better for the wider economy and for society as a whole. In this scenario, by 2050, cars and vans are almost entirely decarbonised. More jobs are created because of large scale infrastructure deployment. The impact of substantial reductions in oil imports is offset, slightly by the higher vehicle costs.

For the consumer, the higher vehicle costs for relatively smaller reductions in fuel costs (compared to Tech 1) might be a barrier. Moreover, the realisation of this scenario is complex and traditional business models of vehicle sales and ownership might have to be replaced by other models that include leasing elements. The difficulty of such a transition will be developing the business models that can extract:

1. the value of infrastructure investment

2. the value to the electricity system of mass deployment of batteries

3. the lifetime reductions in the total cost of ownership of advanced vehicles

4. the value to society of reducing carbon emissions and other local air pollutants

Fig. 13.1

Impacts on CO_2, employment and vehicle fleet costs in the four scenarios in 2050 Source: SULTAN, E3ME
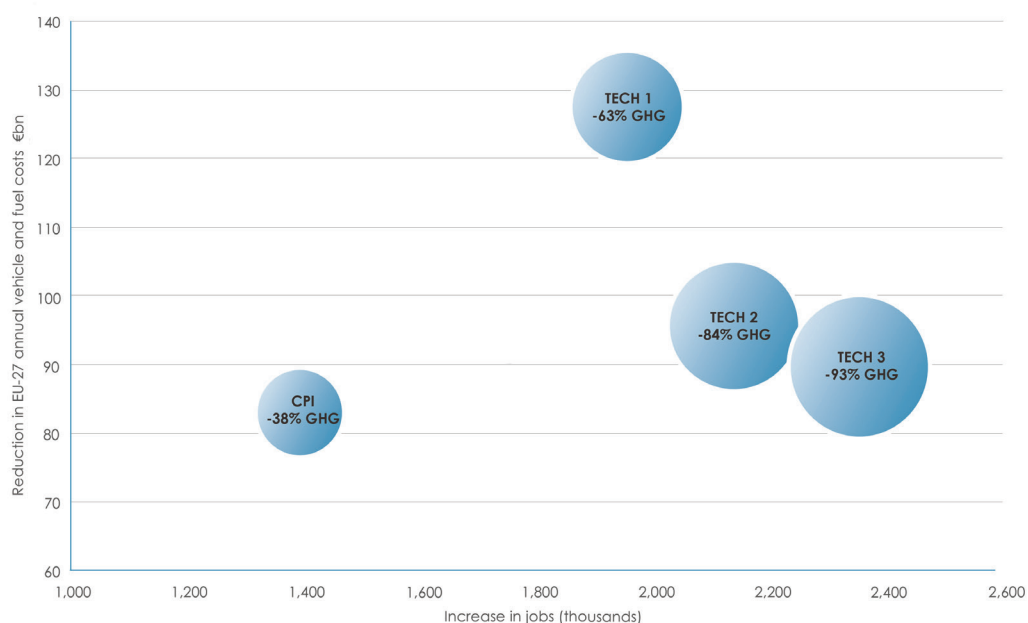
The last of these would almost certainly require some form of government intervention, since its value is not captured by economic markets.

Overall, any of these transitions to low carbon vehicles in Europe would deliver economic co-benefits, and this remains the case for all the plausible sensitivities tested.

There remain, however, a number of limitations to the analysis. This analysis does not assess whether consumers can be convinced that more expensive vehicle costs are a worthwhile investment given the reduction in lifetime fuel costs.

This transition will require more accessible information to be available to consumers to enable comparisons between:

• fuel costs for a given distance travelled

• fuel costs for different vehicle types using different fuels

• the potential for changes in future fuel costs

• expected maintenance costs of advanced vehicles

• the expected residual value in the car at the end of use

Other complex consumer markets have managed this transition recently through intermediary businesses. A relevant example would be consumer financial products, whereby information websites have developed to allow for comparisons between complex financial products.

The potential business models to deliver a transition to the more stretching scenarios are unproven. Recently, Betterplace, an innovator in the sector which attempted to develop a battery-swap business, has filed for bankruptcy in Europe. However, a successful model is likely to emerge by learning from these pioneers. This is often the case in fast emerging sectors that are highly technology focused.

