En route pour un transport durable

A report for the European Climate Foundation

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1.1	17/11/15	Philip Summerton	Draft final report for ECF review

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

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

Element Energy, contributed analysis on fuel cell costs, hydrogen production and refuelling infrastructure, and the supporting report on synergies between electric vehicle charging and the functioning of the electricity grid.

Artelys provided analysis of the power sector and collaborated with Element Energy to identify the impact on the grid of the roll-out of EVs.

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Executive Summary

Overview

- This report assesses the economic costs and benefits of decarbonising passenger cars and vans in France. A scenario approach has been developed to assess a range of possible futures for vehicle technology in France, and then economic modelling has been applied to assess impacts. The study is based on a similar analysis undertaken for the EU as a whole, published in Fuelling Europe's Future[1].
- Three scenarios of the future French passenger car and van fleet were developed:
  - a Reference (REF) scenario which includes no efficiency improvements to new vehicle efficiency after 2015
  - a Current Policies Initiative (CPI) scenario, based on the latest European Commission legislation which sets a standard for carbon emissions from new cars of 95 g/km by 2021
  - a low carbon technology scenario (TECH) which has a stronger penetration of advanced powertrains and more efficient internal combustion engines than the CPI by 2020, cutting new car emissions to 84 g/km. This falls further to 45 g/km by 2030 and 9 g/km by 2050

The impact on motorists

- The technologies required to improve the carbon efficiency of passenger cars and vans will add to the purchase cost. In the TECH scenario the average cost of a new (medium) car in 2020 is €22,000 compared to €20,400 in the REF; and by 2030 it is expected to cost €23,900 compared to €20,200 in the REF scenario (all in 2014 prices). However, the annual fuel bill savings are also significant. By 2030 the annual average fuel bill of all cars in the French parc (predominantly cars sold between 2020 and 2030) will have fallen by €590.
- Overall, a transition to low carbon cars and vans will reduce the total cost of ownership. By 2020 a new Hybrid Electric Vehicle is expected to have a total cost of ownership lower than today's average car and a new Plug-in Hybrid would be even cheaper to own over the lifetime of the vehicle. By 2025, pure Battery Electric Vehicles could achieve cost parity with a traditional car (depending on range) and by 2030, Fuel Cell Electric Vehicles in the large vehicle market segment will also be competitive.

The economic impact

- The economic impact of reduced spending on petrol and diesel, the increase in spending on car purchase and the net reduction in the total cost of car ownership that are associated with the transition will be neutral to mildly positive for GDP and will lead to marginally higher levels of employment. By 2030, the transition to a low-carbon vehicle stock would reduce oil and petroleum imports by €5.9bn. After allowing for the additional expenditure required on the new technology which goes to the

[1] Cambridge Econometrics et al. (2012), 'Fuelling Europe's Future', with contributions from industry experts at CLEPA, Eurelectric, European Aluminium Association, Eurobat, General Electric, IndustriAll, SSE ,T&E and Zero

motor vehicles sector, these savings will be spent across the economy on consumer goods and services. Overall this leads to a small increase in GDP and around 66,000 net additional jobs by 2030 (taking account of the impact of measures to recompense the government for the loss of fuel duty revenue).

- The competitiveness of France based car manufacturers and component suppliers is an important consideration for the economic results. If French-based companies were able to manage the transition to a low-carbon vehicle fleet effectively and gain market share across Europe, the benefits of decarbonising the road transport sector could be more positive for the French economy than the modelling suggests.

The economic benefits are reduced if oil prices remain low

- The scenarios were tested against an assumption of persistently low oil prices, in which the oil price remains at today's level. This reduces the economic gains from switching to low-carbon vehicles (because a low-oil price future reduces the cost of conventional technologies), but there were still net positive results.
- By purchasing more fuel efficient vehicles, consumers reduce their exposure to volatile (and/or increasing) fuel prices. For the economy as a whole, this reduces the impact of volatile oil prices on economic growth.

The environmental impact

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

Carbon emissions from passenger cars will be halved by 2030

- As a result of improved efficiency and a transition to advanced powertrains that are powered by electricity and hydrogen, carbon emissions from passenger cars are reduced substantially. Tail-pipe carbon emissions from passenger cars could be nearly halved by 2030 (compared to 2012) if efficiency measures and more advanced powertrains are taken up.
- Air quality would be improved by the penetration of advanced powertrains, particularly through the reduction of NO_X emissions. Emissions of particulate matter are likely to be reduced considerably from today's levels through the implementation of the Euro V and Euro VI new vehicle standards, but could be almost wholly eradicated by a transition to zero tailpipe emission cars and vans. The improvement in air quality will have most impact in densely populated urban areas where the concentration of air pollutants is highest.
- Accounting for embodied emissions, the emissions associated with the extraction and production of the fuel used by a car as well as the emissions associated with the production of the car itself, reduce the relative benefit of EVs to ICEs. However, even on a lifecycle basis, a 2030 BEV will still be less than 30% as carbon intensive as an average 2030 ICE over the full lifetime of the vehicle.

1 Background

1.1 Policy background

European policy context

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

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

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

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

Historically, Japan and the EU have led vehicle emission performance (see

Figure 1-1: Global vehicle emissions performance and standards

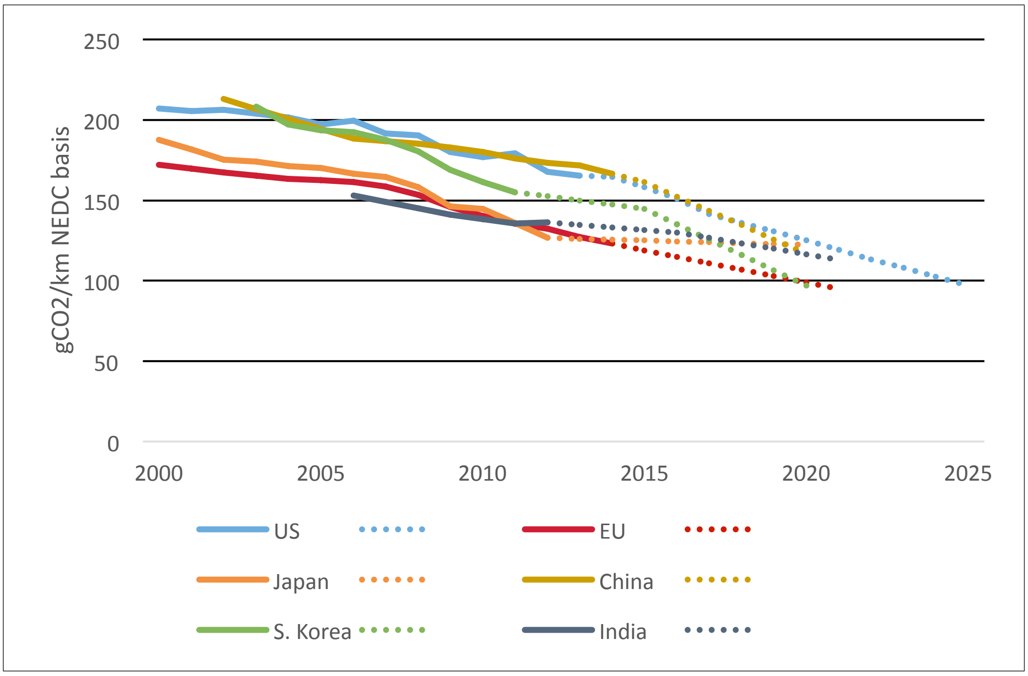

Figure 1-1: Global vehicle emissions performance and standards[2]). For the EU this is expected to continue, but Japan has recently set a standard for 2020 of just 122 g/km which is considerably less stringent than in the EU. South Korea, by comparison, has set fuel standards for 2020 that are in line with the EU. Canada and the US have recently introduced measures to reduce vehicle emissions between 2011 and 2016 by around 4 percent per annum. In 2012, the US agreed a 2025 standard of 107g/km (93g/km for cars alone). As a result, the emissions performance in various vehicle markets is expected to converge towards 2025.

The policy in France is designed to support the over-arching European policy framework and is based on a bonus / malus system on vehicle purchases. Since January 2008, this encouraged the purchase of the least CO_2 emitting vehicles. A premium to purchase (bonus) is paid to purchasers of vehicles emitting less than 60 g/km. Conversely, a purchase tax (malus) applies to cars emitting more than 130 g/km (thresholds in force on 1 January 2015).

1.2 Report layout

This report sets out an analytical approach to assessing the costs and benefits of a transition to low-carbon light-duty vehicles in France. The analysis presented in this report builds on the 'Fuelling Europe's Future'[3] study, which identified the economic effects of the transition to a low carbon vehicle fleet in Europe. Chapter 3 discusses the costs of vehicles and technologies required to improve the efficiency and reduce the tailpipe emissions of vehicles. Infrastructure will be required to support a transition to electric and fuel cell vehicles, this is discussed in Chapter 4. The considerations facing the consumer and the potential impact on the consumer are set out in Chapter 5 while the net impact to the economy is discussed in Chapter 6. Chapter 7 discusses the impact on emissions and local air pollution. In Chapter 8, we present the results from analysis by Element Energy and Artelys on the synergies between EV charging and the electricity grid.

All monetary values are expressed in Euros, 2014 prices, unless otherwise stated.

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[2] Sourced from the ICCT.

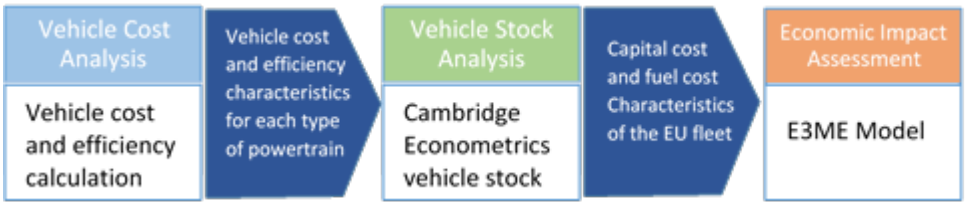
[3] Fuelling Europe's Future, Cambridge Econometrics (2012)

2 Approach

2.1 Analytical approach

The analytical approach taken follows that employed in the EU-wide study, ‘Fuelling Europe’s Future’ (see **Error! Reference source not found.**). To determine the economic impact of deploying low-carbon vehicles, the additional cost of vehicle technology was calculated based on a framework similar to the Road Vehicle Cost and Efficiency Calculation Framework used in ‘Fuelling Europe’s Future’. The per-unit cost was then applied to the vehicle fleet characteristics in each scenario, using Cambridge Econometrics’ model of the French vehicle stock, to arrive at annualized total capital costs for the whole French vehicle fleet. This was combined with the calculated costs of supporting vehicle infrastructure and annualized fuel costs to provide the main inputs for the macroeconomic model E3ME[4].

Figure 2-1: Analytical approach



For each scenario (discussed below) we developed assumptions on the uptake of technology and advanced powertrains.

The outputs of the vehicle stock modelling, and the assumptions highlighted, form the inputs to Cambridge Econometrics’ model of the global economy, E3ME (see Appendix A for details), which includes France as an individual region. E3ME is a global macroeconomic model that covers the EU Member States’ economies, with linkages between the economy to energy consumption and CO_2 emissions.

E3ME’s historical database covers the period 1970-2013 and the model projects forward annually to 2050. The main data sources are Eurostat, the EC’s AMECO database and the IEA. The E3ME model embodies two key strengths relevant to this analysis. The model’s integrated treatment of the economy and the energy system enables it to capture two-way linkages and feedbacks between these components and its high level of disaggregation enables relatively detailed analysis of sectoral and national effects.

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

Table 2-1: Assumptions, inputs and outputs associated with the vehicle stock modelling

Key assumptions	Value/comments
Average distance travelled per year	Based on analysis by Ricardo AEA, we assume diesel cars are driven further than petrol cars and that mileage is higher in the first three years of a cars life and diminishes thereafter. The average vehicle distance is just over 13,000km per year.
Average vehicle lifetime	We assume an average lifetime of 14.5 years (with a standard deviation of 4 years) in the projection period for all powertrain types. The distribution of the vehicle stock by age is based on information from TREMOVE 3.3.2.
Annual vehicle sales	We assume that total vehicle sales in France remain constant at 2.1m per annum over the projection period. This assumption is the same in all scenarios.
Characteristics of the current vehicle stock	Based on sales data for 1980- 2014 sourced from the ICCT (2014), CCFA (2014) and Eurostat (2014).
Electricity price	The electricity generation mix is based on RTE's "Nouveau Mix" scenario for 2030 and ADEME's 'Vision ADEME' for 2050. Electricity prices are then calculated for this specific generating mix (as described in Chapter 4). It is assumed that EV users will be charged the same price for electricity as households.
Oil price	Oil prices are based on central projections from the IEA's World Energy Outlook (2014). The price of petrol and diesel includes the Contribution Climat-Énergie (CCE).
Average vehicle emissions in the rest of the EU	For each scenario, we assume that vehicle emissions in the rest of the EU follow a similar path to average vehicle emissions in France.
Technology options costs	Refer to Chapter 3.
Test-cycle versus real-world performance	We assume that the real-world driving efficiencies are 38% higher than the reported test cycle performance and that this gap persists over the projection period. This is based on a recent report by Element Energy and the ICCT[5]. New vehicle efficiency is reported on the test-cycle basis, all other calculations are based on the real-world performance.
Inputs	
New vehicle sales mix by powertrain type	Scenario specific (refer to Section 2.2). Based on the scenarios used in the 'Fueling Europe's Future' report.
The uptake of fuel-efficient technologies in new vehicle	Scenario specific (refer to Section 2.2). The uptake of various fuel-efficient technologies is based on uptakes in

[5] Element Energy, ICCT (2015), 'Quantifying the impact of real-world driving on total CO_2 emissions from UK cars and vans'

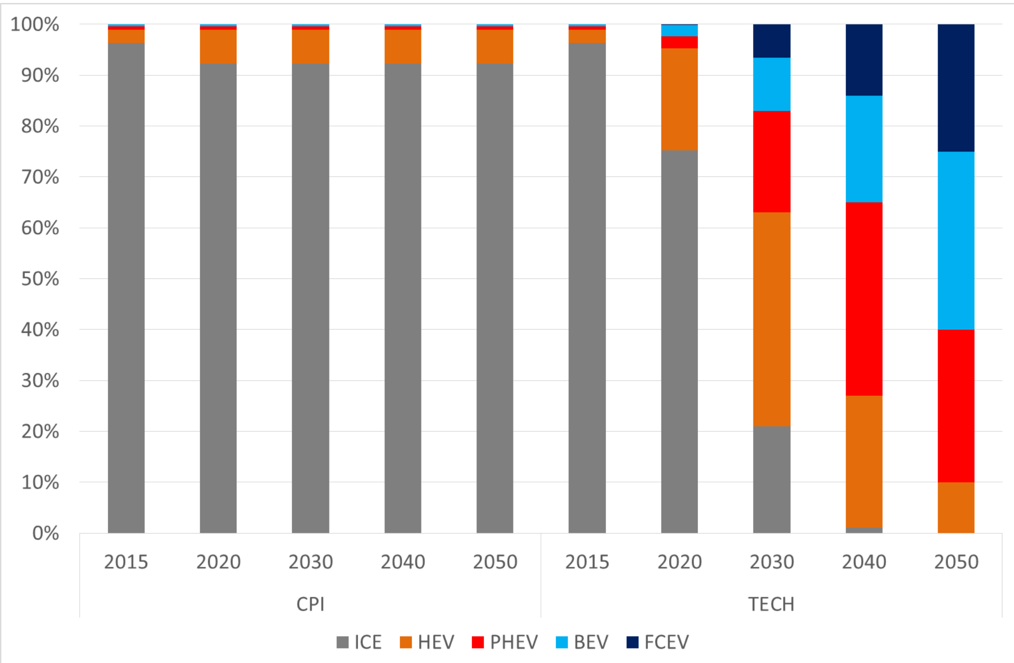
sales	the equivalent scenarios from the 'Fueling Europe's Future' report.
Outputs	
Average cost of new vehicles Fuel consumption of the vehicle stock, by fuel type	Determined by: • the share of various powertrains in the sales mix and stock • the efficiency technologies installed across all powertrains

2.2 Scenario design

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

- A Reference (REF) scenario which includes no improvements to new vehicle efficiency after 2015. Total energy use in the vehicle stock still falls, however, as today's new vehicles replace older (less efficient) vehicles in the stock.
- A Current Policies Initiative (CPI) scenario which is based on the latest European Commission legislation to regulate the new vehicle efficiency of cars to 95 g/km by 2021.
- A low carbon technology scenario (TECH) which is consistent with the TECH 2 scenario developed for Fuelling Europe's Future. The TECH scenario has a stronger penetration of advanced powertrains and more efficient ICE's than the CPI by 2020 leading to new vehicle emissions of 84 g/km. By 2030 this is reduced to 45 g/km as advanced powertrains account for 37% of sales and efficient hybrids 42% (see Figure 2-2). Advanced powertrains account for 90% of sales by 2050, with HEVs accounting for the remaining 10% resulting in new vehicle efficiency of 9 g/km. Vans achieve CO_2 performance of 139 g/km in 2020, 78 g/km in 2030 and 19 g/km in 2050.

