European Climate Foundation

Low-carbon cars in Spain: A socio-economic assessment

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clarity from complexity

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Authorisation and Version History

Version	Date	Authorised for release by	Description
1.0	10/07/18	Jon Stenning	Technical Report – Fuelling Spain's Future

Acknowledgments

Background

This study on the impacts of low-carbon mobility in Spain builds on a series of previous studies examining the potential impacts of the transition to low-carbon mobility, at a European ('Fuelling Europe's Future'[1], 2018) and Member State ('Fuelling Britain's Future', 2015[2], 'En route pour un transport durable', 2016[3], 'Low-carbon cars in Germany', 2017[4]). The technology cost analysis published in Fuelling Europe's Future, developed by Ricardo-AEA and the core working group for that project, forms the starting point for this analysis.

Core analytical team

Cambridge Econometrics provided the lead for the economic analysis presented in this report, undertaking vehicle stock modelling and economic modelling in E3ME. Element Energy carried out analysis on synergies between electric vehicle charging and the functioning of the electricity grid.

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

Disclaimer

The stakeholders who contributed to this study shared the aim of establishing a constructive and transparent exchange of views on the technical, economic and environmental issues associated with the development of low-carbon technologies for cars. The objective was to evaluate the boundaries within which vehicle technologies can contribute to mitigating carbon emissions from cars across Spain. Each stakeholder contributed their knowledge and vision of these issues. The information and conclusions in this report have benefitted from these contributions but should not be treated as necessarily reflecting the views of the companies and organisations involved.

[1] https://www.camecon.com/how/our-work/fuelling-europes-future/
[2] https://www.camecon.com/how/our-work/fuelling-britains-future/
[3] https://www.camecon.com/how/our-work/en-route-pour-un-transport-durable/
[4] https://www.camecon.com/how/our-work/low-carbon-cars-in-germany/

Contents

Acronyms and Abbreviations

Table 0.1 sets out the acronyms and abbreviations commonly used in the report.

Table 0.1 Acronyms and abbreviations

	Abbreviation	Definition
Powertrain types		
Internal combustion engine	ICE	These are conventional petrol or diesel cars with an internal combustion engine. In the various scenarios modelled there is variation in the level of efficiency improvements to the ICE. Efficiency improvements cover engine options, transmission options, driving resistance reduction, tyres and hybridisation. Under our definition of an ICE, hybridisation is limited to micro-hybrids with start-stop technology and regenerative breaking.
Hybrid electric vehicles	HEV	This definition covers full hybrid electric vehicles that can be run in pure EV mode for some time. They have a larger battery than the micro-hybrids (that are classified as ICEs).
Plug-in hybrid electric vehicle	PHEV	Plug-in hybrid electric vehicles have a large battery and an internal combustion engine. They can be plugged in to recharge the vehicle battery. EVs with range extenders are not included in the study.
Battery electric vehicle	BEV	This category refers to fully electric vehicles, with a battery but no engine.
Fuel cell electric vehicle	FCEV	FCEVs are hydrogen fuelled vehicles, which include a fuel cell and a battery-powered electric motor.
Zero emissions vehicle	ZEV	Includes all vehicles with zero tailpipe emissions (e.g. FCEVs and BEVs).
Economic terminology		
Gross domestic product	GDP	A monetary measure of the market value of all final goods and services in the national economy
Gross Value added	GVA	A measure of the total value of goods and services in the economy netted from value of inputs and taxes.
Other acronyms		
New European Driving Cycle	NEDC	Test cycle used for the certification of cars in Europe until September 2017
Original equipment manufacturers	OEMs	Refers to equipment manufacturers of motor vehicles
Million barrels of oil equivalent	mboe	A unit for measuring oil volumes
Worldwide harmonized Light vehicles Test Procedure	WLTP	Test cycle used for the certification of cars in Europe since September 2017

Executive Summary

This report assesses the economic costs and benefits of decarbonising passenger cars in Spain. A scenario approach has been developed to envisage various possible vehicle technology futures, and then economic modelling has been applied to assess impacts. The study follows a similar approach to that of the 2013 and 2018 *Fuelling Europe's Future* studies[5].

Cambridge Econometrics and Element Energy were commissioned by the European Climate Foundation (ECF) to assess the likely economic impacts and the transitional challenges associated with decarbonising the Spanish car fleet in the medium term (to 2030) and the long term (to 2050).

This technical report sets out the findings from our analysis. It provides details about the charging infrastructure requirements, technology costs and economic impacts of the transition to low-carbon mobility. A summary report, presenting the key messages from the study, is also available[6].

The study shows that, while there are potentially large economic and environmental benefits associated with decarbonising passenger car transport in Spain, there are also transitional challenges which must be addressed if the benefits are to be realised. In recent years, there has been a strong push to decarbonise transport in Europe, including the publication in late 2017 of draft emissions reduction targets for 2025 and 2030. There have also been announcements from OEMs regarding deployment of advanced powertrain models across their ranges, signalling how rapidly the landscape is changing.

The potential benefits if Spain embraces the transition are substantial.

- Reduced use of oil and petroleum products will cut energy import dependence and bring about large reductions in carbon emissions.
- There are net gains in value added and employment gains which increase as oil imports are reduced over time. By 2030, the TECH scenario would lead to an increase in GDP of 0.2% compared with a 'no change' case, and an increase in employment of around 23,000 jobs.
- There is substantial potential for EV and grid synergies using smart charging strategies to shift EV charging demand away from peak periods to periods of low system demand. This would mitigate the challenges to the electricity system posed by EVs, limiting increases in peak electricity demand.
- For the consumer, the four-year total cost of ownership of Zero-Emission Vehicles is likely to converge towards that of conventional petrol and diesel cars in the next decade.

However, our modelling, in combination with insight from the Core Working Group, also highlights a number of transitional challenges:

- The implementation of a rapid charging infrastructure will require investments reaching around €500 million per year by 2030. A determined

[5] https://www.camecon.com/how/our-work/fuelling-europes-future/
[6] See: https://www.camecon.com/how/our-work/fuelling-spains-future/

and joint effort of the industry, government and civil society is needed to deploy sufficient charging infrastructure. Timing, location, capability and interoperability are key issues.

- The transition to low-carbon mobility causes a wide range of impacts in employment across several sectors. Employment in the automotive sector is a little higher in our central scenario than in the ‘no change’ case until 2030, during which time climate goals are met through a balanced mix of hybrids, plug-in vehicles and increasingly efficient ICEs. After 2030, the transition to electric mobility will increase employment in sectors such as electrical equipment, as well as services, but is likely to have an adverse impact on employment in the automotive value chain.
- The transition will challenge the competitiveness and market share of the European auto industry, requiring the sector to remain at the cutting edge of clean technology innovation.

1 Introduction

1.1 Background

Low-carbon transport policy

In November 2013, the European Parliament and the Council of the European Union set out legislation to limit the emissions of new vehicles. The EU CO_2 standards required fleet-wide average vehicle emissions to be below 95g CO_2 per km by 2021. In 2017, the Commission announced[7] proposed new standards for 2025 and 2030; a 15% reduction in average new vehicle emissions between 2021 and 2025, and a 30% reduction in new vehicle emissions in 2030 compared to 2021. These aim to continue to move Europe along a low carbon pathway and to meet EU-wide targets for a 60% reduction in transport CO_2 emissions by 2050.

There is substantial evidence that change is coming to the European motor vehicle industry. France and the UK have already announced that new sales of conventional petrol and diesel cars will be banned by 2040, while in Spain an updated version of the Movalt program was announced, providing €20m in financial incentives for alternative powered vehicles, and €15m towards the development of supporting infrastructure. As well as supporting the curtailment of CO_2 emissions, the impetus for this change is, in part, due to increasing concern about the level of local air pollutants (such as NOx) emitted by vehicles and the negative health outcomes associated with this pollution, especially in densely populated urban areas.