The problem of congestion is not addressed in this analysis, neither is the role for modal switch (from cars to trains, trams, buses and bicycles). The analysis is limited to a technology-based economic assessment rather than a wider review of passenger demands for transport. Any transition would ultimately sit within this wider context.

Importantly, none of these limitations are likely to undermine the key finding of this report: that a transition to low-carbon vehicles yields several economic and environmental co-benefits.

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Chatper 6 - Vehicle Technology Costs

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Chapter 9- Economic Impacts

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The average vehicle (cars and vans combined) travels 11,650 km per annum.

4

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Chapter 10 - Skills

1

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4

The 20-24 age group is used purely as a benchmark to enable comparisons to be made across countries

5

There are still temporary restrictions on inward movements into EU Member States from Bulgaria and Romania, which will be removed in 2014

Chapter 11- Environment & Health

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Chapter 12- Synergies between transport and power

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Annex

Table 14.1 - Global Vehicle Standards

COUNTRY	VEHICLE EMISSION STANDARDS
Australia	In 2005 introduced a voluntary target to reduce national average carbon emissions from light-duty vehicles to 222gCO2/km by 2010 (under NEDC cycle).
Canada	In 2010 outlined limits on GHG emissions from light-duty vehicles, based on the footprint structure proposed by the US. Average of fleet anticipated to be 153gCO2/km by 2016 (~154gCO2/km under NEDC).
China	In 2009 introduced Phase III fuel consumption regulation to limit new passenger cars to 7L/100km (~167gCO2/km unde Source: ICCT r NEDC) by 2015.
EU	Previously had voluntary targets. In 2009 set out a mandatory requirement for average new car fleet to meet target of 130gCO2/km by 2015. This was later extended to 95gCO2/ km by 2020. The EU also has a mandatory emission target for vans of 175gCO2/ km by 2017 and 147gCO2/km by 2020.
Japan	Regulation in 2007 to set weight-based binned standards for cars registered in 2015, with fleet average fuel economy limited to 16.8 km/L (~125gCO2/km under NEDC) by 2015.
Russsia	Required to meet European emission standards for manufactured and imported vehicles.
South Korea	In 2010, set out combined fuel consumption and GHG emission standards of 17km/L or 140gCO2e/km respectively by 2015. This standard is weight-based, and uses the US CAFE cycle, but is equivalent to ~150gCO2/km under NEDC.
US	In 2010, introduced greenhouse gas emission and fuel economy standards for light duty vehicles between 2012 and 2016. By 2016, limits have been specified as 250 gCO2e/mile or 34.1 miles per gallon (under the US CAFE combined driving test cycle). This is equivalent to ~172gCO2/km under the NEDC cycle.

Table 14.2 - Summary of the additional technology assumptions for fuel cell electric vehicles (FCEVS)

Area	Category	Unit	2010	2020	2030	2040	2050
Fuel cell system cost	Central cost	€/kW	880	100	55	42	36
	Low cost	€/kW	880	80	45	35	30
	High cost	€/kW	880	150	80	55	43
H2 storage cost	Central cost	€/kWh	59	16	10	10	10
	Low cost	€/kWh	59	13	6	6	6
	High cost	€/kWh	59	20	13	13	13

Table 14.3 - Assumptions for the base costs of 2010 conventional internal combustion engines (ICE), before the addition of further technological improvements

	Category	Unit	2010	2020	2030	2040	2050
Petrol ICE	Central cost	€/kW	26.0	24.7	23.5	22.4	21.3
	Low cost	€/kW	22.0	20.9	19.9	18.9	18.0
	High cost	€/kW	28.3	26.9	25.6	24.3	23.1
Diesel ICE	Central cost	€/kW	34.0	32.3	30.8	29.3	27.8
	Low cost	€/kW	33.0	31.4	29.9	28.4	27.0
	High cost	€/kW	37.1	35.3	33.6	31.9	30.4

Table 14.4 - Summary of the technology package definition, efficiency improvement and cost assumptions used in the study for passenger cars

(X = technology applied at 100% level)