Figure 2-2: Sales mix in the CPI and TECH scenarios



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

3 Vehicle Technologies

3.1 Technology options and costs

In broad terms, four groups of technology deployment were considered in the Fuelling Europe's Future report and re-applied (and to a certain extent re-reported[6]) in this study:

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

Improvements to the internal combustion engine, downsizing and hybridisation

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

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).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.

The costs for these technologies were developed by R-AEA and based on the TNO (2011) study "Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars", then adapted in Fuelling Europe's Future and Fuelling Britain's Future and then further adapted across market segments. Table 3-1 summarises the main technologies included and the associated

[6] Primarily based on the analysis undertaken and reported by Ricardo-AEA in Fuelling Europe's Future Chapter 6 and developed as part of this project.

energy savings and cost increase compared to an average 2010 European new car without these features.

Table 3-1: Cost and energy savings from improvements to the ICE

Downsizing options	**Energy saving**	**Cost (€)**		
		Small car	Medium car	Large car
Mild (15% cylinder volume reduction)	4-6%	200	250	300
Medium (30% cylinder volume reduction)	7-9%	400	435-450	500-510
Strong (45% cylinder volume reduction)	16-18%	500-550	600	700
Other engine options	**Energy saving**	**Cost (€)**		
		Small car	**Medium car**	**Large car**
Direct injection (homogenous)	4.5-5.5%	180-200	180-200	180-200
Direct injection (stratified)	8.5-9.5%	400	500	600
Thermodynamic cycle improvements	13-15%	475	500	535
Cam phasing	4%	80-90	80-90	80-90
Variable valve actuation and lift (petrol and diesel)	9-11%	280	300	310
Transmission options	**Energy saving**	**Cost (€)**		
		Small car	**Medium car**	**Large car**
Optimising gearbox ratios / downspeeding	4%	60	60	60
Automated manual transmission	5%	300	300	300
Dual clutch transmission	6%	650	700	750
Partial hybridisation	**Energy saving**	**Cost (€)**		
		Small car	**Medium car**	**Large car**
Start-stop	5%	175	200	225
Start-stop with regenerative breaking	7%	325	375	425

Efficiency improvements in the CPI and TECH scenario

Table 3-2 highlights the efficiency improvements in the ICE that come about from engine improvements, transmission improvements and partial hybridisation in the CPI and TECH scenarios respectively. In the post 2030 period relatively little is done to improve the efficiency of the ICE, as sales in advanced powertrains dominate the market and few additional improvements are deemed cost effective.

In 2030 in the TECH scenario, nearly all new ICE vehicles have the following features (as applicable[7]):

- start stop (all) plus regenerative braking (75%)
- between 30% and 45% cylinder content reduction
- variable valve actuation and lift
- gear box optimisation
- direct injection or HCCI

In the period to 2050 the additional improvements to ICE efficiency that can be attributed to the engine and transmission (rather than light-weighting and improved rolling resistance) are the mainstreaming of dual clutch transmissions, regenerative braking and 45% cylinder content reduction across the board. The data suggests less technological potential to further improve the efficiency of a diesel engine than petrol engines.

Table 3-2 New ICE efficiency CPI and TECH scenarios compared to new 2010 car

			CPI			TECH	
	Fuel	2010	2015	2020	2020	2030	2050
Small	Petrol	-	11%	22%	24%	41%	45%
Medium	Petrol	-	12%	23%	25%	43%	47%
Large	Petrol	-	12%	24%	26%	45%	48%
Small	Diesel	-	4%	12%	13%	24%	27%
Medium	Diesel	-	4%	12%	13%	24%	27%
Large	Diesel	-	4%	12%	13%	24%	27%

The impact of full hybridisation in the TECH scenario

In 2015, full hybridisation adds around €2,000 to the cost of a car compared to a like-for-like ICE and delivers 22%-25% reductions in energy consumption per kilometre driven. The cost of a full hybrid falls to around €1,000 by 2030 and €750 by 2050.

In the long term in the TECH scenario the relative efficiency gap between ICE's and standard hybrids (non plug-in) closes because of ICE engine improvements that can only be considered as additional technologies to non-hybrid engines[8]. However, this is partially offset by improvement in the performance of hybrid engines which are expected to improve in line with the development of electric motor systems. The net effect is that the efficiency gap closes by 3 percentage points, so that new hybrids offer a 19-22% efficiency improvement relative to a new ICE in the 2030-2050 period.

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[7] Some technologies are not applicable to diesel cars

[8] As an example, hybrids include start-stop technology and so while it is possible to add start-stop to an ICE, it is not possible to add it to a hybrid as defined by this framework because it is already included

Light-weighting, aerodynamics and low rolling resistance tyres

The costs and energy savings from light-weighting presented in Table 3-3 were first developed by Ricardo-AEA for Fuelling Europe's Future and based on the TNO (2011) study "Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars". The data was further revised and only slightly adjusted in a separate piece of work by Ricardo-AEA for the European Commission (2015) "The potential for mass reduction of passenger cars and light commercial vehicles in relation to future CO_2 regulatory requirements".

The costs relate to mass of the vehicle as a whole in line with the approach used by the US EPA, rather than separating cost estimates for body-in-white (BIW) and the rest of the vehicle.

Table 3-3: The cost and energy savings of modelled light-weighting options

Light-weighting option	Energy saving	Cost (€)		
		Small car	Medium car	Large car
Mild (10%)	6.7%	31	39	48
Medium (20%)	13.5%	200	250	300
Strong (30%)	20.0%	738	923	1,106
Very strong (35%)	23.5%	1,440	1,800	2,160
Extreme (40%)	27.0%	2,400	3,000	3,600

All vehicles, regardless of powertrain type, can be made more efficient through reducing weight. 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. However, requirements for increasing safety features and consumer demands for comfort and entertainment features add to the weight of the car. As a result, the lowest cost options for light-weighting are often countered by the increasing weight of additional features. We assume that, in the absence of the modelled light weighting features which vary by scenario, there is an increase in weight of all vehicles of 0.4% pa in all scenarios.

Very significant gains are believed to be possible in the short term according to highly detailed analysis by Lotus (2010) and more recently FEV (2012). These studies demonstrated that achieving up to 20 per cent reduction in overall vehicle weight (i.e. across all vehicle subsystems) at minimal or even zero net cost was possible by 2020 while maintaining performance parity relative to the current vehicle (although our data and calculations remain much more conservative). 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

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.

For electrically-powered vehicles, the benefits of reduced weight, drag and rolling resistance are particularly strong. 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 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.

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. The current EU vehicle CO_2 regulation sets a target for each manufacturer based on the average weight of its vehicles. This means that vehicle weight reduction results in a more stringent CO_2 target, removing some of the incentive to apply more aggressive weight reduction strategies. For example the current weight-based standard for CO_2 limits could be replaced with a size based standard to provide a stronger incentive for the full potential of lightweight materials be achieved.

Tyres

In addition to light-weighting, substantial efficiency improvements can also be achieved from low rolling resistance tyres. In 2012, the European Commission introduced a tyre labelling system, where tyres are labelled according to rolling resistance during driving. In the vehicle stock model, the assumptions for the costs of tyres in each grade and the fuel efficiency savings associated with reductions in rolling resistance are broadly in line with the European Commission's Tyre Labelling Impact Assessment (2008), where it is estimated that there is a 1.5% efficiency saving for each 1kg/t reduction in the rolling-resistance coefficient. However, we have refined this calculation in line with the approach used by industry, such that fuel consumption improvement is directly calculated as a function of the rolling resistance coefficient and the mass of the vehicle. It is noted that we do not take account of the potential for the replacement of tyres in the existing stock, and only model tyre grade improvements in new vehicles.

The Table 3-4 below shows our assumptions for tyre costs and efficiency savings associated with moving from a grade G tyre to a higher grade tyre. Table 3-5 shows the proportions of each tyre grade in new vehicles in the TECH scenario.

Table 3-4: Tyre grade options and associated cost and efficiency improvements

Tyre Grade	Price for 4 tyres (incl VAT). €	Rolling-Resistance Coefficient (kg/t)	Fuel efficiency improvement relative to G grade tyres (%)
A	404	<6.5	-9.5%
B	386	6.6-7.7	-8.4%
C	374	7.8-9.0	-6.3%
E	360	9.1-10.5	-3.9%
F	348	10.6-12.0	-1.3%
G	340	>12.1	-

Table 3-5: Tyre grade deployment

Tyre Grade	2015	2020	2030	2040	2050
A	2%	3%	38%	69%	99%
B	12%	23%	42%	21%	1%
C	39%	55%	19%	10%	0%
E	39%	19%	1%	0%	0%
F	8%	0%	0%	0%	0%
G	0%	0%	0%	0%	0%

Batteries

Building on the definitions of the Element Energy 2012 study for the Committee on Climate Change (UK) and those implemented in Fuelling Europe's Future, Table 3-6 shows the battery sizes applied across the three market size segments in the model. In the period to 2020, the BEV market for small and medium passenger cars is assumed to be evenly split between a short and long range battery option. From 2020 onwards, the reduction in battery costs for large batteries is expected to improve the market for long range battery options, which is assumed to dominate the market from 2030 onwards.

Table 3-6 Assumed battery sizes (kWh)

Powertrain	Market segment	2020	2030	2040	2050
PHEV	Small	7.00	6.30	5.60	4.90
PHEV	Medium	10.00	9.00	8.00	7.00
PHEV	Large	15.00	13.50	12.00	10.50

BEV – Short	Small	14.70	14.70		
BEV – Short	Medium	19.60	19.60		
BEV – Long	Small	27.30	27.30	27.30	27.30
BEV – Long	Medium	36.40	36.40	36.40	36.40
BEV – Long	Large	55.00	60.00	65.00	65.00

Given the expected increase in charging infrastructure availability, we assume that after 2020 OEMs prioritise reduced vehicle costs over further increases in battery capacity. In practice there are a wide range of options and specifications available to manufacturers, leading to a wide range of costs, performance and range.

Costs and energy savings

The principal factor determining the speed of progress for powertrain electrification is battery or energy storage technology.

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, 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.

In 2010 the battery of a plug-in electric vehicle was estimated to cost between €6,000 and €16,000 (ACEA, 2011) although this is expected to halve in the decade to 2020, and in the longer-term to decrease to around €3,000 to €4,000. Detailed analysis for the UK Committee on Climate Change in 2012 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 estimates used in the technology costs calculations of this study for BEVs. They are more conservative estimates than other recent estimates from Roland Berger (~US$316-352 /kWh for the total pack by 2015) and McKinsey (US$200 by 2020 and US$160 by 2025 for the total pack), and the EUROBAT R&D roadmap target of reaching €200/kWh (US$260/kWh) by 2020.

PHEV batteries cost more than BEV batteries, per kWh. This is because the power requirements place a proportionally larger demand on the smaller battery pack in a PHEV, so batteries with higher power capability are needed at a somewhat higher cost. The higher costs also reflect fixed costs such as battery management systems and packing costs spread over fewer kWh of capacity in PHEVs compared to BEVs.

The costs presented in Table 2 refers to both the battery and the battery system (or pack), but not the electric drive powertrain (see Table 3). The costs are therefore lower per kWh for a large battery than a small battery, and equally, there is a notable step in cost when considering the extra system and power requirements for a PHEV.

Table 3-7: Battery system costs (€/kWh)

Powertrain	Market segment	2020	2030	2040	2050
PHEV	Small	393	363	324	294
PHEV	Medium	338	310	277	251
PHEV	Large	281	262	234	212
BEV – Short	Small	338	273		
BEV – Short	Medium	283	230		
BEV – Long	Small	188	148	126	105
BEV – Long	Medium	158	127	116	105
BEV – Long	Large	158	127	114	105

Table 3-8: Electric powertrain costs (€)

Powertrain	Market segment	2020	2030	2040	2050
PHEV	Small	844	761	687	622
PHEV	Medium	1031	930	840	760
PHEV	Large	1406	1268	1145	1036
BEV – Short	Small	844	761		
BEV – Short	Medium	1031	930		
BEV – Long	Small	844	761	687	622

BEV – Long	Medium	1031	930	840	760
BEV – Long	Large	1406	1268	1145	1036

The powertrain costs range by almost a factor of two between the powertrain required for a small and a large BEV. Overall, the total battery system and powertrain costs are shown in Table 3.9 for the total electric system and powertrain for each of the different market segments based on the derived battery size.

Table 3-9: Total cost of electric powertrain and battery (€)

Powertrain	Market segment	2020	2030	2040	2050
PHEV	Small	3594	3046	2503	2061
PHEV	Medium	4408	3720	3057	2518
PHEV	Large	5627	4802	3953	3263
BEV – Short	Small	5811	4773		
BEV – Short	Medium	6587	5443		
BEV – Short	Large	-	-		
BEV – Long	Small	5985	4798	4468	4138
BEV – Long	Medium	6769	5544	5300	5056
BEV – Long	Large	10075	8874	8699	8524

Note(s): The cost difference between BEV and PHEV will be smaller than the battery cost difference, since a BEV system entirely displaces an ICE, whereas a PHEV only allows for a smaller ICE engine to support it. An ICE has a cost of around €2,000 in the medium category.

Battery range

In line with Fuelling Europe's Future and Element Energy (2012), we apply State of Charge (SOC) assumptions to derive the useable energy of the battery. The expected range (Table 3-10) is then derived based on the test cycle efficiency of the vehicle (in all electric mode).

Table 3-10: Vehicle range in all electric mode (km – test cycle)

Powertrain	Market segment	2020	2030	2040	2050
PHEV	Small	42	44	46	46
PHEV	Medium	49	51	53	54
PHEV	Large	61	64	67	67
BEV – Short	Small	107	125	n/a	n/a

BEV – Short	Medium	116	135	n/a	n/a
BEV – Long	Small	199	232	273	288
BEV – Long	Medium	216	251	295	312
BEV – Long	Large	274	348	442	467

The implicit assumption in the modelling is that vehicle manufacturers will maintain battery sizes for BEVs such that efficiency and performance improvements are used to improve the range of the vehicle. In contrast, as all-electric range is less of an issue in the PHEV market, manufacturers reduce battery sizes to improve cost and only allow for modest increases in all-electric range.

For BEVs, there has been consideration of the split in market between low(er) cost short range vehicles and high cost and long range vehicles, where short range models are aimed at those looking for an urban “run around” whereas the long range model aim to fully replace an ICE vehicle for everyday use. As a result, of this we only consider the large market segment for long range BEVs.

In 2020, we assume that EV sales are split evenly between the short range and long range option. By 2030, the long range (large battery options) are much more cost effective than the short range options and so at this point, we make the assumption that BEV sales are dominated entirely by the long range option.

Fuel cell vehicle systems

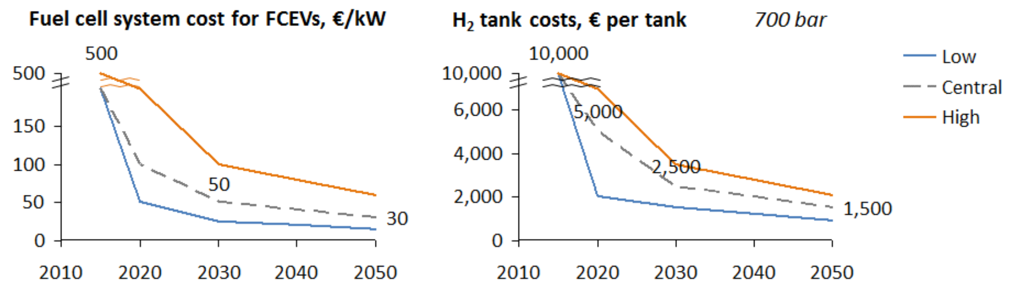
Next to pure EVs, renewably produced hydrogen used in fuel cell electric vehicles (FCEVs) offers one of the largest potential reductions in CO_2 in the longer term. FCEVs also offer the benefit of a range and refuelling time comparable to conventional vehicles. FCEVs are therefore particularly well-suited to long-distance driving.