As such, most major car manufacturers in Europe have developed new product lines that are increasingly fuel efficient and are now moving increasingly towards electrification or fuel cells as the next step in reducing emissions to meet the proposed targets.

Motivation for the study

There has been much debate about the potential impacts of the transition to ZEVs. The purpose of this study is to shed light on the potential benefits and the transitional challenges of decarbonising passenger cars for the Spanish automotive industry, environment and the wider economy over the period to 2050. In doing so, it highlights some of the key issues that policy makers should focus on, including;

- What is the scale and pace of investment in infrastructure required?
- How will government tax revenues be affected due to reduced fuel duty?
- What will be in the impact on the electricity grid, and peak electricity demand, and how could this be better managed?

The study also addresses some of the key uncertainties about the transition: What if technology costs and battery costs are different to expected? What if cars driving on CNG/biomethane are deployed at scale to meet the emission reduction targets instead of ZEVs?

[7] https://ec.europa.eu/clima/policies/transport/vehicles/proposal_en

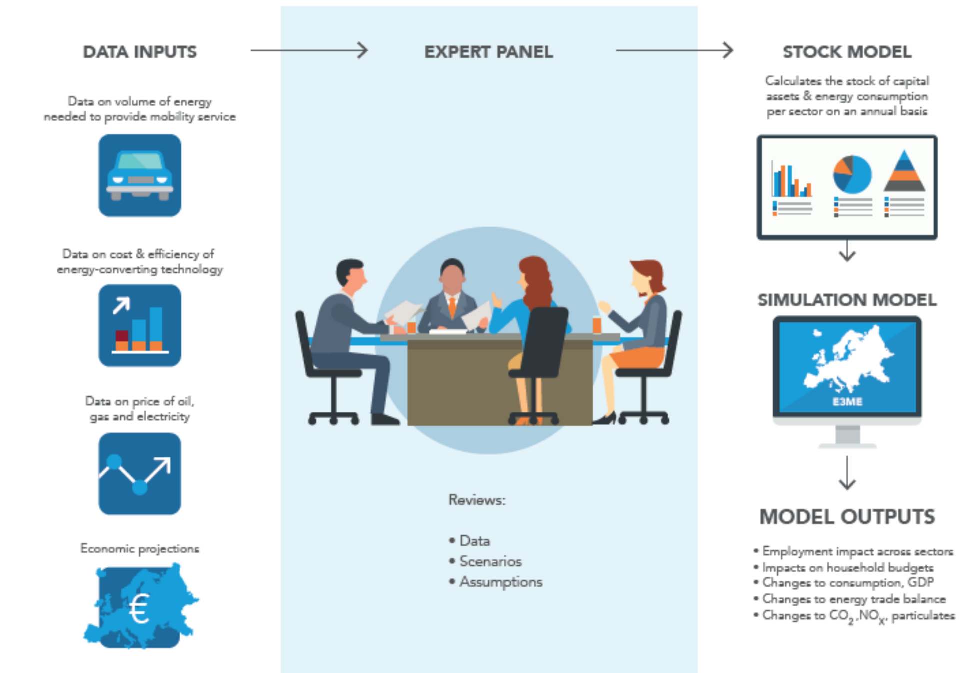
1.2 Methodology

For this study, a set of scenarios were defined in which it was assumed that a certain low-carbon vehicle technology mix would be introduced and taken up in response to vehicle CO_2 emissions regulations. The particular factors affecting consumers' decisions to purchase alternative vehicle technologies were not assessed.

As shown in the graphic below, the methodology involved three key stages:

1) Stakeholder consultation to define the scenarios and agree on the key modelling assumptions
2) An integrated modelling framework that involved (i) application of the Cambridge Econometrics vehicle stock model to assess the impact of alternative low-carbon vehicle sales mix on energy demand and emissions, vehicle prices, technology costs and the total vehicle cost of ownership and (ii) application of the E3ME model to assess the wider socio-economic effects of the low-carbon vehicle transition.
3) Off-model analysis to consider the energy system and grid benefits of increased use of BEVs and FCEVs (e.g. through the provision of grid balancing services).

Figure 1.1: Our approach



The three models that were applied in our framework are:

- Cambridge Econometrics' Vehicle Stock Model
- Cambridge Econometrics' E3ME model
- Element Energy's EV profile calculator and electricity system model

Cambridge Econometrics' Vehicle Stock Model

The vehicle stock model calculates vehicle fuel demand, vehicle emissions and vehicle prices for a given mix of vehicle technologies. The model uses information about the efficiency of new vehicles and vehicle survival rates to assess how changes in new vehicles sales affect stock characteristics. The model also includes a detailed technology sub-model to calculate how the efficiency and price of new vehicles are affected, with increasing uptake of fuel efficient technologies. The vehicle stock model is highly disaggregated, modelling 5 powertrains, 6 fuels and three different size-bands (small, medium and large)[8].

Cambridge Econometrics' E3ME model

Some of the outputs from the vehicle stock model (including fuel demand and vehicle prices) are then used as inputs to E3ME, an integrated macro-econometric model, which has full representation of the linkages between the energy system, environment and economy at a global level. The high regional and sectoral disaggregation (including explicit coverage of every EU Member State) allows modelling of scenarios specific to Spain) and detailed analysis of sectors and trade relationships in key supply chains (for the automotive and petroleum refining industries). E3ME was used to assess how the transition to low carbon vehicles affects household incomes, trade in oil and petroleum, consumption, GDP, employment, CO_2, NO_x and particulates.

For more information and the full model manual, see www.e3me.com. A summary description of the model is also available in Appendix A of this report.

Element Energy's EV profile calculator, dispatch model, and revenue model

The grid analysis of the report aims to identify synergies between EV deployment and the electricity grid and to determine the impact of different EV charging options (which can offer a net cost or benefit to the system). Using the EV profile calculator, three distinct charging options are investigated:

- "passive" (uncontrolled)
- "smart" (controlled)
- "active Vehicle to Grid" (V2G) charging

These options are compared using a whole system approach that identifies the impact of charging on each part of the electricity system. The electricity system model evaluates these impacts on an operational level as well as on an infrastructure investment level in 2030 and 2050 to determine how the significance of EVs and their net cost or benefit to the electricity system is evolving.

1.3 Structure of the report

The report is structured as follows:

- **Section 2** sets out the scenarios that were developed to inform the analysis and are required to answer the questions raised by the Core Working Group.

[8] See Section 3, Table 3.1 for more details.

- The main modelling assumptions and technology cost data are set out in **Section 3.**
- New infrastructure requirements are a key consideration for the deployment of zero emission vehicles, these are considered in **Section 4.**
- Above all, a transition requires consumers to adopt low and zero emission cars. In **Section 5** we look at the capital and fuel costs facing the consumer for new cars in the future.
- A transition to electric vehicles has implications for the electricity grid. In **Section 6**, Element Energy has assessed the implications for the Spanish electricity grid of electric vehicles and the extent to which the challenges that arise are offset by the application of smart charging.
- **Section 7** focuses on the socio-economic impact of the different scenarios. The net impacts and transitional challenges are set out.
- The main driver of low emissions cars is to reduce the harmful impact that road transport has on the local and global environment. The contribution of passenger cars to CO_2 emissions and local air quality pollutants is set out in **Section 8**.
- An additional scenario was developed to look at the economic and environmental impact should CNG/biomethane be deployed at scale to reach the EU emission targets in Spain. The results are presented in **Section 9**.
- The report finishes with our conclusions in **Section 10**. These are the views of the report’s authors and do not necessarily represent the views of the European Climate Foundation or the members of the Core Working Group, either individually or collectively.