Sub-component	Type	T#	% Red'n Energy	2010 Mass Manufacturin	1	2	3	4	5	6	7	8
Petrol - low friction design and materials	PtrainsE	1	-2,0%	€ 39	10%	x	x	x	x	x	x	x
Petrol - gas-wall heat transfer reduction	PtrainsE	2	-3,0%	€ 55	10%		x	x	x	x	x	x
Petrol - direct injection (homogeneous)	PtrainsE	3	-5,3%	€ 199	15%	x	x					
Petrol - direct injection (stratified charge)	PtrainsE	4	-9,3%	€ 608	0%			x				
Petrol - thermo-dynamic cycle imporvements (e.g. HCCI)	PtrainsE	5	-14,5%	€ 539	0%				x	x	x	x
Petrol - cam-phasing	PtrainsE	6	-4,0%	€ 88	10%	x	x					
Petrol - variable valve actuation and lift	PtrainsE	7	-10,5%	€ 310	5%		x	x	x	x	x	
Diesel - variable valve actuation and lift	PtrainsE	8	-1,0%	€ 310	0%		x	x	x	x	x	
Diesel - combustion improvements	PtrainsE	9	-6,0%	€ 55	10%	50%	x	x	x	x	x	x
Mild downsizing (15% cylinder content reduction)	PtrainsE	10	-5,5%	€ 304	20%	x						
Medium downsizing (30% cylinder content reduction)	PtrainsE	11	-8,5%	€ 522	5%		x	x				
Strong downsizing (>=45% cylinder content reduction)	PtrainsE	12	-17,5%	€ 719	0%				x	x	x	x
Reduced driveline friction	PtrainsE	13	-1,0%	€ 55	5%		x	x	x	x	x	x
Optimising gearbox ratios / downspeeding	PtrainsE	14	-4,0%	€ 66	10%		x	x	x	x	x	x
Automated manual transmission	PtrainsE	15	-5,0%	€ 332	0%			x	x			
Dual clutch transmission	PtrainsE	16	-6,0%	€ 802	0%					x	x	x

Table 14.4 - Summary of the technology package definition, efficiency improvement and cost assumptions used in the study for passenger cars

Sub-component	Type	T#	% Red'n Energy	2010 Mass Manufacturin	1	2	3	4	5	6	7	8
Start-stop hybridisation	PtrainE	17	-5,0%	€ 235	5%		X	X				
Start-stop + regenerative braking (smart alternator)	PtrainE	18	-10,0%	€ 442	0%				X	X	X	X
Non-specific general improvement	PtrainE	19	-10,0%	€ -	10%	20%	40%	60%	80%	X	X	X
Aerodynamics improvement	Aero	1	-1,8%	€ 61	5%		X	X	X	X	X	X
Low rolling resistance tyres	Rres	1	-3,0%	€ 41	20%	X	X	X	X	X	X	X
Mild weight reduction (~10% total)	Weight	1	-6,7%	€ 39	10%	X						
Medium weight reduction (~20% total)	Weight	2	-13,5%	€ 243	3%		X	X	X			
Strong weight reduction (~30% total)	Weight	3	-20,2%	€ 896	0%					X		
Very strong weight reduction (~35% total)	Weight	4	-23,5%	€ 1.800	0%						X	
Extreme weight reduction (~40% total)	Weight	5	-26,8%	€ 3.000	0%							X
Thermo-electric waste heat recovery	Other	1	-2,0%	€ 1.106	0%					X	X	X
Secondary heat recovery cycle	Other	2	-2,0%	€ 250	0%			X	X	X	X	X
Auxiliary systems efficiency improvement	Other	3	-12,0%	€ 498	15%		X	X	X	X	X	X
Thermal management	Other	4	-2,5%	€ 166	10%		X	X	X	X	X	X
Long term ICE improvements (stage 1)	Other	5	-7,5%	€ 400	0%						X	X
Long term ICE improvements (stage 2)	Other	6	-5,0%	€ 1.000	0%							X

Note: Similar packages were also developed for vans with van-specific assumptions for costs and efficiency.