The two largest components influencing the costs of fuel cell vehicles are the fuel cell system and the high pressure hydrogen tank. Future values for these costs are subject to significant uncertainty, since they depend strongly on both improvements at a technology level (for example reducing the precious metal content in the stack) and substantial increases in manufacturing volumes. For current costs, representing very low production volumes, fuel cell costs of 200 EUR/kW are assumed as a central estimate, with a high value of 500 EUR/kW (see Figure 3-1). This is consistent with the 2010 values in the EU Powertrains study[9], reflecting the fact that fuel cell vehicle commercialisation is occurring later than assumed in that analysis. A cost of 200 EUR/kW implies a system cost of 20 000 EUR for a 100kW system. This is broadly consistent with the retail price of the Toyota Mirai of €60 000 excluding VAT in Germany (the Mirai is not yet in sale in France), but it is not possible to derive directly the

[9] FCH JU (2010): A Portfolio of Powertrains for Europe: A Fact-based Analysis

fuel cell cost based on the vehicle selling price since the margins for these initial vehicles are unknown. Given the very low sales of fuel cell vehicles before 2020 (compared with the overall vehicle parc in France), current fuel cell assumptions have only a small impact on the economic modelling in the study.

Figure 3-1 Current and projected costs of fuel cell systems and hydrogen tanks



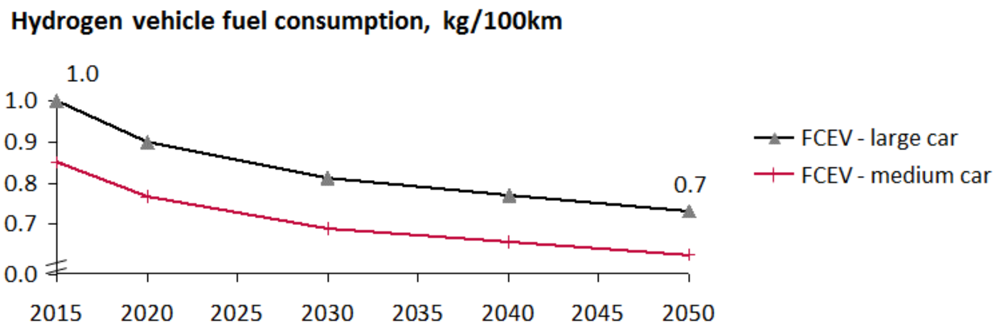
In 2020 and beyond, significant cost reductions in fuel cell systems are expected due to technology improvements and increasing production volumes. Future assumptions are based on the EU Powertrains Study and the UK's Hydrogen Technology Innovation Needs Assessment carried out by Element Energy and the Carbon Trust. These costs would result in a 100kW fuel cell system costing 5 000 EUR by 2030 and 3 000 EUR by 2050. Low and high estimates of 50% and 200% of the central value respectively were defined to test the sensitivity of the economic modelling to this assumption.

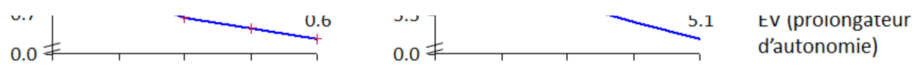
Figure 3-1 also shows the expected cost progression of hydrogen tanks. These are based on the UK TINA and bilateral discussions with vehicle manufacturers. Like fuel cell costs, significant cost reductions are expected as manufacturing volumes increase, with a reduction of 75% relative to today's prices by 2030.

Hydrogen vehicle fuel consumption

Fuel consumption assumptions were developed from the stated NEDC range and hydrogen tank size of current generation FCEVs (for example the Hyundai IX-35). This gives a current fuel consumption of c.1kg/100km for a large car, and 0.85kg/100km for a medium car such as the Toyota Mirai.. Fuel consumption is expected to decrease in future model generations, partly due to increasing fuel cell efficiency but also through efficiency savings at a vehicle level such as weight reduction or improved aerodynamics. Assumed fuel efficiency improvements are in-line with those in the Portfolio of Powertrains for Europe study, and are equivalent to a 10% reduction per decade.

Figure 3-2: Hydrogen vehicle fuel efficiency





Driving range and system power outputs

The driving range between refuelling events is significantly higher than current generation electric vehicles, at 590km on the New European Drive Cycle (NEDC). Range assumptions and the assumed motor and fuel cell powers are shown below. As fuel cell costs decrease and fuel efficiency improves, vehicle manufacturers may choose to increase vehicle range, or reduce hydrogen tank sizes while keeping the range constant. This also applies to fuel cell and motor powers, where manufacturers can trade-off increased power (and hence increased performance) with cost reduction for a given performance. These decisions will depend on perceived customer needs as well as technology progression.

As a simplifying assumption, vehicle ranges and motor/fuel cell powers are assumed to remain constant throughout the study timeframe. This is consistent with manufacturers favouring cost reduction to improve total costs of ownership relative to conventional vehicles, rather than 'spending' technology improvements on better performance.

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4 Infrastructure

4.1 Electricity generation and prices

The structure of the power sector and, in particular, the renewable content of electricity generation, has three important implications for the results of the study:

1. It determines the net environmental impact of electrification of the vehicle fleet (the transition to a high proportion of EVs in the stock will have greatest environmental benefits if electricity generation is also decarbonised).
2. It determines the price of electricity that EV owners will be charged (as the costs of electricity generation can vary substantially depending on the technologies that are deployed). This has implications for the Total Cost of Ownership (TCO) for an EV relative to a conventional ICE.
3. It could affect net electricity system costs negatively (due to additional distribution costs and additional power requirements) or positively (through synergies between EV and the power grid). This is discussed further in Element Energy et al (2015).

Generation mix

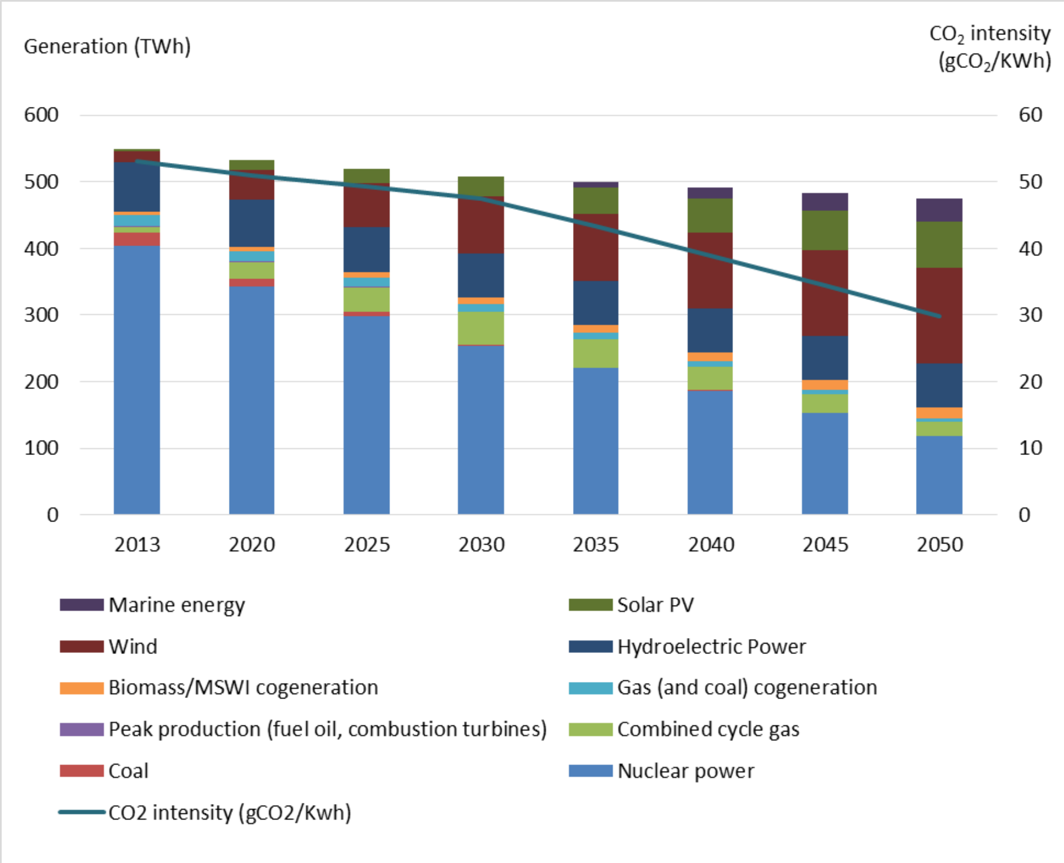
The key characteristics of the power sector in this study include:

- a reduction in the share of electricity generation from nuclear power plants (which falls from 73% in 2013 to 49% in 2030 and to 25% by 2050)
- a small reduction in electricity generation from coal and gas CCGT over the period to 2050
- these sources of generation are replaced by an increase in renewables, most notably an increase in wind generation

The structure of the power sector in 2030 is based on RTE's "Nouveau Mix" scenario. In line with 'La Loi de Transition Energetique', this scenario is consistent with the assumption of a 40% reduction in emissions over the period 1990-2030. The scenario also assumes almost no change in electricity demand compared to current levels, as a reduction of electricity consumption due to improved energy efficiency is offset by an increase in demand due to greater electrification of the French economy, including increases in deployment of EVs. There is also a significant share of renewables in the generation mix. By 2030, renewables cover 40% of electricity generation and renewable electricity generating capacity includes 27.6 GW of onshore wind, 9 GW of offshore wind, 24.1 GW of solar PV and 3 GW of tidal energy.

The 2050 generation mix is based on ADEME's "Vision ADEME 2050" scenario, which assumes a 75% reduction in emissions relative to 1990 levels.

Figure 4-1: Projected Electricity Generation Mix and CO_2 intensity



Renewables are assumed to account for almost 70% of the total electricity generation by 2050, particularly due to growth in generation from wind power and solar PV. The generation mix and carbon intensity of the power sector is shown in **Error! Reference source not found.**.

Source(s): Artelys, RTE, ADEME.

Electricity prices

The price of electricity for final consumers comprises three components: the cost of the generation itself, the cost of transmissions and distribution, and the cost of tax. Historically in France, around one third of the residential electricity price is attributable to each of these three components.

To calculate the generation costs, the levelised cost of generating technologies are calculated for each technology using capital cost and operation and maintenance cost projections from the IEA and the NREL[10].

Transmission and distribution are financed by the TURPE (Tarif d'Utilisation des Réseaux Publics d'Electricité), which is shared between RTE (the French transmission operator), ERDF (a French distribution operator, which operates 95% of France's distribution network) and other (private) distribution

[10] IEA (2014), 'Projected costs of generating electricity', IEA (2014) '*World Energy Outlook', NREL (2014), 'Transparent cost database'*

operators, which operate the remaining 5%. The tariff is fixed every year by the French energy regulator (the CRE). Its value depends on power usage and on the voltage of the electrical connection. Therefore, the tariff paid by industries (that are directly connected to the transmission network) is less than the tariff paid by residential consumers (which are connected to the distribution network). As the EV charging infrastructure is connected to the distribution network, we assumed that the transmission and distribution costs for EV users are the same as in the residential sector, for which the TURPE tariff is about 43 €/MWh. It was assumed that this value remains unchanged over the 2015-2050 period.

Four taxes are taken into account for the electricity prices[11]:

- CSPE (Contribution au Service Public d'Electricité)
- CTA (Contribution Tarifaire d'Acheminement)
- TCFE (Taxes sur la Consommation Finale d'Electricité)
- TVA (Taxe sur la Valeur Ajoutée), which is VAT

This scenario also assumes a very high price for CO_2 (95€/ton in 2030), which includes the cost of the Contribution Climat-Énergie (CCE). The electricity price paid by EV owners is shown in Table 4-1.

Table 4-1 Electricity price for EV users

	2013	2030	2050
Production cost	50.98 €	74.21 €	80.01 €
Selling cost (incl. profit margins)	12.35 €	15.41 €	16.17 €
TURPE	42.85 €	42.85 €	42.85 €
CSPE	4.61 €	5.75 €	6.04 €
CTA	11.59 €	14.46 €	15.17 €
TCFE	9.60 €	11.98 €	12.57 €
TVA (VAT)	24.72 €	30.83 €	32.36 €
Total (€/MWh)	156.69 €	195.49 €	205.18 €

Source(s): Artelys.

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

[11] The part of the CSPE that corresponds to the funding of renewable technologies has been excluded because this cost is already accounted for in the production costs (from which no subsidies have been subtracted). Consequently, only 34% of this tax is included. For CSPE, TCFE and CTA taxes, it was assumed that the same cost ratios as in 2015 are applied for the period 2015-2050.

night at times of low demand from other sources. This could have the double benefit of reducing curtailment of intermittent wind power that might occur through the night (see Element Energy et al (2015)[12]).

4.2 Electric charging infrastructure

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

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

The costs of charging infrastructure have been adapted from the analysis in Fuelling Europe’s Future based on current data and expectations in France, such that a 3 kW one plug domestic charging point has a capital and installation cost of around €1,400. Workplace charging points are included as two plug 7 kW, ground mounted at an installed cost of around €1,500 (see

Table 4-2). Rapid charge points that would be expected at motorway service stations are estimated to cost €35,000 to manufacture and install.

Table 4-2: Charging point cost assumptions

Main application	Charging point features	Power (kW)	Charge time	Production cost (€)	Installation cost (€)
Residential – individual (recharge normale)	Wall box One plug User protection during charging Options for metering	3 kW	7-9 hours	400	1000
Residential – collective (recharge normale)	Wall box One plug Choice of access control systems	3 kW	7-9 hours	500	2000
Workplace (recharge nromale_	Ground mounted Two plugs Choice of access control systems	7 kW	4-8 hours	500	1000
Parking (on-street and shopping centres)	Ground mounted Two plugs High resilience Different access	22 kW	1-2 hours	3000	5000

[12] EV Grid Synergy Analysis, France

(recharge acceleree)	options				
Stations on motorways (recharge rapide)	Rapid charging 2 plugs High resilience	43 kW	30 minutes	20,000	15,000

Clearly, there are likely to be many options that emerge for charging posts, the options presented are archetypes to illustrate the characteristics and costs of charging posts. For the residential sector, the standard option is a 3kW wall box that charges the vehicle overnight taking four to eight hours. However, there is also an obligation to have access to a charging point in a collective building and so this additional technology option has been considered in the short term. In the workplace we consider that two plug ground-mounted charging posts will prevail in the short term, but these could be replaced in the market by 22kW accelerated recharging posts in the medium term. For stations on motorways, a multi-standard AC/DC rapid recharging unit is proposed allowing for a full recharge in around 30 minutes. In the medium term future rapid charging could be deployed at either 88kW or 120kW allowing for even faster recharging. We assume that installation and production costs fall as deployment volumes increase.

Deployment and financing

Over the projection period, we assume that private charging posts (residential and workplace) are financed by the household or business purchasing the EV. For public infrastructure, we assume that in the period to 2025 the investments are paid for by the government. After 2025, we assume that installations in multi-story car parks, retail parks and shopping centres will be undertaken privately to attract customers. Similarly, post 2025 we make the assumption that rapid charging motorway[13] charging posts will be funded privately as the volume of EV's on the road will make a business model viable.

Table 4-3: EV charging post deployment

Charging posts per EV	2020	2030	2040	2050
Residential	1	1	1	1
Workplace	0.4	0.4	0.4	0.4
Parking	0.1	0.1	0.1	0.1
EVs per charging post				
Stations on motorways	50	70	90	100

For deployment we assume that each EV sold has, on average, either a residential wall box or a workplace charging post in place. In addition, we assume that there will be two public charging posts in urban areas for every ten EVs on the road. For rapid charging the assumption is that for every 50

[13] Autoroute, voies rapides et expresse, points de passage stratégiques

EVs on the road there is one rapid recharging point on motorway stations. As the deployment of EVs increases, we assume that this ratio will change so that there is one charging post to every 100 EVs on the road by 2050. This assumption reflects the short term need to over-provide motorway charging in the short term to build up a minimum level of infrastructure to support EV deployment. In the medium to long term the number of motorway stations required for each EV will fall, since there will be a large enough capacity of charging posts and the emphasis will shift to fully utilising each charging post to support a privately funded business model.

Residential and workplace charging are assumed to be equipped with at least Mode 3 capability to allow for the synergies described by Element Energy et al in the accompanying report “EV Grid Synergy Analysis for France”. This technical capability is reflected in the cost of the charging infrastructure. Moreover the investment and cost associated with reinforcing the distribution network, as discussed by Element Energy et al, are reflected in the economic analysis.