2 Overview of scenarios

2.1 Scenario design

The analysis set out in this report is based on a set of scenarios developed in conjunction with the Core Working Group, each assuming a different new vehicle sales mix. These represent a range of decarbonisation pathways and are designed to assess the impact of a shift towards low carbon powertrains; they do not necessarily reflect current predictions of the future makeup of the Spanish car fleet. Uptake of each type of vehicle is by assumption: implicitly we assume that this change is brought about by policy. The four core scenarios to be modelled for this study are summarised in the table below:

Table 2.1 Description of the five core modelling scenarios

Scenario	Scenario description
REF (Reference)	• No change in the deployment of efficiency technology or the sales mix from 2015 onwards • Some improvements in the fuel-efficiency of the vehicle stock, due to stock turnover
CPI (Current Policy)	• Improvements to the efficiency of the ICE and a roll-out of HEVs, PHEVs and BEVs to meet 95gCO_2/km (NEDC) EU vehicle efficiency target for 2021 and a further reduction in average CO_2 emissions of new vehicles of 15% 2025 and 30% in 2030 (relative to CO2/km in 2021), equivalent to ~73 gCO_2/km and 53 gCO_2/km respectively • No further deployment of efficiency technology or advanced powertrains post-2030
TECH	• New cars meet 95gCO2/km (NEDC) target in 2021, and achieve ~73 gCO2/km (NEDC) in 2025 and ~53 gCO2/km (NEDC) in 2030 • Ambitious deployment of fuel-efficient technologies in all new vehicles over the period to 2050 (e.g. light-weighting) combined with an ambitious deployment of advanced powertrains (BEVs and FCEVs) in the period to 2050 • ICE and HEV sales are phased out by 2040, consistent with policies already announced by several other EU Member States (e.g. France, UK, Netherlands, Norway) • FCEVs gain market share after 2030, and are deployed in the medium and large segments (which have higher annual mileage)
TECH Rapid (High technology, ambitious uptake)	• New cars meet 95gCO2/km (NEDC) target in 2021, and achieve ~59 CO2/km (NEDC) in 2025 and ~27 CO2/km (NEDC) in 2030 • A low carbon technology scenario with a more ambitious deployment for advanced powertrains (BEVs and FCEVs) in the period to 2050. • ICE and HEV sales are phased out by 2040, consistent with policies already announced by several other EU Member States (e.g. France, UK, Netherlands, Norway) • Rapid take-up of PHEVs initially but these are considered to be a bridging technology and so are gradually phased out over the 2030-2050 period • PHEV and BEV sales are equal until 2030 after which the market share of PHEVs decline, becoming zero in 2050

	• FCEVs gain market share after 2030, and are deployed in the medium and large segments (which have higher annual mileage)

For the most part, this technical report focusses on the impact of the central **TECH** scenario, but the **TECH Rapid scenario** is useful because it allows us to assess the impact of a rapid transition to low carbon vehicles on CO_2 emissions as well as the associated economic risks and potential benefits.

2.2 Vehicle sales and stock

The uptake scenarios define the proportion of new sales across each powertrain, which are then divided into fuel type (e.g. Petrol ICE vs Diesel ICE) and segment (small, medium and large). For the projections of the future vehicle stock, the share of small/medium/large car and fuel shares of current vehicle sales in Spain are used. Over the total stock of ICEs, HEVs and PHEVs, segment shares remain constant (Small: 39%, Medium: 36%, Large: 25%), while BEVs are introduced mostly in the small and medium segments (Small: 70%, Medium: 23%, Large: 6%) and FCEVs into the medium and large segments (Small: 0%, Medium:35%, Large: 65%).

Table 2.2 Segment split of small/medium/large vehicles by fuel and powertrain type

		ICE	HEV	PHEV	BEV	FCEV
Petrol	Small	14%	14%	14%	-	-
	Medium	13%	13%	13%	-	-
	Large	9%	9%	9%	-	-
Diesel	Small	25%	25%	25%	-	-
	Medium	23%	23%	23%	-	-
	Large	16%	16%	16%	-	-
Electricity	Small	-	-	-	70%	-
	Medium	-	-	-	23%	-
	Large	-	-	-	6%	-
Hydrogen	Small	-	-	-	-	0%
	Medium	-	-	-	-	35%
	Large	-	-	-	-	65%

Vehicle size bands are defined in line with the ICCT definition based on aggregations of the Euro car segments:

Table 2.3 Euro car segments

Vehicle type	Segments	Description
Small (S)	A	mini cars (e.g. Fiat 500)
	B	small cars (e.g. Ford Fiesta)
Medium (M)	C	lower medium cars (e.g. Ford Focus)
Large (L)	D	medium cars (e.g. Vauxhall Insignia)
	E	upper medium cars (e.g. BMW 5-series)
	F	luxury cars (e.g. Jaguar XJ-series)
	J	SUVs (e.g. Nissan Qashqai)

Source: European Commission.

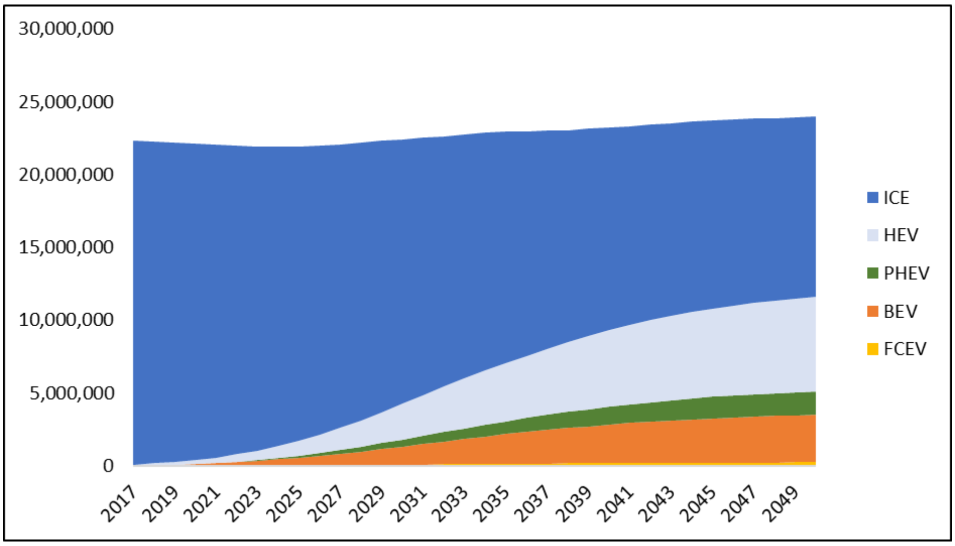
REF & CPI Scenarios

In both the REF and CPI scenarios, ICEs dominate the vehicle sales mix throughout the study period. In the REF scenario, the sales mix is held constant from 2017 onwards, whereas in the CPI scenario there is a deployment of HEVs, PHEVs and BEVs such that new sales meet the 95g/km CO_2 target in 2021 and achieve a further reduction in CO_2 emissions of new vehicles of 15% in 2025 and a reduction of 30% in 2030 (relative to CO2/km in 2021). Once these targets are met, the mix of vehicle sales, and the deployment of fuel-efficient technologies, does not change. The mix of vehicle sales in the REF and CPI scenarios after 2030 is shown in Table 2.4 below. Figure 2.1 shows the EU vehicle stock by powertrain type in the CPI scenario.

Table 2.4 Sales mix of the REF and CPI scenarios from 2030 onwards

	REF	CPI
ICE	95%	50%
HEV	4.4%	28%
PHEV	0%	7%
BEV	0.6%	14%
FCEV	0%	1%

Figure 2.1 Spanish vehicle stock (millions) by powertrain in the CPI Scenario



The composition of vehicle sales and vehicle stock in the TECH and TECH Rapid scenarios are detailed in the subsections below. Whilst the sales shares vary between the two scenarios, the balance between segment shares, and the size of the vehicle stock are kept consistent.