Table 14.5 - Deployment of technology packages to meet CO2 reduction target in 2010-2050

Package		2010	2015	2020	2030	2040	2050
No Further Improvements							
1	~2010 ICE	100%	90%	90%	90%	90%	90%
2	~2015 ICE		9%	9%	9%	9%	9%
3	~2020 ICE		1%	1%	1%	1%	1%
Current Policy Initiatives							
1	~2010 ICE	100%	50%	5%			
2	~2015 ICE		45%	20%	10%	5%	
3	~2020 ICE		5%	60%	60%	50%	40%
4	~2025 ICE			10%	23%	34%	44%
5	~2030 ICE			5%	6%	8%	10%
6	~2035 ICE				1%	2%	3%
7	~2040 ICE					1%	2%
8	~2050 ICE						1%
All Technology Scenarios							
1	~2010 ICE	100%	40%	5%			
2	~2015 ICE		50%	10%			
3	~2020 ICE		10%	70%	5%		
4	~2025 ICE			10%	20%		
5	~2030 ICE			5%	60%	5%	
6	~2035 ICE				10%	20%	
7	~2040 ICE				5%	65%	10%
8	~2050 ICE					10%	90%

Table 14.6 - Summary of the key technology assumptions related to HEV, BEV, PHEV, FCEV

Area	Category	Unit	2010	2020	2030	2040	2050
Basic energy consumption reduction (per km) vs equivalent ICE (8)	Petrol HEV (and PHEV, REEV in non-electric mode)	%	25,0%	25,6%	26,2%	26,8%	27,4%
	Diesel HEV (and PHEV, REEV in non-electric mode)	%	22,0%	22,6%	23,3%	23,9%	24,5%
	BEV (and PHEV, REEV in all-electric mode) (vs Petrol ICE)	%	76,0%	76,5%	76,9%	77,4%	77,8%
	FCEV (vs Petrol ICE)	%	63,1%	65,0%	66,8%	68,4%	69,9%
All-electric range (5) (6)	HEV	km	2	2	2	2	2
	PHEV	km	30	35	40	45	50
	REEV	km	60	70	80	90	100
	BEV	km	120	160	200	240	280
	FCEV (H2FC)	km	5	4	3	3	3
Battery usable SOC for electric range (3) (4)	HEV	%	50%	55%	60%	65%	70%
	PHEV	%	60%	65%	70%	75%	80%
	REEV	%	70%	75%	80%	85%	90%
	BEV	%	80%	80%	85%	88%	90%
	FCEV (H2FC)	%	50%	55%	60%	65%	70%
Derived battery size (cars) (9)	HEV	kWh	1,35	1,05	0,84	0,65	0,52
	PHEV	kWh	8,89	8,14	7,45	6,54	5,95
	REEV	kWh	15,24	14,1	13,03	11,53	10,58
	BEV	kWh	26,67	29,36	28,82	29,03	30,47
	FCEV (H2FC)	kWh	2,73	1,59	0,88	0,68	0,57
Derived battery size (vans) (9)	HEV	kWh	1,60	1,30	1,06	0,81	0,63
	PHEV	kWh	10,55	10,10	9,40	8,15	7,20
	REEV	kWh	18,09	17,51	16,46	14,39	12,79
	BEV	kWh	31,66	37,17	37,59	37,65	38,50
	FCEV (H2FC)	kWh	3,91	2,42	1,39	1,07	0,87
BEV battery system (cars) (1)	Central cost	€/kWh	558	245	163	128	111
	Low cost	€/kWh	558	165	125	116	111
	High cost	€/kWh	558	307	201	158	137
BEV battery system (vans) (1)	Central cost	€/kWh	504	221	147	116	100
	Low cost	€/kWh	504	149	113	105	100
	High cost	€/kWh	504	277	181	143	124
Battery system cost increase over BEV (2)	HEV	%	100%	100%	100%	100%	100%
	PHEV	%	50%	50%	50%	50%	50%
	REEV	%	25%	25%	25%	25%	25%
	BEV	%	0%	0%	0%	0%	0%
	FCEV (H2FC)	%	100%	100%	100%	100%	100%

Area	Category	Unit	2010	2020	2030	2040	2050
Electric motor system	Central cost	€/kW	41	22	14	13	12
	Low cost	€/kW	41	14	13	11	10
	High cost	€/kW	41	31	22	20	18
Electric powertrain (HEV) (7)	Additional cost (excl. battery, motor)	€	1014	890	800	720	650
Electric powertrain (Others) (7)	Additional cost (excl. battery, motor)	€	1282	1031	930	840	760

Notes:

(1) Updated primarily based on finalised report for CCC on battery costs (Element Energy, 2012), and additional discussions with the CWG. Converted from $ to € using a 1.3 $/€ exchange rate.