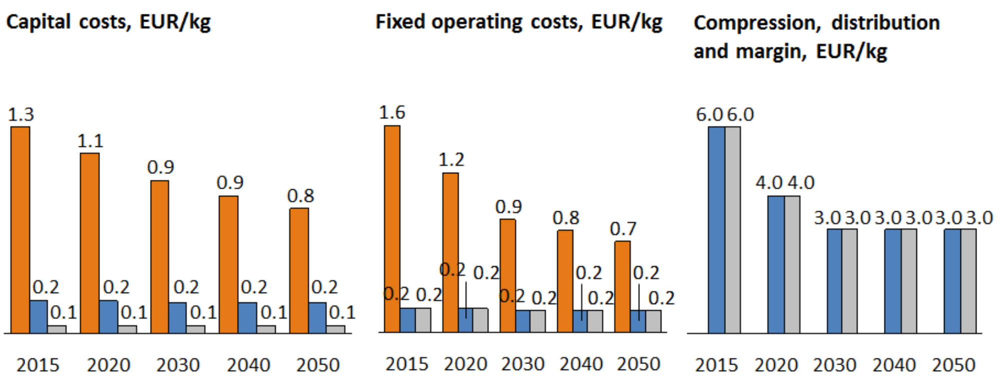
4.3 Hydrogen production and distribution

Hydrogen production costs

Hydrogen production for the transport sector is expected to be dominated by water electrolysers, steam methane reforming (SMR) and by-product from industrial processes (for example chloralkali plants). These sources form the basis of the production mix in this study. Other potential sources include waste or biomass gasification, or SMR with carbon capture and storage. These additional routes could potentially provide low cost, low carbon hydrogen, but are not yet technically proven and have not been included in the cost assumptions below.

Hydrogen production cost data was sourced from the UK Technology Innovation Needs Assessment, and Element Energy and E4Tech’s Development of Water Electrolysis in the European Union study. The data are also consistent with the H2M France public report, which shows the total hydrogen costs but not the individual cost components. The capital and fixed operating costs per kg of hydrogen produced are shown in **Error! Reference source not found.**. SMR and by-product technologies are already mature, and so future cost reductions are assumed to be zero for this study. Current electrolyser costs are relatively high, driven by low manufacturing volumes and relative immaturity at the scale expected for hydrogen production (e.g. 500kg-5t/day). Compression, distribution and margin costs for SMR and by-

Figure 4-2 Capital costs, fixed operating costs and compression, distribution and margin costs in €/kg



Notes:

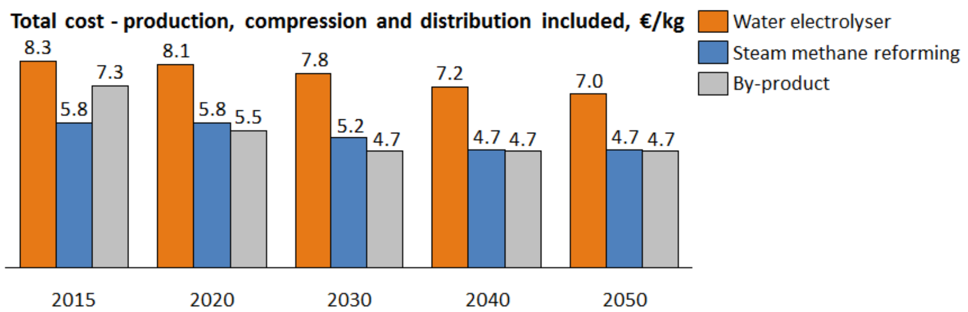
Capital costs based on 90% utilisation, 20 year lifetime, 7% cost of capital. Water electrolyser costs are based on average costs for the two main technologies (PEM and alkaline) and include costs for the

Water electrolyser
Steam methane reforming
By-product

product are specific to each supplier, the number of stations served and the geographical distribution of refuelling stations. Indicative values are shown from 2015-2050 following discussions with Air Liquide, though it should be noted that both significantly lower and higher costs have been observed in recent European demonstration activities.

The total production costs from each production route are shown in **Error! Reference source not found.**. These costs include the feedstock costs assumptions for gas (30 EUR/kWh in 2015 rising to 40 EUR/kWh by 2030) and electricity (107 EUR/kWh in 2015 rising to 148 EUR/kWh in 2050). These costs will varied in the different scenarios in the economic modelling. The results below show significantly higher costs for electrolyser hydrogen compared to SMR and by-product. This is due to the use of a standard electricity price in the baseline scenario that does not account for optimisation in terms of time of day usage. The impact of lower electricity prices through optimised use of renewables in periods of low demand will be considered as a separate scenario, as this is a critical factor if electrolysers are to be

Figure 4-3 Total costs of hydrogen production

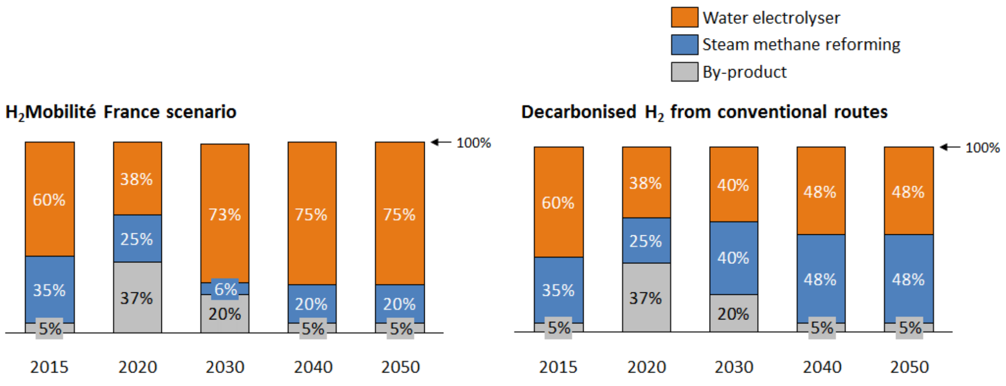


competitive with other hydrogen sources in the future. The water electrolyser costs in Figure 4-3 also include a revenue of 1 EUR/kg from the provision of balancing services to the electricity grid. This is an indicative value based on discussions with RTE, but is consistent with analysis carried for the French and UK H_2Mobility initiatives.

Hydrogen production mix

The hydrogen production mix in France will be influenced by relative costs of each production source, customer demand (in terms of the carbon footprint of the hydrogen) and policies such as incentives for green hydrogen. Two production mix scenarios were developed for this study, shown in Figure 4-4. The first is based directly on the decarbonisation scenario in the H_2Mobilité public report, which targeted a ~50% reduction in well-to-wheel emissions for FCEVs relative to diesel cars in 2020, and ~75% in 2030. This in turn requires approximately 75% of hydrogen to be produced by electrolysers in 2030 and beyond, using the average French electricity mix. A second scenario was considered to reflect the potential availability of low carbon hydrogen from conventional sources, such as SMR using biogas or with Carbon Capture and Storage. In this scenario, water electrolysers and SMR have equal shares of the production mix in 2030 and beyond, with a small residual share for by-production hydrogen. The Mobilité Hydrogène scenario was the main scenario used in the economic analysis.

Figure 4-4 Hydrogen production mix scenarios



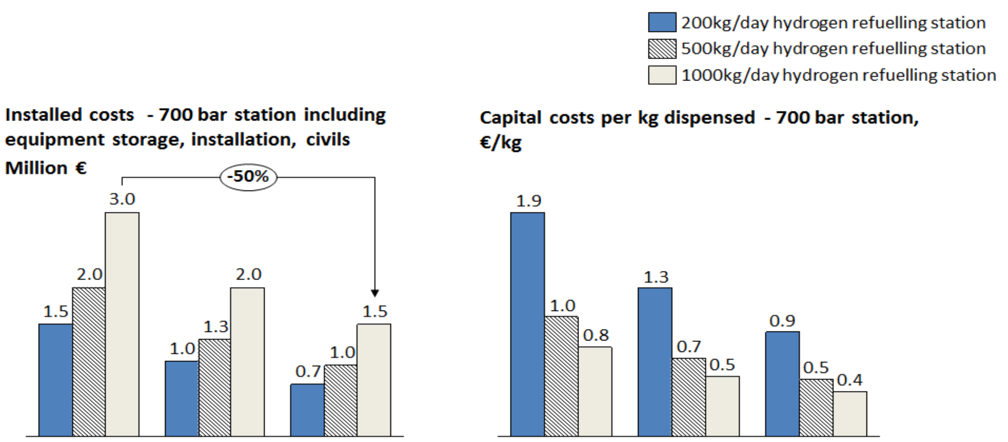
4.4 Hydrogen refuelling

Refuelling station costs

Fuel cell vehicles are refuelled by hydrogen refuelling stations, dispensing high pressure gaseous hydrogen into the vehicles' on-board storage tanks (which store hydrogen at 70MPa/700 bar in passenger cars). The main elements of a hydrogen refuelling station (HRS) are a compressor, hydrogen storage, pre-cooling/refrigeration equipment and dispensers. The exact configuration of an HRS, in terms of its size, the pressure of primary and buffer storage and dispensing rate per hour, vary according to the station supplier and the intended use. HRS costs in this study are based on three different station sizes, dispensing 700 bar hydrogen and meeting the performance specifications set out in the SAE J2601 and ISO 2011 international standards, which ensure a fill time of ~5 minutes for 'full power' fuel cell vehicles with on-board storage of 5kg, which provides a range of approximately 500km. Cost assumptions are drawn from the various H_2Mobility studies around Europe, the UK Tina, and quotations received directly from equipment suppliers. Current and projected installed costs are shown in Figure 4-5, which include equipment, civil works and engineering/project management costs. Costs are also shown per kilogram of capacity, assuming a 7% per year cost of capital, 90% utilisation factor and a 20 year lifetime. These costs are appropriate for hydrogen stations receiving hydrogen deliveries by truck, or from an on-site electrolyser[14]. The costs for the electrolyser itself are included in the production cost section.

Hydrogen refuelling station costs are expected to decrease by approximately 50% by 2030, reflecting design improvements and increases in manufacturing volumes. In particular, this is expected to reduce the cost of components (such as compressors and dispensers) currently produced by a limited number

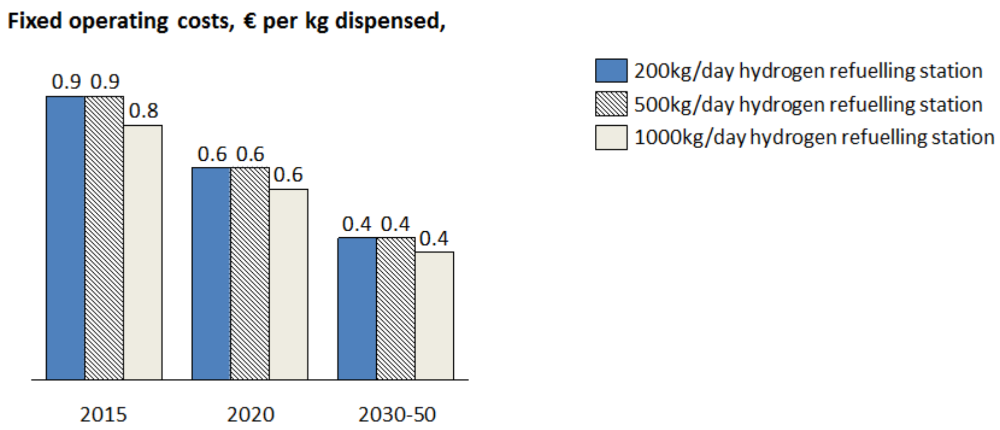
Figure 4-5 Capital costs of hydrogen refuelling stations



of suppliers. By 2030, capital costs represent a relatively small proportion of the expected hydrogen selling price (7-10 EUR/kg), particularly for the larger station sizes. Hence, possible breakthroughs in HRS design leading to much lower costs than predicted here, while beneficial particularly in terms of reducing capital investment for the early network, do not strongly affect the overall economics of hydrogen refuelling.

Operating costs for HRS are shown in Figure 4-6. Like capital costs, significant cost reductions are expected in future, due to more efficient supply chains, use of local labour for maintenance rather than engineering teams from the equipment supplier, and increased component lifetimes. Again, costs beyond 2020 are a relatively small proportion of the overall hydrogen cost structure, which is dominate by the cost of the hydrogen itself. This is similar to the cost structure for conventional petrol stations, and unlike that of electric charging points, whose capital costs are high in proportion to the value of the electricity supplied.

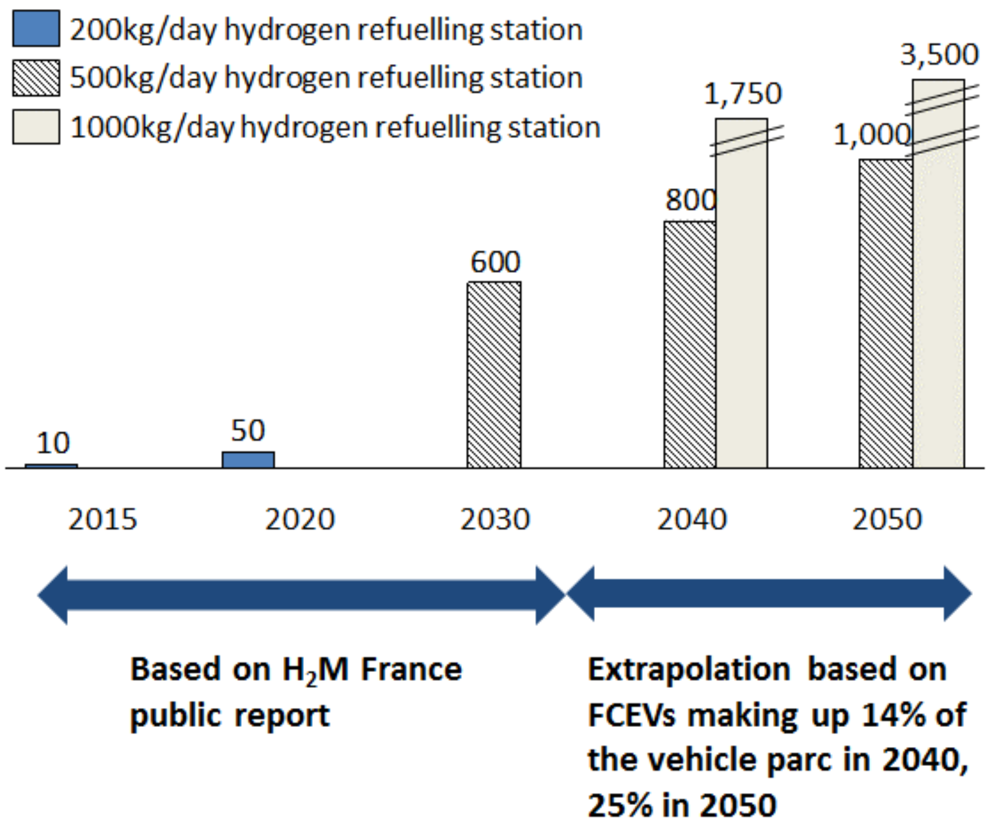
Figure 4-6: Fixed operating costs of hydrogen refuelling stations, EUR/kg



Projected rollout of hydrogen refuelling stations in France

The future rate of deployment of HRS in France is strongly linked to the rollout of fuel cell vehicles, particularly the step change in sales driven by lower cost, second generation vehicles beyond 2020. An indicative projection is shown in **Error! Reference source not found.**. In the short term, public funding will be required to make station deployments economic while likely utilisation remains low. A strategy for supporting this early rollout will be proposed by the French government as part of the Energy Transition Law (la loi de transition énergétique). National and local government will also seek to reduce planning permission and regulatory approval times for new HRS, while respecting all necessary safety measures. HRS numbers to 2030 assumed in this study are based on the Mobilité Hydrogène France public report, reaching 50 station by 2020 (primarily serving FC range-extended electric vans) and 600 stations by 2030. Values for 2040 and 2050 will be linked to the different vehicle sales scenarios to be considered in this study, based on the total hydrogen demand and the capacity per station. Values shown in Figure 4-7 are consistent with fuel cell vehicles making up 14% of French vehicle parc in 2040, and 25% in 2050.

Figure 4-7 Indicative deployment projection for HRS in France



5 Consumer Perspective

5.1 Consumer preferences

Consumers purchase vehicles based on many attributes of the car, and typically fuel efficiency is only one consideration. In fact, car buyers have been shown in some studies to undervalue future fuel savings, but a recent survey of prospective car buyers found that over one third were willing to pay €1,000-2,000 extra for a hybrid car, and over a quarter were willing to pay a premium of more than €2,000.[15]

Moreover, consumers will pay considerable premiums for additional features. Anecdotal evidence of car pricing options for the same brand and model suggests that prices can more than double depending on performance options, interior and exterior finish and additional features. This suggests that the consumer might be willing to pay the technology cost premium associated with more efficient vehicles and advanced powertrains, especially given the expected fuel cost savings.