TECH Scenario

Sales and stock in the TECH scenario are shown in Figure 2.2 and Figure 2.3 below. We assume a gradual increase in the share of advanced powertrains up to 2030. After 2030, BEV market share grows rapidly, and ICEs are phased out in 2040. PHEVs and HEVs are deployed initially, but HEVs are also phased out by 2040, while sales of PHEVs decline after 2040. Sales of ZLEVs (BEVs + FCEVs) account for 22% of sales in 2030, and 73% of new car sales in 2040.

Figure 2.2 New vehicle sales by powertrain type in the TECH Scenario

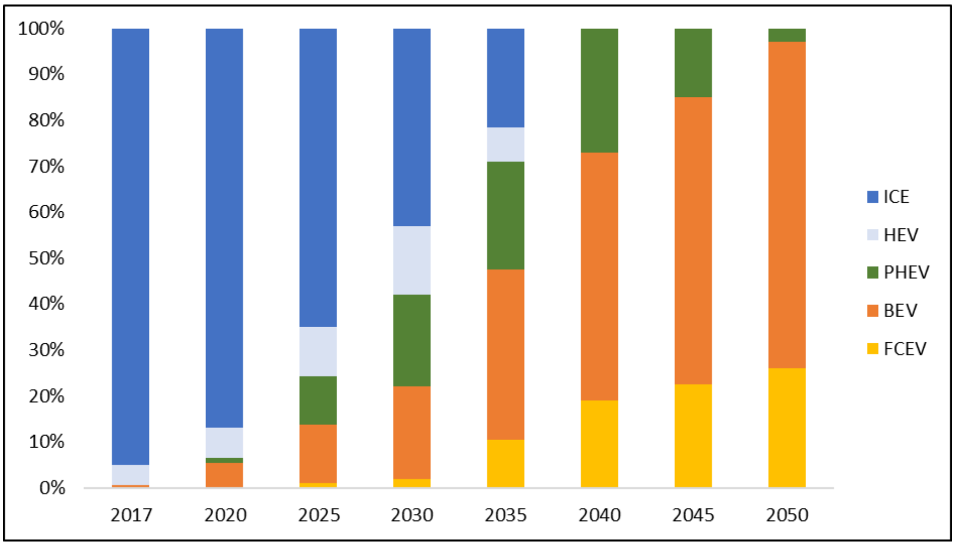
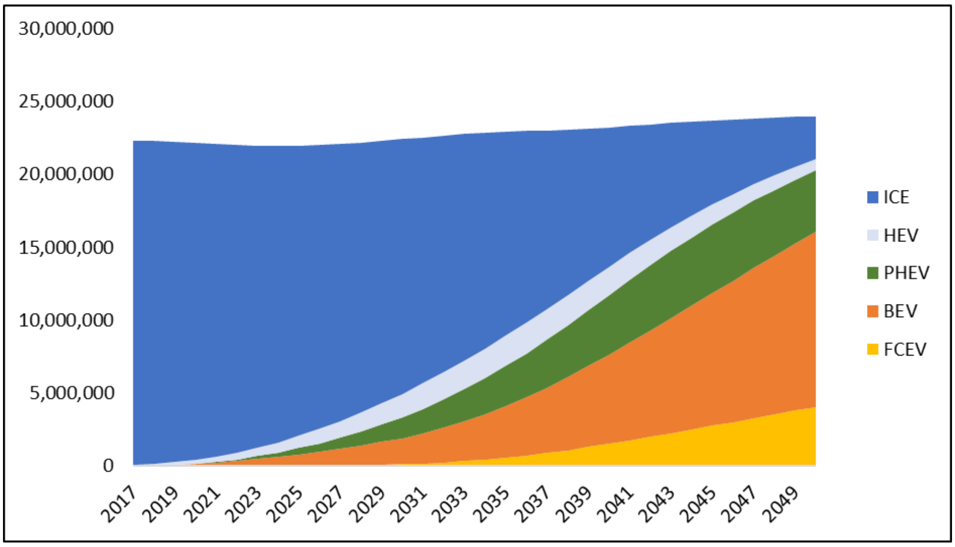


Figure 2.3 Spanish vehicle stock (millions) by powertrain in the TECH Scenario



TECH Rapid Scenario

Sales and stock in the TECH Rapid scenario are shown in Figure 2.4 and Figure 2.5 below. The scenario is characterised by a very rapid deployment of advanced powertrains, with ZLEV shares reaching 23% already in 2025. PHEV and BEV sales are on parity with one another in 2030, after which BEVs begin to dominate. FCEVs achieve almost 20% of new sales in 2040, increasing modestly in the period to 2050.

Figure 2.4 New vehicle sales by powertrain in the TECH Rapid Scenario

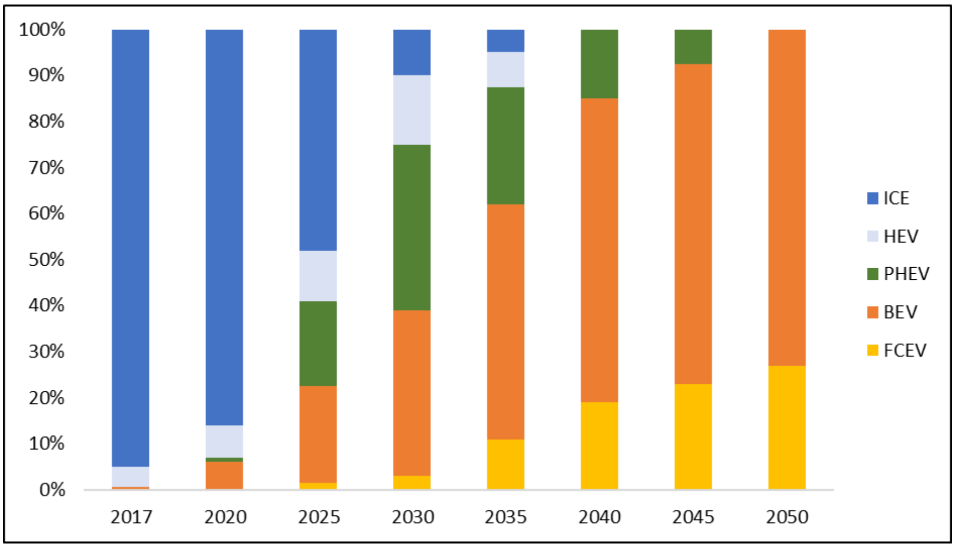
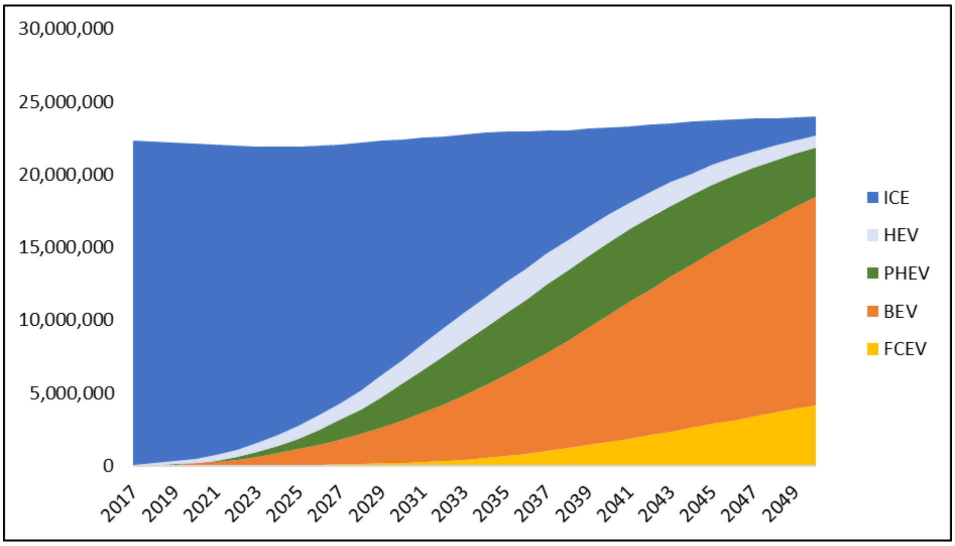