(2) Assumptions on battery costs for HEV, PHEV and REEV have been separated out based on ANL (2010) and discussions with industry experts. In particular, as a result the battery cost assumptions for PHEV and REEV are significantly lower than those used in the earlier study for CCC (AEA, 2012).

(3) In hybrid and electric vehicles it is necessary to provide a reserve state of charge (SOC) 'header' to ensure (a) there is sufficient power for efficient basic operation, (b) to protect the battery from excessively deep discharges which can be significantly reduce battery lifetimes. It is anticipated that this header will reduce in the future as battery technology performance and durability improves.

(4) Separate SOC assumptions have been utilised for different powertrains on the basis of ANL (2010)9 and discussions with industry experts.

(5) Ranges are for real-world performance; equivalent range will be 20-25% higher on a test-cycle basis. Range assumptions for BEVs have been reduced versus AEA (2012) to better reflect the current real-world ranges of BEVs.

(6) Ranges for PHEV and REEV are estimated to increase at slightly lower rate than those for BEVs (previously no increase in range over 2010 levels was assumed for PHEV and REEV).

(7) Excludes battery system and motor system costs. Advanced EVs need larger/more complex electric heating/cooling systems compared to HEVs, since they are not able to draw upon significant waste heat generated by an ICE in very cold conditions.

(8) Factors in combined improvements to the efficiency of basic powertrain component technologies, i.e. batteries, electric motors, fuel cells and the rest of the electric powertrain.

(9) On the basis of vehicle efficiency operating in all-electric mode.

Table 14.7 - Car Marginal Capital Costs compared to 2010 reference vehicle

	2010	2015	2020	2025	2030	2040	2050
Reference case	€ 0	€ 146	€ 292	€ 182	€ 73	-€ 121	-€ 296
Current Policy Initiatives	€ 0	€ 508	€ 1.056	€ 1.051	€ 1.028	€ 970	€ 940
Tech 1 scenario	€ 0	€ 551	€ 1.154	€ 1.563	€ 1.998	€ 2.162	€ 2.172
Tech 2 scenario	€ 0	€ 559	€ 1.402	€ 2.261	€ 2.996	€ 3.310	€ 3.146
Tech 3 scenario	€ 0	€ 638	€ 1.798	€ 3.319	€ 4.031	€ 3.751	€ 3.235

Table 14.8 - Van Marginal Capital Costs compared to 2010 reference vehicle

	2010	2015	2020	2025	2030	2040	2050
Reference case	€ 0	€ 352	€ 703	€ 565	€ 426	€ 184	-€ 14
Current Policy Initiatives	€ 0	€ 590	€ 1.161	€ 1.190	€ 1.198	€ 1.219	€ 1.403
Tech 1 scenario	€ 0	€ 639	€ 1.302	€ 1.816	€ 2.224	€ 3.067	€ 3.342
Tech 2 scenario	€ 0	€ 626	€ 1.429	€ 2.294	€ 2.911	€ 3.814	€ 4.063
Tech 3 scenario	€ 0	€ 626	€ 1.918	€ 3.524	€ 4.316	€ 4.609	€ 4.299

Table 14.9 - The TCO has been calculated for cars from the following elements

Total purchase price (i.e. including all taxes and margins), discounted over the full life of the vehicle at a defined rate (e.g. 3.5%, 5% and 10%).
+ Annual maintenance cost x lifetime of the vehicle (12 years)
+ Total fuel costs (prices including duty and VAT) over the lifetime of the vehicle (i.e. factoring in future increases or decreases in fuel prices)

Further details on the assumptions used in the calculation of the TCO are provided in the tables below for the Technology Scenarios.