5.2 Vehicle costs

The capital cost of each vehicle in the model is derived by combining projections of the powertrain and glider cost (by market segment) with estimates of the cost of fuel-efficient technologies installed in the car (including low-rolling resistance tyres, aerodynamic improvements, weight reductions).

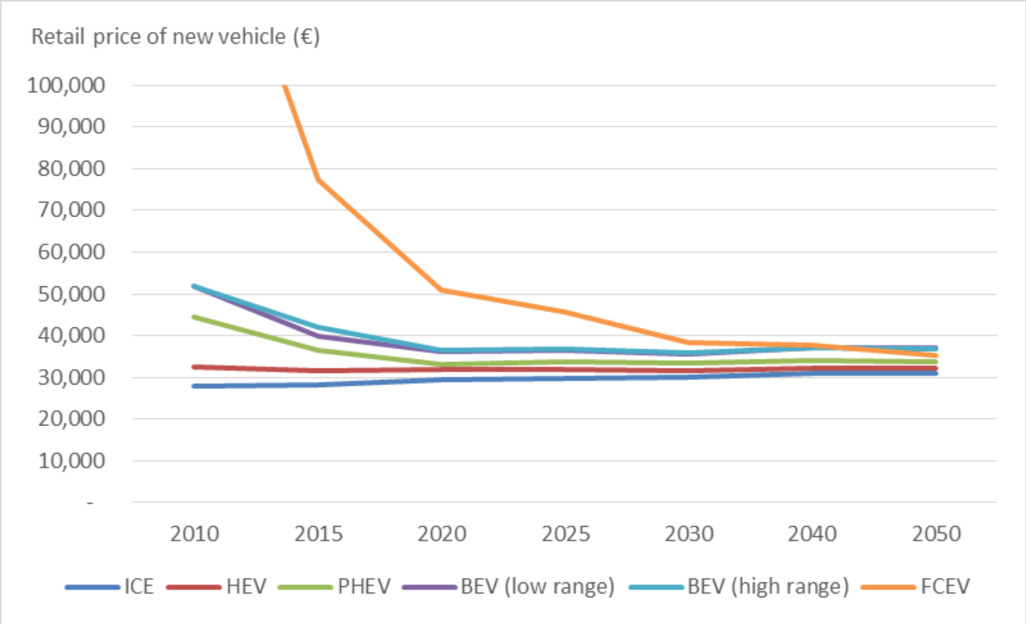
Margins, distribution costs and VAT are added to the vehicle production costs in order to derive the retail price. In 2030 it is assumed that, in monetary terms, the additional retail and distribution costs for ICEs, EVs, PHEVS and FCEVs are approximately equivalent.

VAT is added at 19.6% and is charged on consumer sales of all vehicle types over the period to 2050. As VAT is applied as a percentage of the final sale price, the VAT component for (relatively expensive) BEVs, PHEVs and FCEVs is higher than that for conventional petrol and diesel cars. It is noted that we do take account of the Bonus-Malus payments in the cost of purchasing a vehicle, as it is likely that these taxes and subsidies will be gradually phased out as EV take-up increases.

[15] Europe: The Great Electric Hype? – PWC Autofacts (2014)

We assume that car owners would pay for the capital cost of a car over its lifetime (14.5 years, on average) in monthly instalments with a 3.5% interest rate. The retail price of new vehicles in the TECH scenario is shown in the chat below.

Figure 5-1 Price of new vehicles in the TECH scenario



The price of conventional ICEs and HEVs increases slightly over the period, due to the cost of additional fuel-efficient technologies that are installed in vehicles over the period to 2050. The price of BEVs, PHEVs and FCEVs falls, most noticeably in the period to 2020, due to learning effects which lead to substantial reductions in the cost of batteries. FCEVs see the greatest cost reductions, but do not become cost-competitive until the period 2040-2050.

5.3 Fuel costs

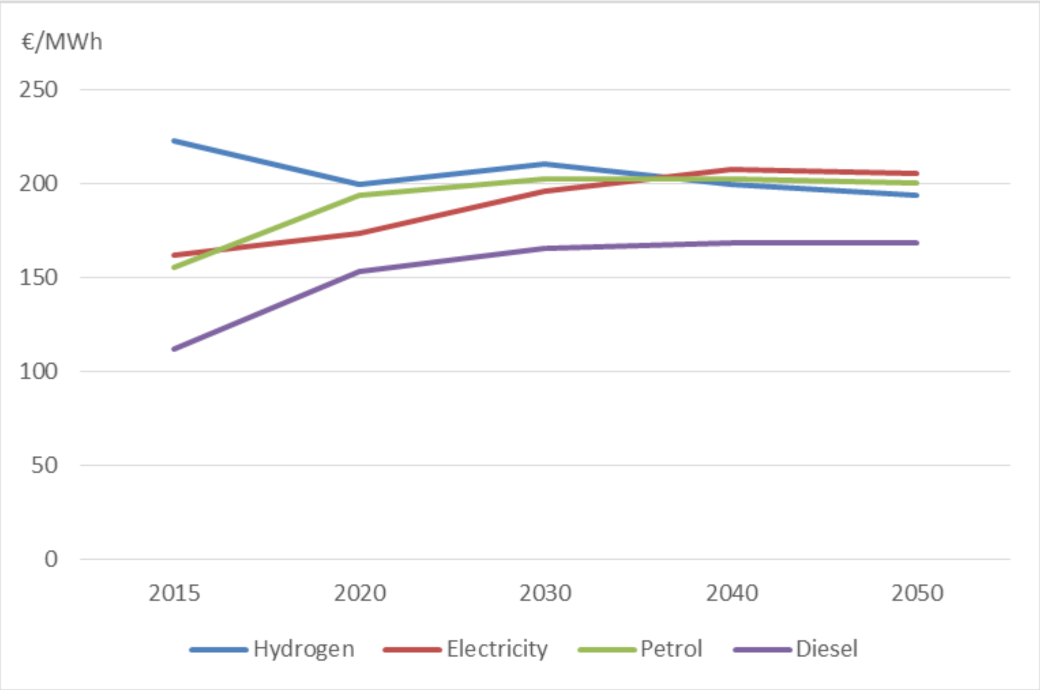
One feature of the TECH scenario is a substantial improvement to the efficiency of conventional ICEs, leading to fuel bill savings for owners of petrol and diesel cars. In addition, the transition towards an increase in the share of PHEVs, BEVs and FCEVs has implications for fuel bills in the TECH scenario due to the differences in the costs of these alternative fuels, as well as the improvements in the efficiency of energy conversion in an electric powertrain relative to a conventional ICE.

The oil price projections used for this analysis are taken from IEA's November 2014 World Energy Outlook and the cost of petrol and diesel production is assumed to grow in line with these oil prices over the period to 2050. Projections for the Contribution Climat-Énergie (CCE) are then added to this cost, to take account of the carbon price component in petrol and diesel prices, and the cost of fuel duty is assumed to stay fixed in real terms (moving with inflation). In the short term the IEA's prices are above current market prices and so a low oil price sensitivity is also explored, where real oil prices are assumed to remain at 2015 levels over the projection period. The macroeconomic results for this sensitivity are reported in Section 6.3.

As PHEVs, EVs and FCEVs, become more prevalent in the vehicle mix, assumptions about the price of hydrogen and electricity become more important. The electricity price is calculated based on the generation mix reflected in RTE's 'Nouveau Mix' scenario (for 2030) and ADEME's 'Vision ADEME' scenario (for 2050). An increase in the share of renewables in the mix leads to a modest increase in the wholesale electricity price over the period to 2050. Furthermore, it is assumed that EV users will pay the same price for electricity as residential consumers, not least because the majority of charging will take place at the home.

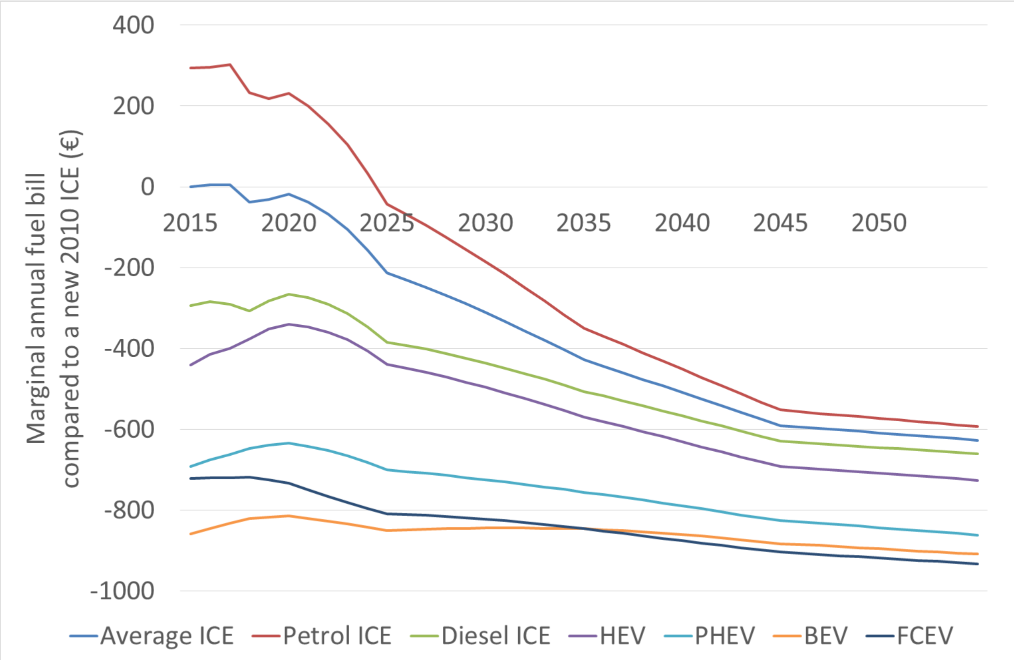
Hydrogen prices are formed on the assumption that the hydrogen production is dominated by water electrolysers, steam methane reforming (SMR) and by-product from industrial processes (for example chloralkali plants). To cover the cost of production, distribution and retail margins we estimate a price of hydrogen of around 208 €/MWh (just under €6.9/tonne) in 2030, falling to around 194 €/MWh (€6.4/tonne) by 2050 as production methods improve.

Figure 5-2 Fuel price assumptions



The annual fuel costs vary substantially for vehicles in different market segments and for different powertrain types. In 2014, the fuel costs associated with running an average vehicle in the French fleet was €1191 pa. In the TECH scenario, despite higher future petrol and diesel prices, efficiency improvements mean that the average annual cost of fuel for a new ICE/HEV vehicle in 2030 is €580 lower than the average ICE vehicle in the stock in 2014. PHEVs, EVs and FCEVs are substantially cheaper to run and, by 2030, the average new vehicle with an advanced powertrain is €1008 cheaper to run than the average (rather than average new) vehicle in 2014.

Figure 5-3: New vehicle annual fuel bill saving compared to average new 2010 ICE



5.4 Total cost of ownership

When making decisions about purchasing a new vehicle, consumers take into account a wide range of factors, including cost, reliability, style, brand and performance. One of the factors considered by some consumers is the total cost of owning and running the car and so it is instructive to compare the Total Cost of Ownership (TCO) of electric vehicles, relative to available alternatives.

For this study, the TCO is calculated as the sum of the cost of the vehicle itself (and interest payments on the purchase cost), fuel and maintenance costs over the vehicle’s lifetime and, where applicable, the cost of purchasing and installing a home charging post

As described in Section 5.2 and Section 5.3, the capital cost of producing an advanced powertrain is expected to be higher than the cost of producing a conventional ICE, particularly in the short-term. However, as deployment of EVs and FCEVs increases, manufactures can benefit from learning and economies of scale that lead to reductions in the cost of production. The cost of running an EV is much lower than an ICE, but starts to increase slightly over the period as electricity prices increase under our high-renewable power sector assumptions. Maintenance costs do not vary significantly for different powertrain types but are expected to be slightly lower for EVs.

The cost of owning and running an advanced vehicle relative to a conventional petrol or diesel car also varies by market segment (see Figure 5-4). We assume that FCEVs are only deployed in the medium and large market segments and that BEVs only penetrate the small and medium markets segments, due to power and range limitations. We also assume that, over the period to 2030, the market for BEVs splits into two distinct groups: long-range BEV's and a standard BEV, which is assumed to have a shorter range. It is unlikely that consumers would assess these two cars for the same mileage profile. For the period post-2030, we assume that the technology develops to an extent that all BEVs are 'long-range' BEVs.

The charts below show the TCO of new vehicles in the TECH scenario relative to an average new vehicle in 2010. By 2030, the TCO of all advanced powertrains are between €2,500 and €4,000 cheaper to own and drive than an average new 2010 ICE. PHEVs are cheapest (on a TCO basis) in all market segments in 2030 and in the small and medium segments in 2050, even after accounting for the cost of purchasing and installing EV charging infrastructure. In the large market segment, FCEVs become the cheapest vehicle to own and run in 2050. FCEVs could have the lowest TCO in 2030, but there is still considerable uncertainty over both the expected cost of hydrogen and, more significantly, the capital cost of the FCEV's.

Figure 5-4 Total cost of ownership in 2030 (euros)

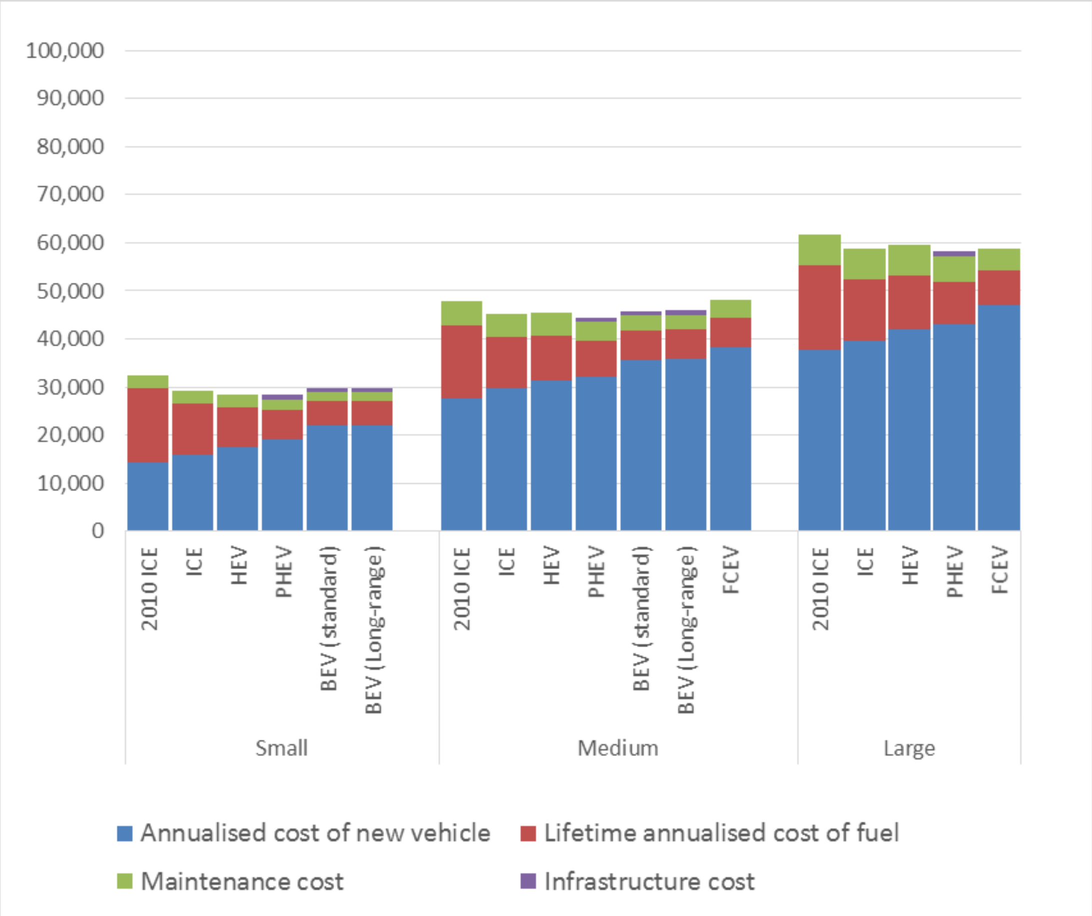
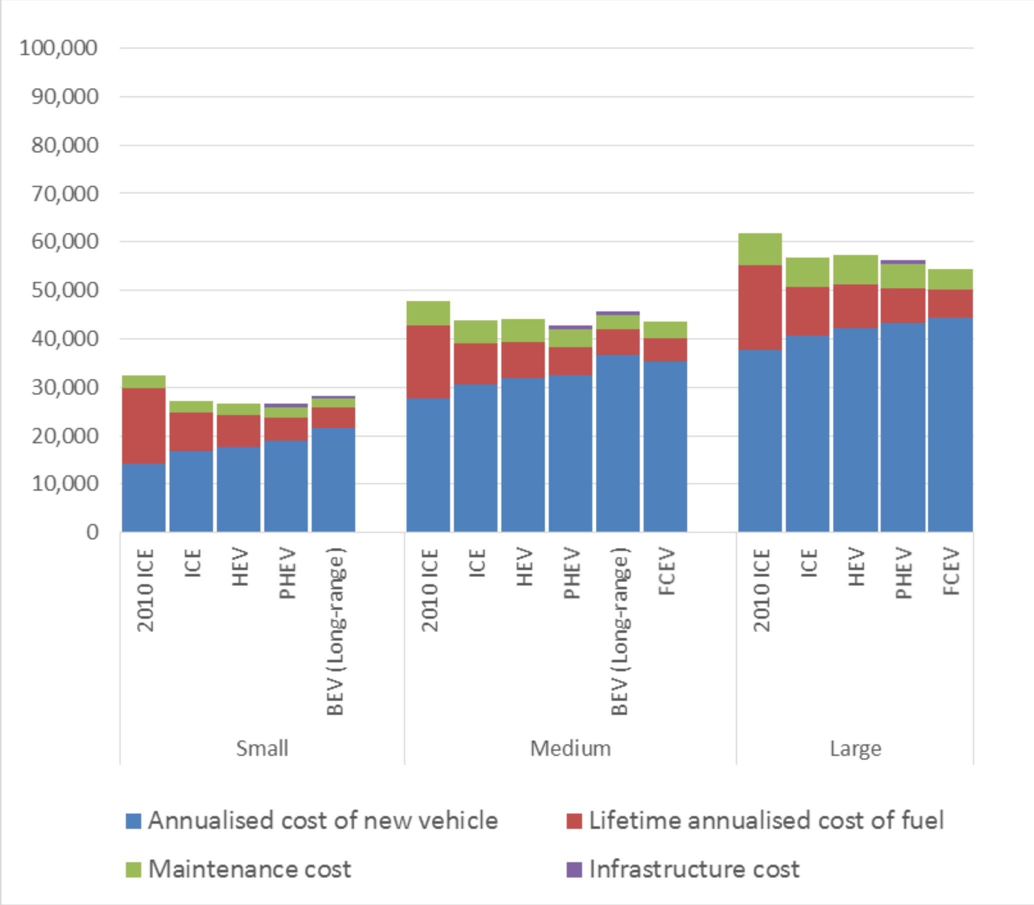