Figure 2.5 Spanish vehicle stock (millions) in the TECH Rapid Scenario

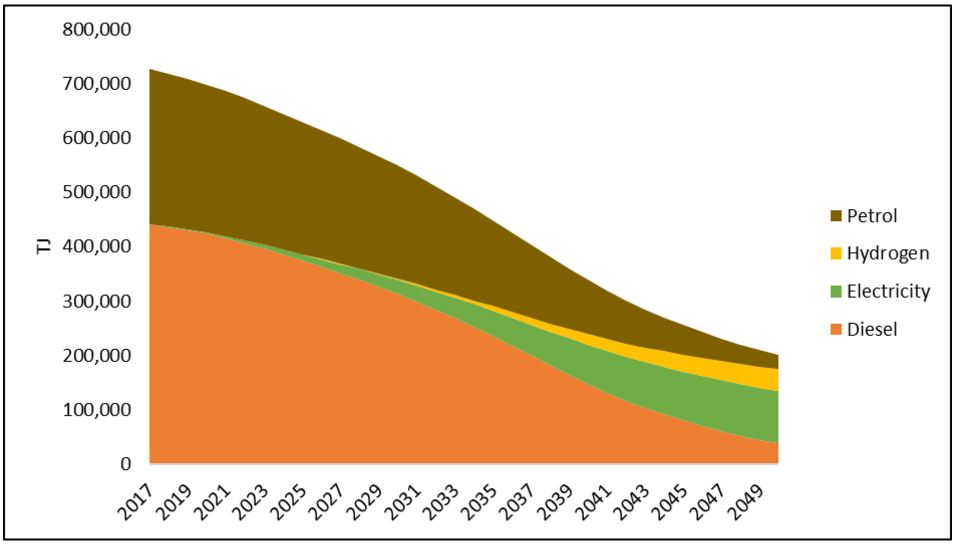


2.3 Fuel demand

Figure 2.6 shows the combined effects of efficiency improvements and deployment of advanced powertrains on fuel consumption by the Spanish vehicle stock in the TECH scenario. By 2030, we see a substantial reduction in demand for fuel, with a 39% reduction in petrol and diesel demand relative to 2017. By 2050, the demand for petrol and diesel will have fallen by 95% compared to 2017 levels.

Electricity and hydrogen demand grows in line with rollout of PHEVs, BEVs and FCEVs. Due to the higher energy efficiency of these vehicles, their share of total energy demand is consistently higher than their share of the vehicle stock.

Figure 2.6 Demand of petrol, diesel, hydrogen and electricity (TJ) in the TECH scenario



The total energy demand of the vehicle stock for each scenario is defined in tera-joules (TJ). In the model, this is converted into demand for the respective energy sources (petrol, diesel, gas, electricity, hydrogen) in volume, and ultimately value, terms.

3 Modelling assumptions

This section sets out the key modelling assumptions underpinning the analysis.

The scenarios are defined by (i) the new sales mix by vehicle powertrain type and (ii) the uptake of fuel efficient technologies. Key assumptions that are common to all scenarios and are briefly outlined in Table 3.1. The subsequent sections provide information about our technology costs and deployment, battery costs, fuel cell vehicle and power sector assumptions.

3.1 Common modelling assumptions

Table 3.1 Key assumptions used in stock model

	Details of assumptions used
Vehicle sales	• Historical sales data is taken from the statistics provided by the Dirección General de Tráfico (DGT) and the Association Auxiliaire de l'Automobile (AAA) • Projections for total new registrations are calculated so that the number of vehicles per capita (ownership rate) is stable over time, between 469 and 487 passenger cars per 1,000 inhabitants.
Efficiency of new vehicles	• We use Spain-specific data on new vehicle efficiency from the ICCT for 2001 to 2014 • Future efficiency of new vehicles is endogenous to the vehicle stock model, based on assumptions about the vehicle powertrain and the energy efficient technologies that are installed in the vehicle, calculated using Ricardo-AEA's latest cost curve study for the European Commission[9]
Mileage by age cohort	• Historical data on mileage is taken from the TREMOVE database • We assume that average annual mileage falls gradually over the lifetime of a vehicle and varies depending on size and powertrain. For instance, in 2015 a medium size diesel drives more than 25,000 km in its first complete year, but only 20,000 km by year 5.
Vehicle survival rates	• The survival rate curve is the key assumption for converting annual sales into a vehicle stock. This curve is defined as the % of vehicles from a given sales cohort that survive to a certain age • The survival rate was derived from analysis of the age distribution of the total Spanish car stock between 2005-2016 (using stock data from the DGT database). The average age of passenger cars in the Spanish fleet in 2016 was 12.7 years • The same survival rate is used for all powertrains and segments. We assume an average survival rate curve for all vehicle types and assume one survival rate curve across the whole-time period
Fuel prices	• Historical data for fuel prices is taken from the Ministerio de Energía, Turismo y Agenda Digital of Spain. In their dataset, oil

[9] Ricardo -AEA (2016), Improving understanding of technology and costs for CO2 reductions from cars and LCVs in the period to 2030 and development of cost curves

	prices are broken down into prices for petrol and prices for diesel, inclusive and exclusive of taxes and levies • For projections we assume oil prices grow in line with the IEA World Energy Outlook Current Policies Scenario (and a constant percentage mark-up is applied to derive the petrol and diesel fuel price)
Electricity prices	• These are derived from a decarbonisation scenario developed by the Spanish utility company Iberdrola • The electricity prices projections for EV charging were developed by Iberdrola as part of the scenario. Prices are similar to the rates paid by households • The impact of additional demand on electricity prices is explored in section 6 of this report
Value chains	• In all scenarios, we assume that Spain captures a consistent share of the vehicle value chain for conventional ICEs • We assume that the assembly of battery modules and battery packs are part of the electrical equipment value chain. In the central scenarios, we assume that battery modules and battery packs for EVs are assembled in Spain directly proportional to the share of electrical equipment demand that is currently met by domestic production
Trade in motor vehicles	• We assume that the decarbonisation of transport is taking place at a similar pace across Europe • Therefore, there is no change in demand for Spanish motor vehicle exports
Air quality	• Real world NO_x and PM emission factors were taken from an EEA study[10] using the Tier 2 emissions calculation method
Vehicle depreciation	• Depreciation rates for vehicles are in line with Element Energy's study for BEUC (The European Consumer Organisation)[11]

3.2 ICE efficiency gains

There remains a large number of measures that can be introduced to improve the efficiency of the internal combustion engine and transmission system, and many of the technologies that are already available can make a significant impact on fuel consumption in the 2020-2025 timeframe.

Table 3.2 and Table 3.3 below show the assumptions used on the uptake of fuel efficient technologies for petrol and diesel ICEs in the TECH scenarios. This deployment builds on the deployments schedules that Ricardo AEA developed for the UK Committee on Climate Change. These deployments were used to create technology packages to represent a central deployment of technologies over time. We then tweaked the deployment of these packages to meet the specific ambitions of our scenarios.

Where applicable (e.g. for technologies and measures that affect the body of the car rather than the engine efficiency), the fuel-efficient technologies are also assumed to be installed in the same proportion of alternative powertrain vehicles.