**Total vehicle manufacturing cost
(excluding manufacturer and dealer margin)**

POWERTRAIN	2010	2015	2020	2025	2030	2040	2050
Petrol ICE	€ 14.483	€ 14.926	€ 15.368	€ 15.781	€ 16.194	€ 16.421	€ 16.511
Diesel ICE	€ 15.095	€ 15.736	€ 16.377	€ 16.655	€ 16.933	€ 17.050	€ 17.037
Petrol HEV	€ 17.552	€ 17.129	€ 16.707	€ 16.770	€ 16.834	€ 16.832	€ 16.835
Diesel HEV	€ 17.982	€ 17.772	€ 17.562	€ 17.498	€ 17.433	€ 17.333	€ 17.243
Petrol PHEV	€ 26.242	€ 23.234	€ 20.226	€ 19.599	€ 18.972	€ 18.369	€ 18.066
Diesel PHEV	€ 26.539	€ 23.590	€ 20.640	€ 19.920	€ 19.200	€ 18.557	€ 18.208
BEV	€ 31.583	€ 26.974	€ 22.365	€ 20.965	€ 19.566	€ 18.644	€ 18.158
FCEV	€ 98.690	€ 61.948	€ 25.207	€ 22.613	€ 20.019	€ 18.757	€ 18.009
LPG ICE	€ 15.948	€ 16.124	€ 16.301	€ 16.522	€ 16.744	€ 16.811	€ 16.840
NG ICE	€ 15.948	€ 16.124	€ 16.301	€ 16.522	€ 16.744	€ 16.811	€ 16.840

**Margin applied to vehicle purchase
(manufacturer and dealer margin applied on top of the manufacturing cost)**

POWERTRAIN	2010	2015	2020	2025	2030	2040	2050
Petrol ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Diesel ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Petrol HEV	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Diesel HEV	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
Petrol PHEV	0,0%	6,1%	12,2%	15,2%	18,2%	22,0%	24,3%
Diesel PHEV	0,0%	6,1%	12,2%	15,2%	18,2%	22,0%	24,3%
BEV	0,0%	6,1%	12,2%	15,2%	19,5%	23,0%	24,3%
FCEV	0,0%	6,1%	12,2%	15,2%	19,5%	23,0%	24,3%
LPG ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%
NG ICE	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%	24,3%

Annual maintenance cost assumptions

POWERTRAIN	2010	2015	2020	2025	2030	2040	2050
Petrol ICE	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340
Diesel ICE	€ 387	€ 383	€ 380	€ 377	€ 373	€ 367	€ 360
Petrol HEV	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340
Diesel HEV	€ 387	€ 383	€ 380	€ 377	€ 373	€ 367	€ 360
Petrol PHEV	€ 313	€ 310	€ 307	€ 303	€ 300	€ 293	€ 287
Diesel PHEV	€ 320	€ 317	€ 313	€ 310	€ 307	€ 302	€ 297
BEV	€ 254	€ 250	€ 247	€ 243	€ 240	€ 237	€ 233
FCEV	€ 321	€ 311	€ 300	€ 290	€ 280	€ 273	€ 267
LPG ICE	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340
NG ICE	€ 373	€ 370	€ 367	€ 363	€ 360	€ 350	€ 340

Fuel cost and tax assumptions for central/low/high fossil fuel cost scenarios

FUEL COSTS (EXCL. TAX)	2010	2015	2020	2025	2030	2040	2050	Taxes	
Central €/MJ	2010	2015	2020	2025	2030	2040	2050	VAT	DUTY
Petrol	0,016	0,024	0,026	0,027	0,029	0,030	0,032	19%	0,018
Diesel	0,015	0,023	0,025	0,026	0,027	0,029	0,030	19%	0,012
Electricity	0,042	0,043	0,044	0,047	0,053	0,056	0,060	19%	0,000
Hydrogen	0,048	0,048	0,050	0,048	0,048	0,050	0,053	19%	0,000
LPG	0,016	0,024	0,026	0,028	0,029	0,031	0,032	19%	0,004
Natural Gas	0,013	0,019	0,021	0,022	0,023	0,024	0,025	19%	0,002
LNG	0,009	0,014	0,015	0,016	0,016	0,017	0,018	19%	0,002
Low €/MJ	2010	2015	2020	2025	2030	2040	2050	VAT	DUTY
Petrol	0,016	0,022	0,023	0,022	0,021	0,019	0,016	19%	0,018
Diesel	0,015	0,021	0,022	0,021	0,020	0,018	0,015	19%	0,012