Figure 5-5 Total Cost of Ownership in 2050 (euros)



6 Macroeconomic Impact

6.1 Economic impacts

The stock model analysis described in Chapter 5 shows that French consumers would benefit from the lower costs of ownership associated with low-carbon vehicles. This section of the report builds on the results from the vehicle stock model analysis to assess the wider macroeconomic implications of a low-carbon vehicle fleet in France. A macroeconomic model of the global economy, namely E3ME, is used to model the effects on French GDP, consumption, investment, the balance of trade and employment resulting from the changes in vehicle costs, fuel consumption and charging infrastructure.

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

Factors affecting the macroeconomic results

The key macroeconomic flows resulting from an increase in purchases of low carbon vehicles and a change in the vehicle fuel mix are shown in Figure 6-1 and Figure 6-2 below.

Figure 6-1: Effects of an increase in deployment of EVs on the vehicle supply chain, consumers and the economy

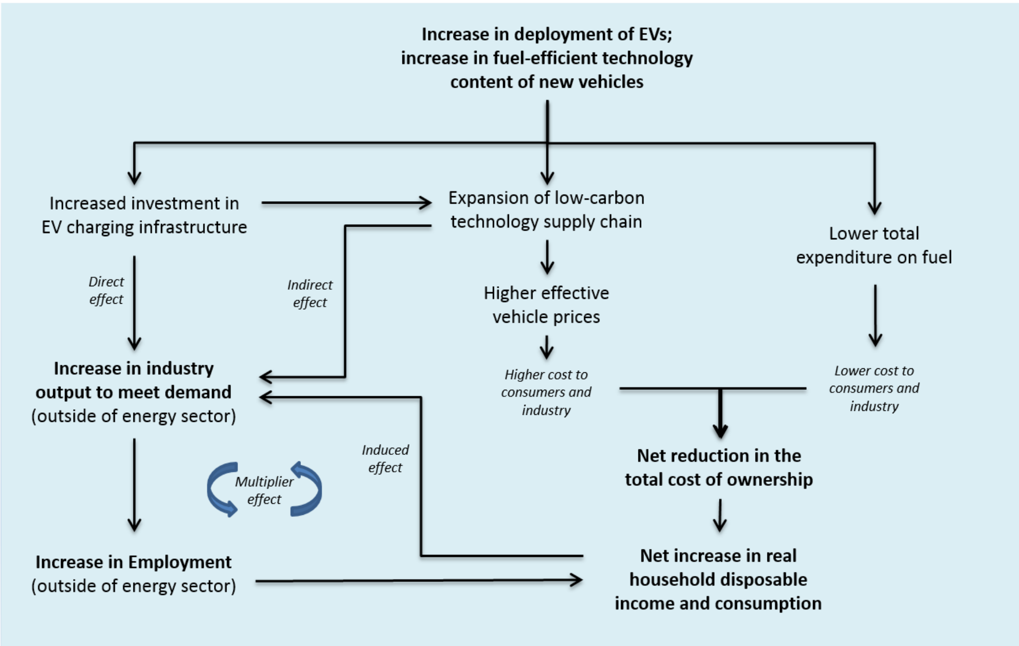
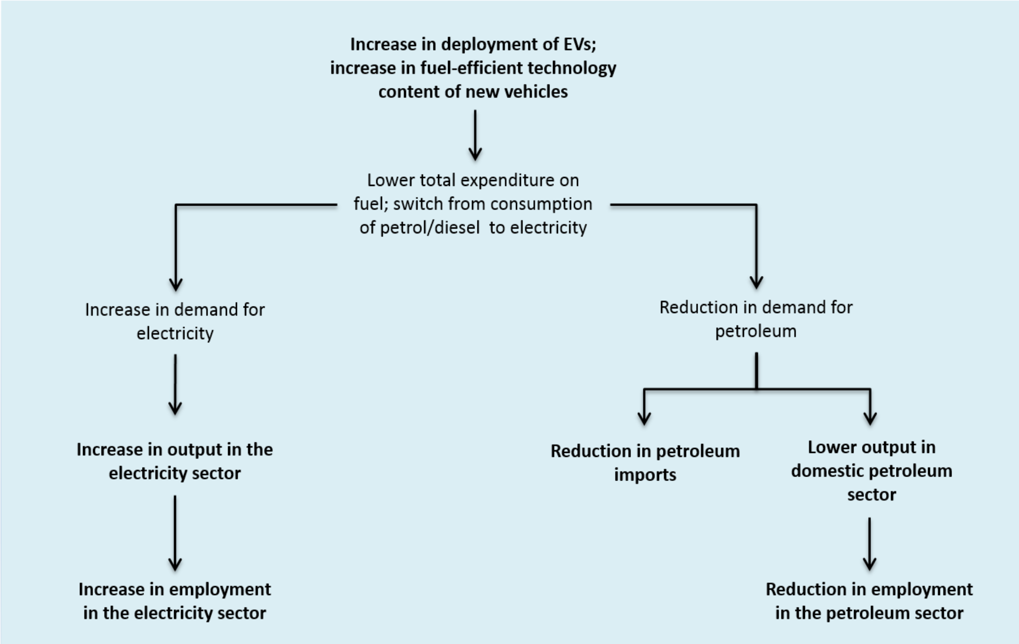


Figure 6-2: Effects of increased deployment of EVs on the energy sector



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

1) The effects on consumers and businesses of higher upfront vehicle costs counteracted by fuel cost savings, which lead to a net reduction in the total cost of vehicle ownership by 2030
2) The effect of reductions in demand for petrol and diesel and increases in demand for electricity and hydrogen
3) The effect on the motor vehicle supply chain due to an increase in demand for energy-efficient component parts
4) The effect of investment in electric vehicle and hydrogen charging infrastructure

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

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

The technologies contained in advanced powertrains are expensive relative to the technologies in conventional ICE vehicles: the results from the vehicle stock model show that, by 2030, the average car in the TECH scenarios costs around 18% more than in the REF scenario and by 2050 (when there is a higher share of advanced powertrains in the vehicle sales mix) they cost around 28% more than in the REF scenario. By 2030, the effect on consumers of this increase in upfront vehicle costs is more than offset by savings in the cost of fuel due to transition to more efficient vehicles and the switch from petrol and diesel fuel to hydrogen and electricity. As a result, by 2030, the total cost of owning and running in a car in the TECH scenario falls below that in the REF scenario. The lower lifetime ownership costs associated with the more fuel-efficient cars in the TECH scenario would lead to an increase in real household incomes, which would lead to an increase in consumer purchasing power and demand for other consumer goods and services. In turn, this would lead to an increase in GDP and gross output.

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

Another key factor driving the macroeconomic result is the effect of changes in fuel consumption on imports of oil. France has very little domestic oil production and so around 98% of crude oil consumed in France is imported. Furthermore, the European Commission’s central energy projections[16] assume that no oil will be produced over the next 30 years, particularly in light of the moratorium on shale oil and gas extraction in France. As expenditure on imports is effectively money that flows outside of the domestic economy, diversion of spending away from oil to other goods and services is particularly beneficial for the French economy.

Although oil and petroleum products are also used by industry, households and other modes of transport, energy demand from cars and vans currently accounts for around 50% of final energy demand for oil in France. Reductions in vehicle demand for petrol and diesel could therefore reduce France’s dependence on oil imports and reduce exposure to potential oil price shocks. Reduced demand for petrol and diesel would also reduce output in the domestic petroleum sector, however, as the petroleum refining sector has a low labour intensity and a relatively short supply chain, the macroeconomic effects of a reduction in demand for domestically produced petroleum would be limited.

Whilst France is heavily dependent on imported oil, electricity and hydrogen are predominantly produced domestically. Increases in consumption of electricity and hydrogen fuels would therefore have a marginal benefit for the French supply chain and for the French economy, relative to the consumption of oil and petroleum products, such as petrol and diesel.

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

The transition towards more efficient vehicles will lead to increases in demand for more sophisticated technologies and on-board computer systems and will stimulate investment and innovation in energy efficient products for vehicles. This increase in demand for more expensive, complex and sophisticated technologies will lead to an expansion of the French vehicle supply chain. The automotive equipment manufacturing industry in France employs around 15,000 people and contributes €3.8bn GVA to the French economy[17]. The vehicle supply chain in France is labour-intensive and has a lower import content relative to the supply chain for petrol and diesel fuels. Taking this effect in isolation, the transition to a low-carbon vehicle fleet (which requires consumers to spend more on the capital cost of vehicles and less on fuel) is likely to lead to net benefits for the French economy, as well as increases in output and employment in the manufacturing and engineering sectors.

The extent to which the low carbon vehicle transition benefits the French economy is heavily dependent on the import content in the motor vehicles supply chain. Historical data suggests that the supply chain for vehicles

[16] European Commission (2014), ‘Trends to 2050: Reference Scenario 2013’

[17] CCFA (2015), ‘The French Automotive Industry: 2014 Analysis and Statistics’

manufactured in France has a relatively high domestic content (around 30%-40%). In addition, according to CCFA, French exports of automotive equipment reached €8.5bn in 2011. This means that increases in demand for energy-efficient technologies in the rest of Europe could also lead to increases in output and employment in the manufacturing sectors in France.

The effect of investment in electric vehicle and hydrogen charging infrastructure

An increase in advanced powertrains in the vehicle fleet will require substantial investment in charging infrastructure. This includes both privately installed infrastructure in people's homes and in workplaces and public infrastructure in shopping centres, cinemas and fast charging points on motorways. The annual investment in charging infrastructure amounts to €2.1bn in TECH by 2050. This investment stimulus would boost gross output in the construction sector and its supply chain.

However, the charging infrastructure investment must have a means of financing and, in these scenarios, we assume that households and businesses pay for the charging points upfront when purchasing a PHEV or BEV, which diverts their spending away from other goods and services. We assume that the public infrastructure, which is installed in shopping centres, cinemas and by motorways, is financed by higher prices in retail sectors. The effect of the investment stimulus on GDP will therefore be dampened slightly by the higher prices faced by consumers in order to finance this investment cost.

Macroeconomic modelling assumptions

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

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

The cost of technology was represented in E3ME 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 France of more efficient technology. It was assumed that all of these higher costs were passed on to final consumers (both in domestic production and imported vehicles) through higher vehicle purchase prices.

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

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

We tested two variants of the scenarios in relation to tax revenues. In the central scenarios, we do not model any form of compensation for the loss of fuel duty revenues and it is implicitly assumed that reductions to fuel duty revenue in the TECH scenario are paid for by increases in French government debt.

For fair comparison between scenarios, it is instructive to model a series of sensitivities where the net government fiscal position is not adversely affected. We therefore modelled a sensitivity where we have assumed that government balances remain neutral between scenarios. The net reduction in government balances in the CPI and TECH scenarios (due to reductions in fuel duty revenue) is assumed to be directly compensated by an equivalent increase in VAT revenue, which is achieved by increasing the rate of VAT. The rationale for this assumption was to ensure that government balances were not affected by the transition to more fuel-efficient vehicles, in order to present a neutral set of scenarios.

Macroeconomic results

Table 6-1 and Table 6-2 shows the macroeconomic results for each scenario in 2030 and 2050 respectively.

Table 6-1: Macroeconomic results in 2030 (percentage difference from REF)

	REF	CPI	TECH
GDP (€ million, 2014)	2,768,041	0.2%	0.4%
Consumption (€ million, 2014)	1,521,963	0.2%	0.4%
Investment (€ million, 2014)	695,243	0.4%	0.6%
Exports (€ million, 2014)	685,525	0.1%	0.0%
Imports (€ million, 2014)	670,724	0.0%	-0.2%
Real income (€ million, 2014)	1,414,354	0.3%	0.6%
Consumer prices 2014=1	1.577	-0.1%	-0.4%
Employment (000s)	29,492	0.1%	0.2%

Source(s): Cambridge Econometrics, E3ME.

Table 6-2: Macroeconomic results in 2050 (percentage difference from REF)

	REF	CPI	TECH
GDP (€ million, 2014)	3,807,527	0.5%	1.4%
Consumption (€ million, 2014)	2,096,007	0.5%	1.6%
Investment (€ million, 2014)	956,280	0.8%	2.2%
Exports (€ million, 2014)	959,001	0.2%	0.0%
Imports (€ million, 2014)	939,240	0.3%	0.1%
Real income (€ million, 2014)	1,335,473	0.7%	2.1%
Consumer prices 2014=1	2.296	0.0%	-0.5%
Employment (000s)	29,866	0.3%	0.8%

Source(s): Cambridge Econometrics, E3ME.

E3ME shows that the transition to a low-carbon vehicle fleet would lead to a small positive impact for the French economy. There is a small increase in real incomes and consumption in the TECH scenario, as consumers save money on the cost of owning and running a vehicle and have more money available to spend on other goods and services. By 2050, there is a 2.2% increase in investment in the TECH scenarios, primarily because of the charging infrastructure investment, but also due to secondary effects, as increases in output and GDP create a more positive environment to stimulate more business investment. There is a small increase in imports (0.1% in 2050) as increases in real consumption drives an increase in demand for imported products and due partly to an increase in imports of energy-efficient products for vehicles. However, the net effect on imports is reduced somewhat due to reductions in imports of crude oil and refined petroleum in the low-carbon vehicle scenarios.

The E3ME results show that the loss of fuel duty revenue would be partially offset by an increase in other tax revenues. The economic stimulus in the low-carbon vehicle scenarios leads to a small increase in income tax revenue (as a result of higher employment and real incomes) and an increase in VAT revenues (due to higher levels of consumption). However, these increases in tax revenues are not sufficient for government revenue neutrality between scenarios. We tested a revenue neutral variant of the TECH scenario, where we assumed government balances are equivalent to in the REF scenario. In the revenue neutral variant, we assumed an increase in the VAT rate in the TECH scenario would compensate for the reduction in fuel duty revenues.