[10] EEA Air pollutant emission inventory guidebook 2016
[11] Element Energy (2016), Low carbon cars in the 2020s: impacts and EU policy implications

Table 3.2 Deployment of fuel efficient technologies in Petrol ICEs over the period to 2050 (as a share of all new vehicles)

Efficiency Technology	2017	2030	2050
Combustion improvements for engines: Level 1	80%	100%	100%
Combustion improvements for engines: Level 2	33%	82%	22%
Combustion improvements for engines: Level 3	0%	7%	78%
Direct injection - homogeneous	40%	36%	1%
Direct injection - stratified charge & lean burn	20%	54%	51%
Thermodynamic cycle improvements	1%	4%	47%
Cylinder deactivation	1%	2%	1%
Mild downsizing (15% cylinder content reduction) + boost	51%	27%	0%
Medium downsizing (30% cylinder content reduction) + boost	29%	60%	22%
Strong downsizing (>=45% cylinder content reduction) + boost	4%	13%	78%
Cooled low-pressure EGR	20%	60%	99%
Cam-phasing	60%	27%	0%
Variable valve actuation and lift	33%	73%	54%
Engine friction reduction: Level 1	65%	34%	0%
Engine friction reduction: Level 2	20%	66%	100%
Start-stop system	36%	17%	0%
Automated manual transmission (AMT)	25%	47%	2%
Dual clutch transmission (DCT)	6%	27%	20%
Continuously variable transmission (CVT)	3%	12%	78%
Optimising gearbox ratios / downspeeding	4%	2%	0%
Further optimisation of gearbox, increase gears from 6 to 8+	30%	64%	99%
Mild weight reduction (10% from the whole vehicle)	2%	1%	0%
Medium weight reduction (20% from the whole vehicle)	48%	34%	1%
Strong weight reduction (30% from the whole vehicle)	21%	66%	100%
Aerodynamics improvement 1 (Cd reduced by 10%)	20%	40%	2%
Aerodynamics improvement 2 (Cd reduced by 20%)	10%	36%	18%
Low rolling resistance tyres 1	2%	10%	81%
Low rolling resistance tyres 2	45%	36%	2%
Reduced driveline friction 1	37%	64%	99%
Reduced driveline friction 2	23%	20%	0%
Low drag brakes	28%	80%	100%
Thermal management	36%	47%	0%
Thermo-electric waste heat recovery	12%	53%	100%
Auxiliary (thermal) systems improvement	8%	27%	83%
Auxiliary (other) systems improvement	29%	60%	99%

Table 3.3 Deployment of fuel efficient technologies in Diesel ICEs over the period to 2050 (as a share of all new vehicles)

Efficiency Technology	2017	2030	2050
Combustion improvements for engines: Level 1	80%	100%	100%
Combustion improvements for engines: Level 2	33%	82%	22%
Combustion improvements for engines: Level 3	0%	7%	78%
Mild downsizing (15% cylinder content reduction) + boost	51%	27%	0%
Medium downsizing (30% cylinder content reduction) + boost	29%	60%	22%
Strong downsizing (>=45% cylinder content reduction) + boost	4%	13%	78%
Cooled low-pressure EGR	20%	60%	99%
Variable valve actuation and lift	33%	73%	54%
Engine friction reduction: Level 1	65%	34%	0%

Engine friction reduction: Level 2	20%	66%	100%
Start-stop system	36%	17%	0%
Automated manual transmission (AMT)	4%	2%	0%
Dual clutch transmission (DCT)	30%	64%	99%
Continuously variable transmission (CVT)	2%	1%	0%
Optimising gearbox ratios / downspeeding	48%	34%	1%
Further optimisation of gearbox, increase gears from 6 to 8+	21%	66%	100%
Mild weight reduction (10% from the whole vehicle)	20%	40%	2%
Medium weight reduction (20% from the whole vehicle)	10%	36%	18%
Strong weight reduction (30% from the whole vehicle)	2%	10%	81%
Aerodynamics improvement 1 (Cd reduced by 10%)	45%	36%	2%
Aerodynamics improvement 2 (Cd reduced by 20%)	37%	64%	99%
Low rolling resistance tyres 1	23%	20%	0%
Low rolling resistance tyres 2	28%	80%	100%
Reduced driveline friction 1	36%	47%	0%
Reduced driveline friction 2	12%	53%	100%
Low drag brakes	8%	27%	83%
Thermal management	29%	60%	99%
Thermo-electric waste heat recovery	0%	4%	25%
Auxiliary (thermal) systems improvement	32%	87%	100%
Auxiliary (other) systems improvement	20%	53%	91%

3.3 Vehicle costs

Our cost assumptions for the improvements mentioned above are based on Ricardo-AEA (2015).

The costs in Table 3.4 are taken from the latest Ricardo-AEA (2015) datasets developed for the European Commission. Table 3.4 summarises the main technologies included and the associated energy savings and cost increase compared to a 2015 new car without those same features.

Table 3.4 Technology Energy Savings and Cost

Efficiency Technologies	Energy saving	Production Cost (€ 2016)		
		Small car	Medium car	Large car
Combustion improvements for engines: Level 1	2-3%	68	68	68
Combustion improvements for engines: Level 2	2-3%	14	15	15
Combustion improvements for engines: Level 3	2-7%	541	541	757
Direct injection - homogeneous	5%	245	245	343
Direct injection - stratified charge & lean burn	7-11%	505	664	883
Thermodynamic cycle improvements	13-25%	610	618	855
Cylinder deactivation	2-3%	268	268	268
Mild downsizing (15% cylinder content reduction) + boost	2-3%	112	147	147
Medium downsizing (30% cylinder content reduction) + boost	2-7%	190	279	285

Strong downsizing (>=45% cylinder content reduction) + boost	8-10%	447	516	522
Cooled low-pressure EGR	2-3%	118	127	174
Cam-phasing	4%	84	89	137
Variable valve actuation and lift	1-7%	236	248	385
Engine friction reduction: Level 1	1-2%	60	60	60
Engine friction reduction: Level 2	3-3%	113	113	113
Start-stop system	1-2%	135	154	195
Automated manual transmission (AMT)	1-2%	446	476	611
Dual clutch transmission (DCT)	1-2%	1437	1618	1996
Continuously variable transmission (CVT)	2-3%	3688	4452	5640
Optimising gearbox ratios / downspeeding	1-5%	441	441	463
Further optimisation of gearbox, increase gears from 6 to 8+	3-9%	467	498	516
Mild weight reduction (10% from the whole vehicle)	5-7%	910	910	956
Medium weight reduction (20% from the whole vehicle)	11-12%	82	82	82
Strong weight reduction (30% from the whole vehicle)	17-19%	156	156	156
Aerodynamics improvement 1 (Cd reduced by 10%)	3-4%	41	53	69
Aerodynamics improvement 2 (Cd reduced by 20%)	5-7%	247	320	401
Low rolling resistance tyres 1	2-4%	1042	1354	1694
Low rolling resistance tyres 2	5-8%	55	57	72
Reduced driveline friction 1	1%	173	179	225
Reduced driveline friction 2	2%	39	45	44
Low drag brakes	1%	109	115	114
Thermal management	2%	29	29	29
Thermo-electric waste heat recovery	2-3%	130	130	130
Auxiliary (thermal) systems improvement	2-3%	74	74	74
Auxiliary (other) systems improvement	2-3%	228	228	262

Note(s): Costs are mass manufacturing cost

3.4 Battery costs and range

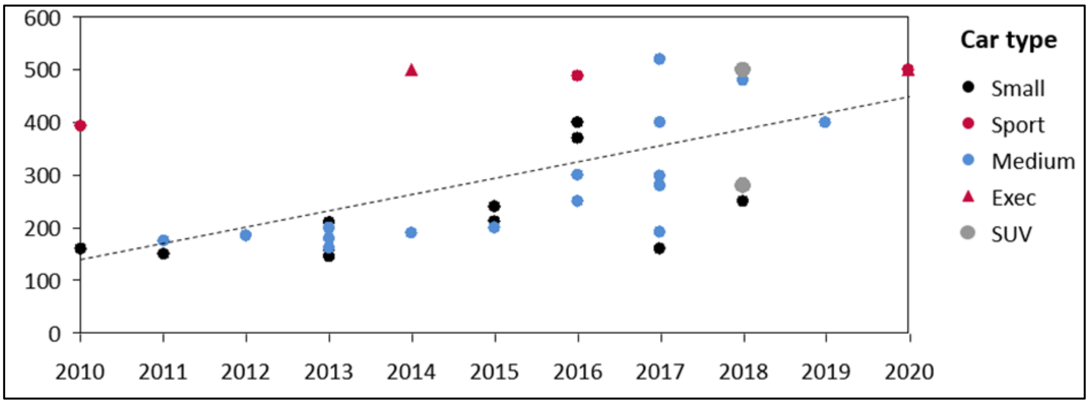
Definitions

A key input to the modelling of EV cost is the battery pack size (kWh). There is currently considerable uncertainty on future battery pack sizes, as these will depend both on future reductions in battery costs and Original Equipment Manufacturer (OEM) design choices to balance vehicle driving ranges against cost based on customer preferences. While the plug-in hybrid market shows a convergence for the electric driving range at around 50km, the battery electric vehicle market shows greater diversity and speed of change. BEVs are beginning the transition from first generation vehicles such as the Nissan Leaf and VW Golf with driving ranges of 150-200km to second generation models such as the Chevrolet Bolt and Tesla Model 3 and new entrants from German OEMs in the premium sector such as the Audi E-tron/Q8 and Porsche Mission E concepts.