FUEL COSTS (EXCL. TAX)	2010	2015	2020	2025	2030	2040	2050	Taxes	
Electricity	0,042	0,043	0,044	0,047	0,053	0,056	0,060	19%	0,000
Hydrogen	0,048	0,048	0,050	0,048	0,048	0,050	0,053	19%	0,000
LPG	0,016	0,023	0,023	0,023	0,022	0,019	0,016	19%	0,004
Natural Gas	0,013	0,018	0,018	0,018	0,017	0,015	0,013	19%	0,002
LNG	0,009	0,013	0,013	0,013	0,012	0,011	0,009	19%	0,002
High €/MJ	2010	2015	2020	2025	2030	2040	2050	VAT	DUTY
Petrol	0,016	0,025	0,029	0,033	0,036	0,041	0,048	19%	0,018
Diesel	0,015	0,024	0,028	0,031	0,034	0,040	0,046	19%	0,012
Electricity	0,042	0,043	0,044	0,047	0,053	0,056	0,060	19%	0,000
Hydrogen	0,048	0,048	0,050	0,048	0,048	0,050	0,053	19%	0,000
LPG	0,016	0,026	0,030	0,033	0,036	0,042	0,049	19%	0,004
Natural Gas	0,013	0,020	0,023	0,026	0,029	0,033	0,038	19%	0,002
LNG	0,009	0,015	0,017	0,019	0,020	0,023	0,027	19%	0,002

Table 14.10 - Literature findings on density of infrastructure per FCEV vehicle (station per vehicle)

Source	Approach	2015		2020		2025		2050	
		No. vehicles	Density ratio	No. vehicles	Density ratio	No. vehicles	Density ratio	No. vehicles	Density ratio
European Expert Group on Future Transport Fuels (2011) Infrastructure for alternative fuels	Policy-driven – Europe	5000	0.04-0.06	500	0.004				
McKinsey: A portfolio of power-trains for Europe: a fact-based analysis*	Policy-driven – Europe				0.0008			68.2m	0.0003
UC Davis (2010) An analysis of near-term hydrogen vehicle rollout scenarios for Southern California	Demonstration project – Southern California	25,000 (2017)	0.001-0.002						
LBST (2010) Sustainability of Statoil's hydrogen strategy: Case study for H2 infrastructure build-up in the Greater Oslo Area	Oslo-based spatial modelling					55000	0.0003-0.0005		
GermanHy (2008) Where Will the hydrogen in Germany come from by 2050?	Policy-driven - Germany				0.003-0.004				

Table 14.11 - Infrastructure density assumptions for PHEVs/EVs – Scenario 1

LOCATION AND CHARGE TYPE	DENSITY 2012	DENSITY 2020	DENSITY 2030	DENSITY 2050
Residential	0.8	0.8	0.8	0.8
Workplace	0.1	0.13	0.2	0.2
Convenience public charging	0.15	0.3	0.18	0.1
Fast chargers	0.001	0.003	0.003	0.003
Total for charging points	1.05	1.23	1.18	1.1
Battery swap stations	0.00033	0.00033	0.00017	0.00017

Table 14.12 - Infrastructure density assumptions for PHEVs/EVs – Scenario 2

LOCATION AND CHARGE TYPE	DENSITY 2012	DENSITY 2020	DENSITY 2030	DENSITY 2050
Residential	0.8	0.78	0.61	0.6
Workplace	0.1	0.13	0.2	0.2
Convenience public charging	0.15	2.2	0.4	0.4
Fast chargers	0.001	0.053	0.006	0.004
Total for charging points	1.05	3.16	1.2	1.2
Battery swap stations	0.00033	0.00033	0.00017	0.00017

Table 14.13 - Infrastructure density assumptions for PHEVs/EVs – Scenario 3

LOCATION AND CHARGE TYPE	DENSITY 2012	DENSITY 2020	DENSITY 2030	DENSITY 2050
Residential	0.8	0.78	0.61	0.6
Workplace	0.1	0.13	0.2	0.2
Convenience public charging	0.15	2.2	0.5	0.5
Fast chargers	0.001	0.053	0.008	0.008
Total for charging points	1.05	3.16	1.3	1.3
Battery swap stations	0.00033	0.00033	0.00033	0.00033