6.2 Jobs

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

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

Figure 6-3 presents the E3ME model results for the net impact on employment in each scenario. The results show that the transition to a low-carbon vehicle fleet would lead to a 0.2% increase in employment by 2030 and a 0.8% increase in employment by 2050. The reason why employment in TECH is higher than in the REF scenario is partly due to direct and indirect effects (i.e. an increase in employment in the motor vehicles supply chain and in the installation of EV chagrining points), and partly due to induced effects, as the total cost of ownership of an EV falls below that of a conventional ICE resulting in an increase in real household incomes, an increase in demand for consumer goods and services and, in order to meet this increase in demand, an increase in output and employment.

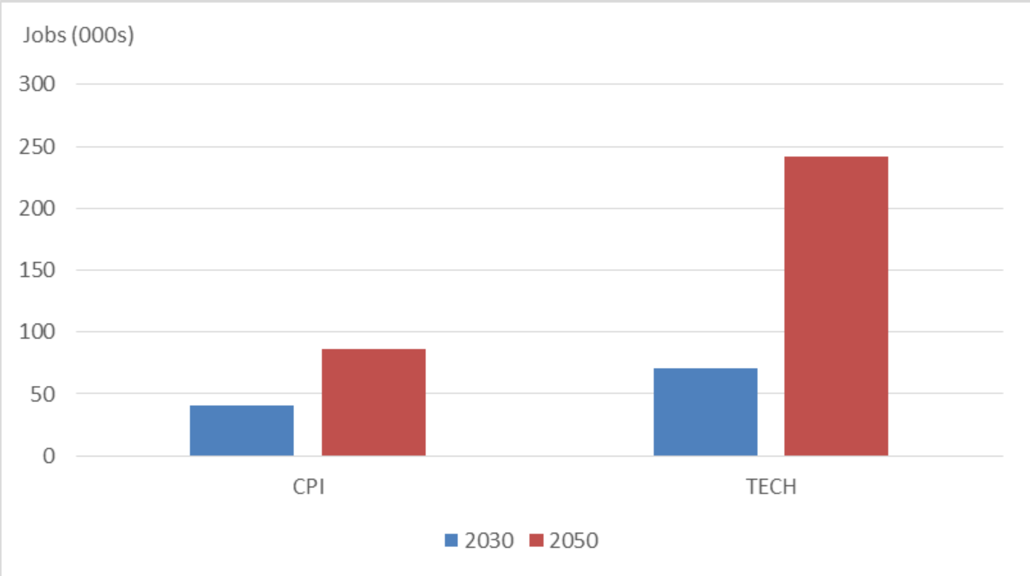


Figure 6-3: Net additional jobs in 2030 and 2050 (relative to the REF scenario)

Figure 6-4 shows the net effects of the low-carbon vehicle transition on employment by sector in France in 2030. There is an increase in employment in the manufacturing sector, reflecting the effects of an expansion of the motor vehicle supply chain, and there is a reduction in employment in manufactured fuels (refining), reflecting the reduction in the road transport sector's demand for petroleum. The net increase in jobs is highest in the service sectors due to a strong induced effect resulting from the rise in real incomes and consumer purchasing power brought about by the lower cost of vehicle ownership and direct employment effects.

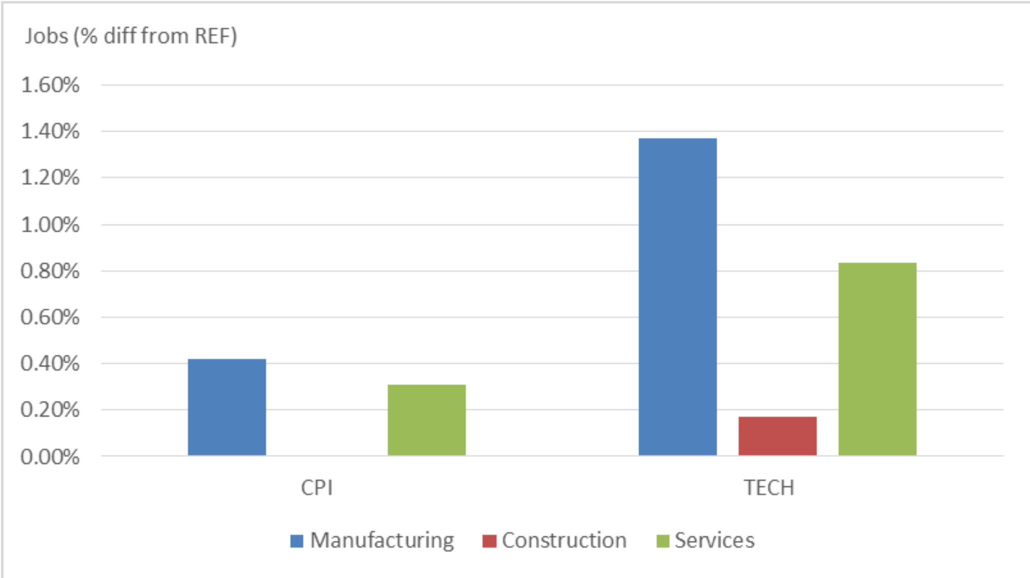


Figure 6-4: Percentage increase in employment in 2050 (relative to the REF scenario)

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

6.3 Energy dependence and resilience

France is heavily reliant on oil imports: 1700 kb/d of crude oil are imported to France and imports of oil account for around 98% of domestic oil consumption. In 2012, oil imports were predominantly sourced from OPEC countries (accounting for 43% of imports) and countries from the former Soviet Union (accounting for 32% of imports)[18]. France's energy independence could be improved by reducing demand as the CPI and TECH scenarios envisage, which would reduce the economy's exposure to oil price shocks.

The macroeconomic effects under a low oil price scenario

In 2014/2015, oil prices fell substantially, reducing the relative economic benefits of the transition to low-carbon vehicles. Our central oil price assumptions are based on projections from the IEA's 'World Energy Outlook 2014'. However, the scenarios were also tested under an assumption that the 2015 low oil price persisted over the projection period. Although this slightly reduced the relative benefits of the low-carbon transition, we found that there

[18] IEA, 'Energy Supply Security 2014', available online at: https://www.iea.org/media/freepublications/security/EnergySupplySecurity2014_France.pdf

were still net positive results in the TECH scenario. This is mainly because the efficiency savings still lead to a net reduction in the total cost of owning a car and there is an additional economic stimulus brought about by the investment in charging infrastructure. The results from the low oil price sensitivity analysis are shown in Table 6-3 below.

Table 6-3: Macroeconomic results in 2030 (percentage difference from REF)

	TECH (central scenario)	TECH (low oil price sensitivity)
GDP	0.4%	0.3%
Consumption	0.4%	0.1%
Investment	0.6%	0.6%
Exports	0.0%	0.0%
Imports	-0.2%	-0.3%
Real income	0.6%	0.2%
Consumer prices	-0.4%	0.1%
Employment	0.2%	0.2%

Source(s): Cambridge Econometrics, E3ME.

The reduction in oil demand that results in the scenarios, if matched across the major oil consuming countries could itself cause a reduction in the oil price. In doing so, the economies of oil importing countries could be boosted further as a direct result of the efficiency improvements. Lower oil prices would benefit consumers and businesses through lower costs.

6.4 Government revenues

The results for the TECH scenario under an assumption of government revenue neutrality are show in the table below. In the central TECH scenario, there is an increase in VAT revenues (as real consumption increases) and an increase in income tax revenues and national insurance payments (due to the increase in employment). However, this increase in revenue is not sufficient to compensate for the loss of fuel duty revenue and there is a net €8.9bn reduction in government balances. A one percentage point increase in the rate of VAT is required to maintain revenue neutrality in the TECH scenario. This increase in the rate of VAT to maintain government revenue neutrality is the main explanation for the small increase in consumer prices relative to the central scenario (and the consequent reduction in real incomes and consumption), as shown in Table 6.4. However, there is still a net positive impact on GDP and employment, relative to the REF scenario, as spending is diverted from imported fossil fuels to the domestic automotive equipment industry and due to the investment stimulus brought about by the deployment of charging infrastructure.

Table 6-4: Macroeconomic results in 2030 (percentage difference from REF)

	TECH (central scenario)	TECH (revenue neutral)
GDP	0.4%	0.2%
Consumption	0.4%	0.0%
Investment	0.6%	0.5%
Exports	0.0%	0.0%
Imports	-0.2%	-0.4%
Real income	0.6%	0.1%
Consumer prices	-0.4%	0.3%
Employment	0.2%	0.2%

Source(s): Cambridge Econometrics, E3ME.

7 Environmental Impact

7.1 Greenhouse gas emissions

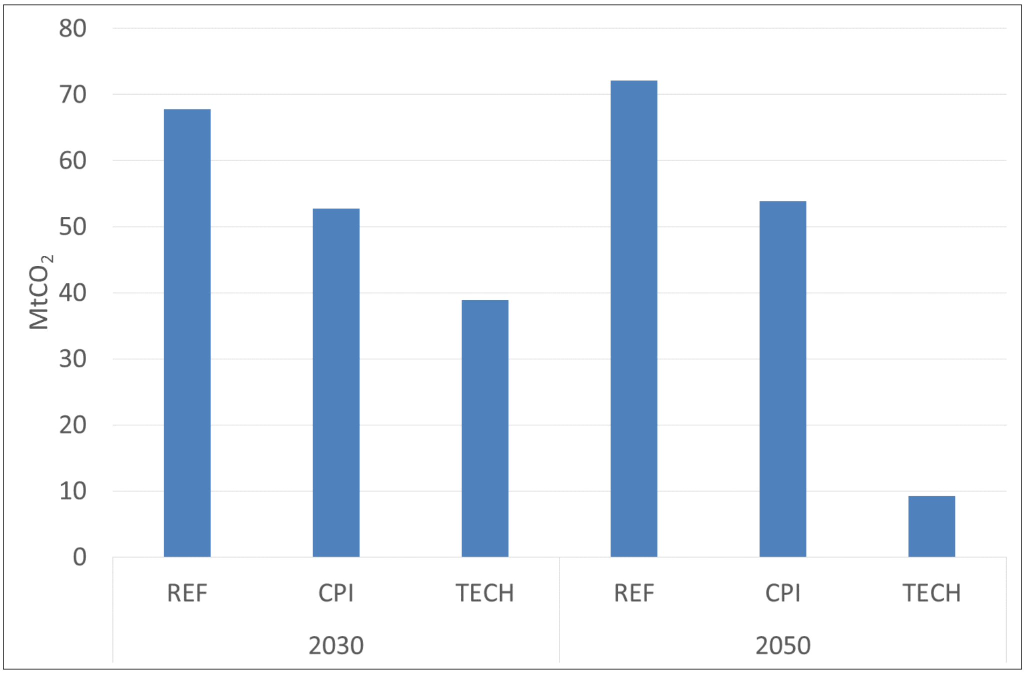
In 2012, French greenhouse gas emissions were around 478 mtCO_2e, of which 353 mtCO_2 came from carbon emissions. Of this, 120 mtCO_2 were from transport and two-thirds of transport emissions were from passenger cars (67 mtCO_2) and vans (24mtCO_2).

By 2030, tail-pipe emissions from passenger cars could be reduced to around 52 mtCO_2 under the CPI scenario, and even fall as low as 38 mtCO_2 if the uptake of ultra-low emission vehicles envisaged in the TECH scenario is realised (see Figure 7-1).

In 2030 a new BEV is expected to have twice the fuel efficiency of a new petrol ICE, moreover, electricity is expected to have a carbon intensity more than four times lower than petrol. The combination of these factors suggests that the ‘in use’ emissions of a BEV will be over 8 times lower than that of a petrol ICE in 2030.

The transition to an ultra-low carbon vehicle stock envisaged by the TECH scenario (and variants) would all but eliminate tail-pipe emissions from passenger cars and light-duty vehicles by 2050. For the TECH scenario, tailpipe CO_2 emissions from passenger cars could fall to 9 mtCO_2. Moreover, electricity and hydrogen production are both expected to become almost entirely zero-carbon.

Figure 7-1: Annual CO_2 emissions from passenger cars



7.2 Embodied emissions

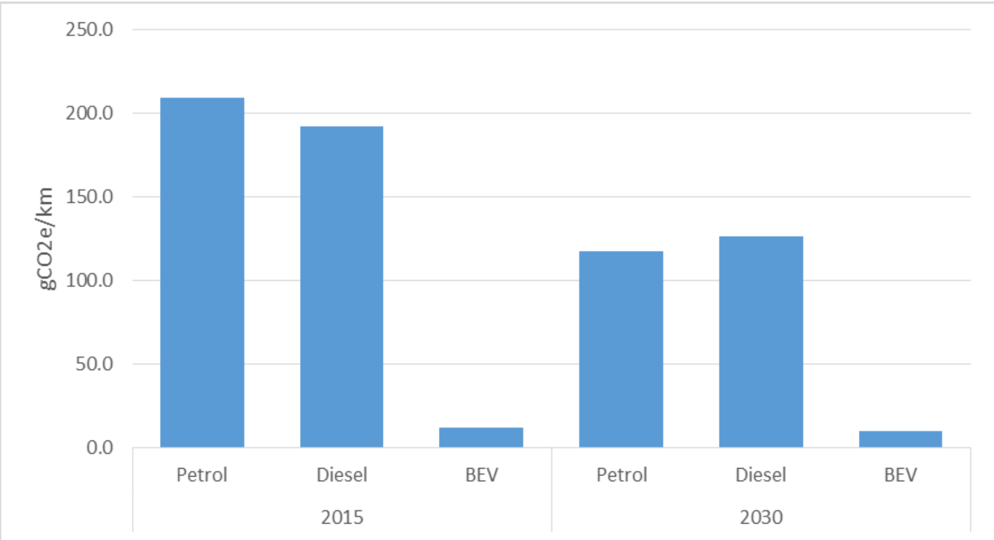
When assessing the emissions produced by passenger cars, the focus is usually on “in use” emissions, otherwise known as tailpipe emissions, the results for which are outlined in the previous section of this report. However, tailpipe emissions represent just part of the total emissions produced over the lifetime of a vehicle. To compare the net CO_2 impact of an increase in the share of electric vehicles in the fleet, it is important to also consider the embodied emissions from manufacturing the vehicles and extracting and manufacturing the fuels used. These embodied emissions, combined with the tailpipe emissions, reflect the full lifetime emissions of the vehicle on a lifecycle basis.

For BEVs, tailpipe emissions are zero, but these technologies are not entirely zero-carbon when you take account of the CO_2 emissions related to manufacturing the vehicle itself and producing the electricity and hydrogen that it uses.

Using the BEV data in the TECH scenario combined with assumptions from Ricardo-AEA[19], an estimate of embodied emissions which incorporates the fixed CO_2 emissions from production of a car over the period to 2030 was derived. To outline the difference in embodied emissions between powertrains, this analysis was carried out for petrol and diesel ICE’s and for long-range BEV’s.

First of all well-to-wheel emissions for each vehicle type were calculated by combining emissions associated with the production of petrol, diesel and electricity in addition to the vehicle tailpipe emissions. On this basis BEVs are not entirely zero–carbon, however, electricity generation is assumed to be highly decarbonised with a high renewable content and this fact, combined with the higher relative efficiency of BEVs compared to ICE’s, means that the well-to-wheel CO_2 intensity of BEVs in 2015 is only 5% of that for a Petrol ICE.

Figure 7-2 Well to wheel CO_2 Intensity of passenger cars



[19] Ricardo-AEA (2013) Lifecycle emissions of low carbon technologies

When evaluating the embodied emissions of an ICE compared to a BEV, the difference largely comes down to the differences in the CO_2 emissions related to manufacturing the powertrain and, in the case of BEVs, the additional CO_2 emissions associated with producing the batteries. When considering the vehicle powertrain in isolation (and excluding manufacturing the battery), the CO_2 emissions of an ICE are around 21% higher than for a BEV powertrain. However, the embodied emissions associated with manufacturing heavy duty batteries for BEVs are substantial. Therefore, when factoring in the battery emissions, the emissions from producing and manufacturing the vehicle are 63% higher for a BEV.