OEM statements suggest that medium size next generation BEVs will target driving ranges of 320km or more, while large vehicles will have longer ranges of 500km or more, similar to the Tesla Model S. In smaller segments, Renault has almost doubled the range of the B-segment Zoe [to 400km New European Driving Cycle (NEDC)] by upgrading the battery pack size to c.40kWh. The figure below plots the driving ranges of BEVs (past models and some of the announced models). It shows an overall upward trend, but a virtually constant range for small cars (with the exception of 2016).

Figure 3.1 plots the driving ranges of BEVs (past models and some of the announced models). It shows an overall upward trend, but a virtually constant range for small cars.

Figure 3.1 Official driving range (km, NEDC) of battery electric vehicles introduced on the EU market (2010-2017) and announced (2018-2020). EE compilation of publicly available data.



Taking these trends into consideration, Table 3.5 shows the proposed battery size assumptions for hybrid, plug-in hybrid and battery electric vehicles between 2020 and 2050.

Given the costs of increasing BEV driving ranges through additional battery capacity, it is expected that OEMs will offer multiple battery configurations to allow customers to make a trade-off between vehicle price and range. This is already seen in the Nissan Leaf, where 24kWh and the newer 30kWh are both on sale. To account for this, we assume 'short range' and 'long range' versions of BEVs in the modelling.

Beyond 2020, we have used different assumptions for PHEVs and BEVs on changes in battery capacity. For PHEVs, we assume that electric range will be increased to 80km (NEDC) by 2025 in order to provide approximately 50km of real world range. Beyond this point, it is assumed that OEMs maintain this electric driving range of 80km, and decrease pack sizes over time as vehicle efficiency improvements lead to reductions in energy use per km. For BEVs, we assume that pack sizes are held constant, and vehicle driving ranges increase over time as improvements in battery energy density reduce pack weight (currently over 400kg for the 60kWh pack in the Chevrolet Bolt) and vehicle-level efficiency improvements reduce energy consumption per kilometre.

The battery sizes are intended to be representative, since in practice there are a wide range of options and specifications available to manufacturers, leading to a wide range of costs, performance and range.

Table 3.5 Battery size assumptions

Battery sizes (kWh)					
Powertrain	Market segment	2020	2030	2040	2050
HEV	Small	0.95	0.82	0.78	0.74
HEV	Medium	1.00	0.86	0.81	0.77
HEV	Large	1.27	1.11	1.05	1.00
PHEV	Small	4.47	4.51	4.25	4.03
PHEV	Medium	7.62	7.58	7.14	6.77
PHEV	Large	10.51	10.71	10.24	9.78
BEV – Short range	Small	21.00	21.00	21.00	21.00
BEV – Short range	Medium	28.00	28.00	28.00	28.00
BEV – Short range	Large	-	-	-	-
BEV – Long range	Small	45.00	45.00	45.00	45.00
BEV – Long range	Medium	60.00	60.00	60.00	60.00
BEV – Long range	Large	92.00	92.00	92.00	92.00

Costs and energy savings

The primary influence on plug-in vehicle cost and performance is battery technology, since other components such as electric motors are already well developed and have more limited potential for future improvements. There are four key areas of battery technology 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, for example allowing rapid charging at 150 kW+ with no impact on battery state of health

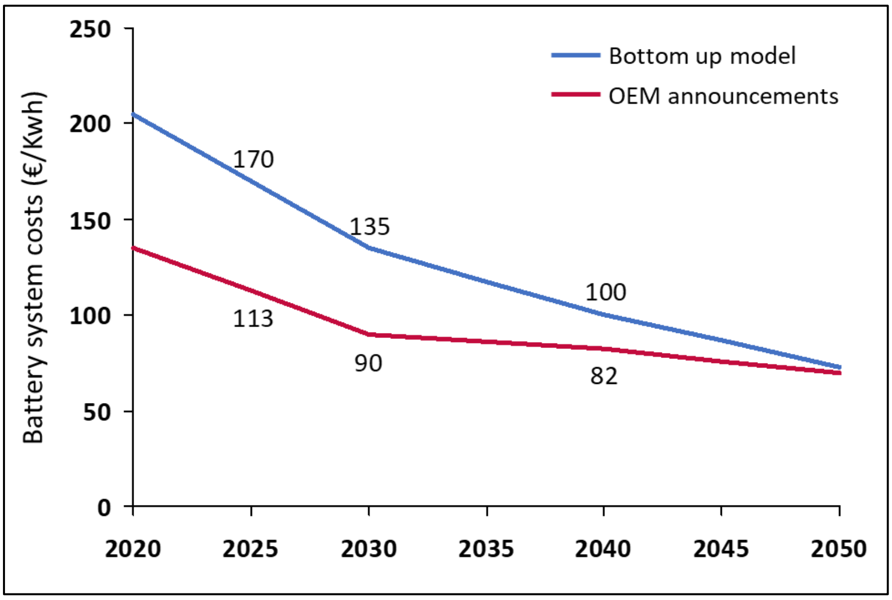
According to estimates by Bloomberg New Energy Finance (BNEF), the price of lithium-ion batteries in 2016 was $273/kWh – a drop of 73% since 2010 (BNEF, 2017). Price decreases between 2010 and 2016 are in part due to technology improvements and economies of scale. Battery pack prices are predicted to continue to drop in 2018, but at a slower pace than in previous years.

In the short- to medium-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). Discussions with OEMs and cell suppliers have confirmed there is significant scope for innovation within lithium ion chemistries, such as increasing use of silicon in the anode, use of solid state electrolytes and improved packaging efficiency. In the medium-term, lithium-sulphur and lithium-air holds perhaps the most promise (up to five and ten times the energy density of lithium ion respectively in theory, twice and three times in practice at pack level), but these technologies are believed to be relevant only in 2030 and beyond, if key challenges such as short life are overcome.

Two variants are used for the battery cost projections. The TECH Rapid scenario uses an 'OEM announcement' variant, which is in line with OEM announcements and other publications, while the TECH scenario uses a more conservative 'Bottom up model' variant, which is based on a recent Element Energy study for BEUC (the European Consumer Association). That study employed Element Energy's component-level model of battery costs, which takes into account cell costs and performance developments over time, as well as packing costs such as thermal management, wiring harnesses, containers and the Battery Management System.

The battery cost projections of each scenario are outlined in Figure 3.2.

Figure 3.2 Battery system costs (€/kWh) for a large long-range BEV in both the 'Bottom up model' and 'OEM announcement' variants



Bottom up model case

Results from Element Energy's battery cost model suggest strong reductions in battery costs between now and 2030, reaching a cost of €135/kWh for a large (>60kWh) pack. This is based on materials and manufacturing costs plus a margin, and does not account for short term strategic pricing such as incurring losses in early deployments to build market share. These strategic pricing decisions could take place either at the OEMs or their suppliers, for example with cell manufacturers offering low prices to build market share and maximise throughput in new plants, or OEMs cross-subsidising zero emission models with profits from conventional vehicles.