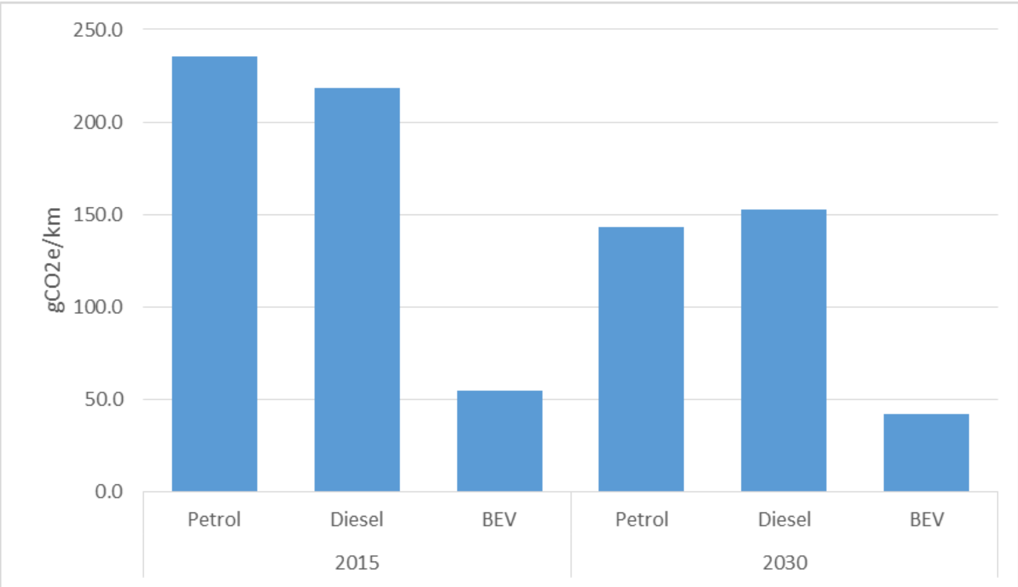
For a petrol ICE, the tailpipe emissions are substantially higher, making up around 65% of well-to-wheel emissions. As such, we see that in 2015, a long-range BEV has only 17% of the well-to-wheel emissions of a petrol ICE.

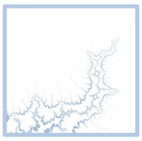
Comparing petrol to diesel ICE's, the embodied emissions from producing and manufacturing the vehicle and the fuel it uses are very similar, so the difference in well-to-wheel emissions is entirely explained through the differences in tailpipe emissions.

Looking ahead to 2030, we expect the reduction in embodied emissions from ICE's to be negligible as the efficiency in production techniques is offset by an increase in the amount of technology installed in the vehicle. However, the reduction in tailpipe emissions due to improved vehicle efficiency are substantial so the well-to-wheel CO_2 intensity of a petrol ICE will fall by around 35%. The petrol ICE even outperforms a diesel ICE by 2030 due to greater improvements in vehicle efficiency.

For BEVs, it is expected that developments in battery technology will help reduce the embodied emissions in the battery manufacturing process, however, it is expected that the embodied emissions would still be around 23% higher than for an ICE. Furthermore, the modest efficiency improvements for BEVs leads to reduced electricity consumption.

Figure 7-3 Lifetime CO_2 Intensity from passenger cars





The net result of this is that from 2015 to 2030, the lifecycle CO_2 intensity of an ICE falls considerably faster than for a BEV in the TECH scenario. However, a 2030 BEV will still be just under 30% as carbon intensive as an average 2030 ICE over the full lifetime of the vehicle.

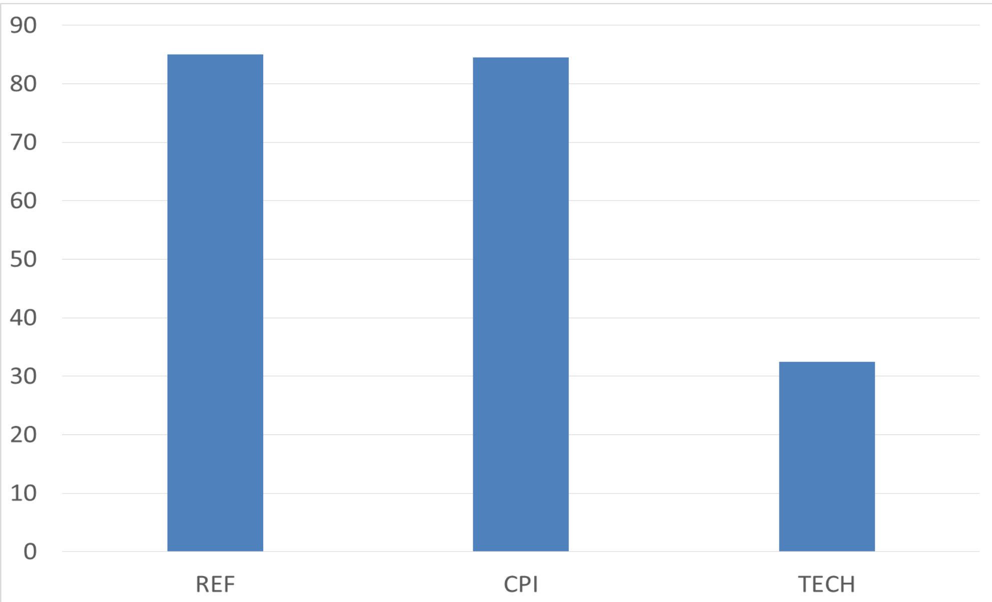
7.3 Local air pollutants

Cars and vans also produce NO_x and particulates: local air pollutants with harmful consequences for human health. In 2012, the Interprofessional Technical Centre for Studies on Air Pollution estimates are that around 320 kilo tonnes of NO_x were emitted by cars and vans in France, and around 31,600 tonnes of particulate matter from the combustion of petrol and (predominantly) diesel[20][21].

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

Since NO_x is produced in the combustion of fossil fuels, the TECH scenario projects a substantial reduction in tailpipe emissions of NO_x as a result of the reduced use of these fuels (Figure 7-4). By 2050, the TECH scenario results in an 86% reduction in direct NO_x emissions from cars and vans compared to 2012, since so little fossil fuel is consumed in this scenario. In short, decarbonisation would have the additional benefit of effectively eradicating direct NO_x emissions from the vehicle tailpipe. Under the REF scenario, NO_x emissions might fall by as much as 63% (by 2050) as a result of implementing the existing Euro V and Euro VI air pollutant standards. However, these reductions are much less certain than the reductions in the TECH scenario and its variants, which include high levels of vehicles using hydrogen and electricity with zero tailpipe emissions.

Figure 7-4 NO_X emissions from cars in 2050



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

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

Particulate emissions are expected to be reduced in all scenarios, including the REF, as a result of the implementation of Euro 5 and Euro 6 standards which dramatically limit the particulate emissions on new diesel passenger cars and vans (see Table 7-1).

Table 7-1: EU emissions standards for passenger cars

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

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

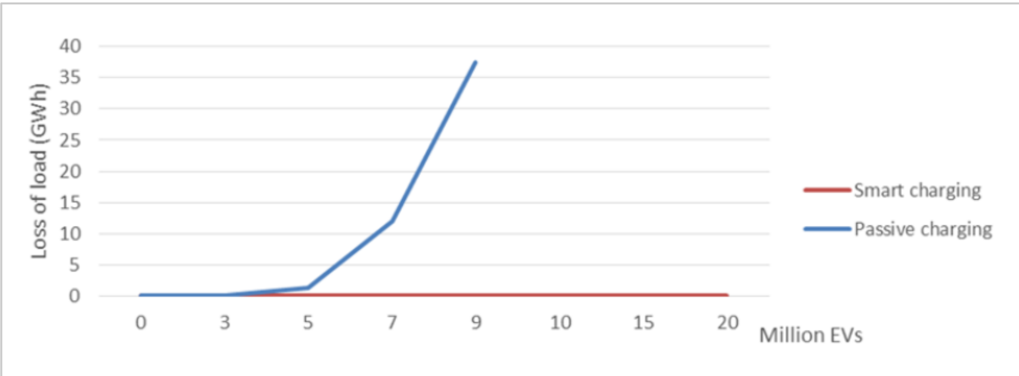
8 Grid Synergy Analysis

Alongside this study, the European Climate Foundation commissioned Element Energy and Artelys to carry out a review to estimate the maximum deployment of EVs in France that is possible without creating additional generation capacity requirements. The analysis also quantified the overall value of synergies between EVs and the electricity system and reviewed the potential impact on distribution networks. The methodology and results from the analysis of synergies is presented in: Element Energy and Artelys (2015), 'EV Grid Synergy Analysis: France'. This section of the report summarises the key findings from that analysis.

The grid synergy analysis was developed through a combination of literature review, techno-economic modelling of ancillary services provision and impacts on the distribution network, and electricity generation optimisation modelling. The analysis is based on the EV deployment scenarios in the ECF TECH scenario and furthermore uses the RTE Nouveau mix scenario to assess the impact of EV deployment on the generation system.

The analysis shows that large uptake of EVs may impact the electricity system, particularly if charging is un-managed. If EV owners charge on arrival at home or at work (passive charging), this will introduce peaks in charging demand in the evening and in the morning.

Figure 8-1 Loss of load from different levels EV deployment

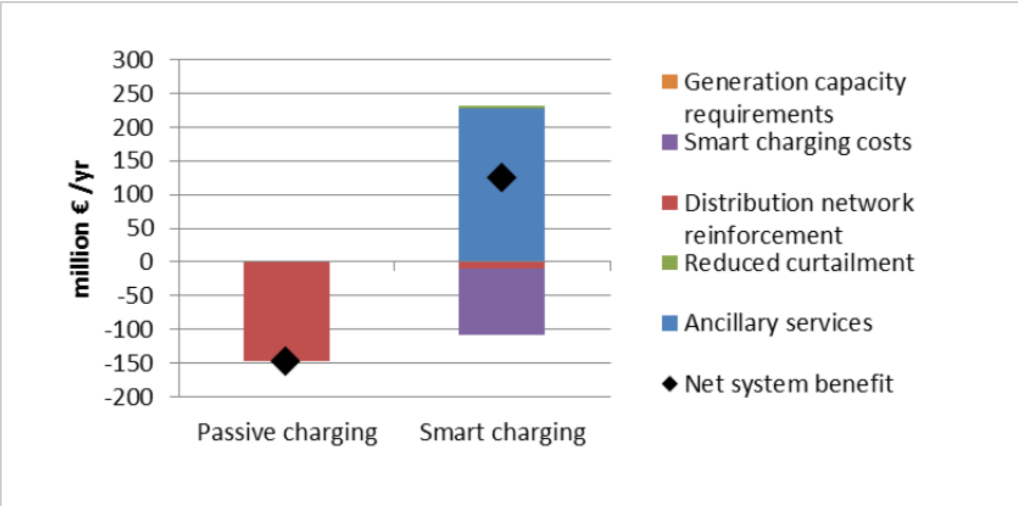


Source: Element Energy and Artelys (2015)

The level of EV deployment in the ECF TECH scenario of 4.1 million EVs in 2030 represents the maximum number of EVs that can be deployed with passive charging in 2030 without requiring additional generation capacity. For any further increase in EV deployment, significant investments in additional generation capacity would be required in order to meet the increase in peak demand caused by EV charging. For the 6.9 million EVs in RTE's Nouveau Mix scenario in 2030, passive EV charging would require 3GW of additional generation capacity in 2030. Due to the high peak in EV charging demand, this would likely need to be met by peak generation units, rather than mid-merit or baseload plants. The large peak in EV demand also results in increased running hours for peaking plants, with relatively high CO2 emissions.

By using smart charging strategies to shift EV charging demand from peak periods to periods of low system demand, the challenges posed on the electricity generation system by EVs can be largely mitigated. Smart charging prevents any requirements for additional generation capacity, with the 2030 electricity system capable of accommodating over 20 million EVs, five times the projected uptake in the ECF TECH scenario. This shift in EV demand also results in EV demand being met to a larger extent by mid-merit and baseload plants with lower CO2 emissions than peaking plants.

Figure 8-2 Net system benefit under passive charging and smart charging



Source: Element Energy and Artelys (2015)

The potential benefits of smart charging are higher than the costs of implementing smart charging, resulting in a 125 million €/yr net benefit for smart charging in 2030, compared to a 150 million €/yr cost for passive charging. Smart charging mitigates the costs of distribution network reinforcements to a large extent and provides additional benefits for EVs by providing ancillary services and reducing renewable curtailment. These potential benefits are larger than the costs of implementing smart charging, which consist of additional hardware, communications and telemetry infrastructure and operation.

Passive charging increases distribution network peak load by 3 GW in 2030, corresponding to 150 million €/yr reinforcement costs. Smart charging has the potential to reduce the required distribution network reinforcements on average by a factor of ten, resulting in annual reinforcement costs of €10 million per year in 2030.

In addition, smart charging EVs have the potential to benefit the electricity system, by reducing the curtailment of renewable generation, and by providing ancillary and balancing services to the system operator. Smart charging acts as a flexibility provider for the transformation of the French power system. It may reduce the need for CO_2 intensive thermal peak generators, supporting the integration of further intermittent renewable generation, especially photovoltaic production in the middle of the day, mitigating their curtailment. Renewable curtailment, which is relatively low in France due to existing energy storage in the form of hydro, could be further reduced through smart charging, resulting in a benefit of €4 million per year in 2030.

Ancillary and balancing service provision by smart charging EVs represents a technical potential equivalent to €228 million per year in revenues in 2030.

While the opportunity for smart charging EVs is large, with a significant potential overall benefit, this is diluted on an individual EV level. This is a key challenge in developing this opportunity, as efficient commercial models are needed to incentivise participation by EV owners. Access to services and the ability to combine the provision of multiple services to different actors are therefore key aspects in maximising the benefit available at an individual EV level. Developing these services moreover requires installation of charge points that support the required control and communication signals, as well as development of the telemetry and communication platforms between aggregators and EV charge points.

Appendices

Appendix A The E3ME Model

A.1 Introduction

Overview

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

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

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

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

Recent applications

Recent applications of E3ME include:

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

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

A.2 E3ME's basic structure and data

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

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

A.4 The main dimensions of the model

The main dimensions of E3ME are:

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

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

A.5 Standard outputs from the model

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

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

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

A.6 E3ME as an E3 model

The E3 interactions

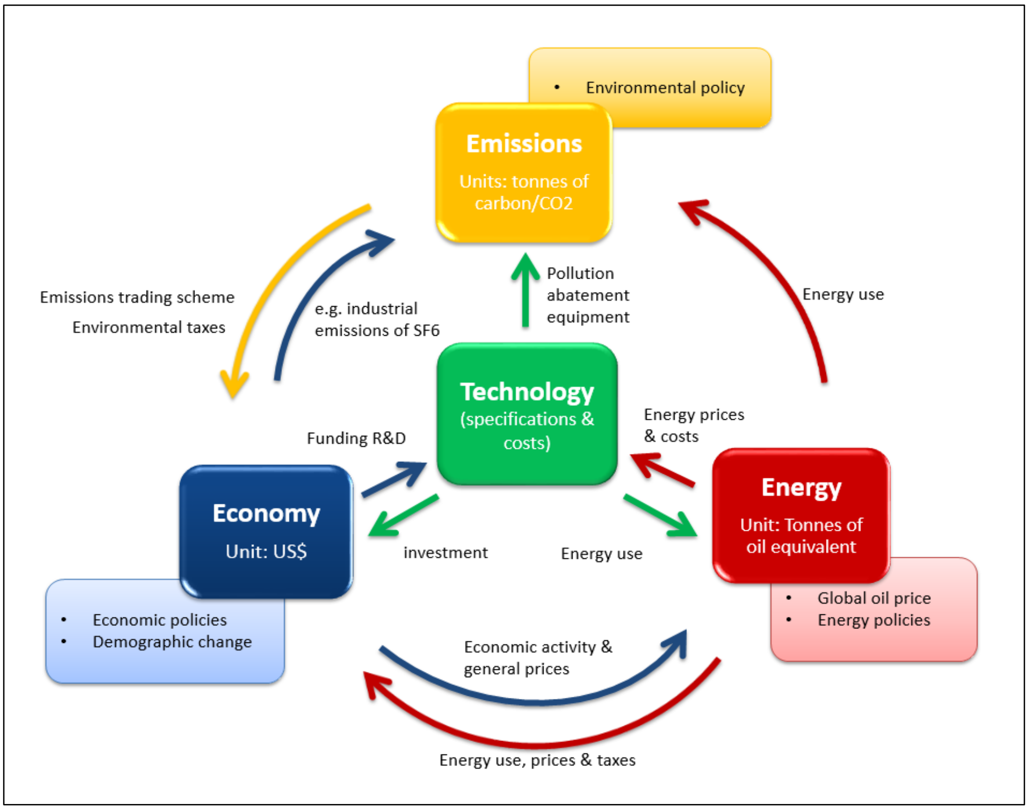
Figure A.1 shows how the three components (modules) of the model - energy, environment and economy - fit together. Each component is shown in its own box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling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

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

The role of technology

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

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



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

A.7 Treatment of international trade

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

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

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

A.8 The labour market

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

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

A.9 Comparison with CGE models and econometric specification

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

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

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

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

A.10 Key strengths of E3ME

In summary the key strengths of E3ME are:

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

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

Table 1: Main dimensions of the E3ME model

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

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

Source(s): Cambridge Econometrics.