The Element Energy costs projections are comparable to the projections made by battery experts Avicenne, who forecast a pack level cost of €260/kWh and €205/kWh in 2020 and 2025 respectively for a 30kWh pack (vs. €249/kWh and €198/kWh in the Element Energy cost estimates).

Nonetheless, these estimates are seen as conservative compared to some cost projections recently published; they are therefore used for a high cost case sensitivity test.

OEM announcement case

The costs are an average taken from announcements from car OEMs, as well as publications by the ICCT (2016) and McKinsey (2017). We assume that battery costs reach €130/kWh at a pack level by 2020, falling to €90/kWh by 2030. This is equivalent to achieving the 2030 'bottom up model' costs 10 years early, in 2020. Under this scenario, only long range BEVs are assumed to be sold since vehicles would be cost effective even with relatively large battery packs. The two cost scenarios are shown in Table 3.6 and Table 3.7.

For comparison, OEM announcements include estimates from General Motors (GM) that the cost of the Chevrolet Bolt battery is $145/kWh at the cell level, equivalent to €175/kWh at a pack level assuming that packing costs add 33% to the cell cost)[12]. GM also published a roadmap for cell costs suggesting that a cell cost of $100/kWh (€90/kWh) is expected by 2022. The most optimistic recent estimates suggest that battery packs from the Tesla Gigafactory could reach $125/kWh by 2020 at a pack level (€110/kWh, $88/kWh cell cost plus $38/kWh for packing costs)[13]. Tesla itself expects a 33% reduction in cost from the approximately $250/kWh pack costs in the current Model S.

Table 3.6 Battery system costs - OEM announcement case

Battery system costs (€/kWh)					
Powertrain	Market segment	2020	2030	2040	2050
HEV	Small	490	326	256	222
HEV	Medium	490	326	256	222
HEV	Large	490	326	256	222
PHEV	Small	274	190	173	149
PHEV	Medium	274	190	173	149
PHEV	Large	274	190	173	149
BEV – Short	*Small*	*176*	*129*	*118*	*101*
BEV – Short	*Medium*	*157*	*115*	*105*	*90*
BEV – Short	*Large*	*135*	*90*	*82*	*70*
BEV – Long	Small	141	98	89	76
BEV – Long	Medium	141	98	89	76
BEV – Long	Large	135	90	82	70

[12] http://cleantechnica.com/2015/10/05/chevy-bolt-battery-cells-145kwh-new-chevy-volt-with-autonomous-driving/

[13] http://www.streetinsider.com/Analyst+Comments/Jeffereis+Sees+1%2C000bps+of+GM+Tailwind+for+Tesla+%28TSLA%29%3B+PT+Up+to+%24365/10899606.html

In their assessment of next-generation EV technologies of 2016, the ICCT estimates that OEMs producing in high volume will reach a €135-160/kWh price range by 2020-2023, while OEMs producing at lower scale would be in the €160-200/kWh band. In the 2017 McKinsey report, battery pack costs are envisioned to fall below the $100/kWh (€90/kWh) threshold "between 2025 and 2030".

Table 3.7 Battery system costs - Bottom up model case

Battery system costs (€/kWh)					
Powertrain	Market segment	2020	2030	2040	2050
HEV	Small	490	326	256	222
HEV	Medium	490	326	256	222
HEV	Large	490	326	256	222
PHEV	Small	438	295	217	160
PHEV	Medium	438	295	217	160
PHEV	Large	438	295	217	160
BEV – Short	Small	279	194	143	106
BEV – Short	Medium	249	173	127	94
BEV – Short	Large	205	135	100	73
BEV – Long	Small	224	146	108	80
BEV – Long	Medium	224	146	108	80
BEV – Long	Large	205	135	100	73

Note on pack cost across pack sizes

The costs used in the scenario descriptions refer to relatively high capacity batteries used in BEVs. For PHEV, batteries cost more than BEV batteries, per kWh. This is because the power requirements place a proportionally larger demand on the smaller battery pack in a PHEV, so batteries with higher power are needed at a somewhat higher cost.

The costs presented in Table 3.6 and Table 3.7Table 3.7 refer to both the battery and the battery system (or pack), but not the electric drive powertrain; costs for the latter are shown in Table 3.8Table 3.8. The costs are therefore lower per kWh for a large battery than a small battery. In addition, PHEV and HEV batteries cost more than BEV batteries on a per kWh basis. This is due to the use of different chemistries to allow high current draws from a comparatively small battery, and the fact that fixed battery costs (e.g. thermal management, BMS) are spread over fewer kilowatt-hours of capacity.

Table 3.8 Electric powertrain costs (motor, inverter, booster)

Powertrain	Market segment	2020	2030	2040	2050

HEV	Small	791	711	640	577
HEV	Medium	890	800	720	650
HEV	Large	1098	987	888	802
PHEV	Small	916	826	746	675
PHEV	Medium	1031	930	840	760
PHEV	Large	1272	1148	1037	938
BEV – Short	*Small*	*916*	*826*	*746*	*675*
BEV – Short	*Medium*	*1031*	*930*	*840*	*760*
BEV – Short	*Large*	*1272*	*1148*	*1037*	*938*
BEV – Long	Small	916	826	746	675
BEV – Long	Medium	1031	930	840	760
BEV – Long	Large	1272	1148	1037	938

The powertrain costs vary by approximately a factor of two between the powertrain required for a small HEV and a large BEV. These costs are based on the combination of kW assumptions (shown in the last column above) and the system cost (motor, inverter, boost converter) as used in R-AEA (2015), where the cost goes from a fixed €88 and €16.80/kW in 2020 down to €70 and €13.40/kW in 2030.

Overall, the total battery system and powertrain costs are shown in Table 3.9Table 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

Total cost of electric powertrain and battery (€)					
Powertrain	Market segment	2020	2030	2040	2050
HEV	Small	1248	954	787	680
HEV	Medium	1405	1074	886	765
HEV	Large	1733	1325	1094	945
PHEV	Small	3982	2685	1961	1459
PHEV	Medium	5411	3585	2576	1880
PHEV	Large	7842	5130	3641	2618
BEV – Short	*Small*	*6460*	*4795*	*4001*	*3321*
BEV – Short	*Medium*	*7611*	*5634*	*4676*	*3896*
BEV – Short	*Large*	-	-	-	-

BEV – Long	Small	10006	7396	5606	4275
BEV – Long	Medium	13151	9690	7320	5560
BEV – Long	Large	19452	13298	10037	7508

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, expect in the case of the large segment, where an overall higher kW is assumed. An ICE has a cost of around €2,000 in the medium category.

Battery range

In line with recent vehicle cost modelling for ECF and BEUC (2016), we apply State of Charge (SOC) assumptions (Table 3.10) to derive the useable energy of the battery. The expected range (Table 3.11) is then derived based on the test cycle efficiency of the vehicle (in all electric mode, under the Worldwide Harmonised Light Vehicles Test Procedure[14]).

Table 3.10 Battery usable State of Charge (SOC)

Battery usable SOC for electric range (%)					
Powertrain	Market segment	2020	2030	2040	2050
PHEV	Small	70%	72%	74%	75%
PHEV	Medium	70%	72%	74%	75%
PHEV	Large	70%	72%	74%	75%
BEV	Small	85%	90%	90%	90%
BEV	Medium	85%	90%	90%	90%
BEV	Large	85%	90%	90%	90%

Table 3.11 Vehicle range in full electric mode

All electric range (km – WLTP)					
Powertrain	Market segment	2020	2030	2040	2050
PHEV	Small	38	50	50	50
PHEV	Medium	60	80	80	80
PHEV	Large	60	80	80	80
BEV – Short	Small	202	246	260	271
BEV – Short	Medium	253	313	334	353
BEV – Long	Small	352	468	495	517
BEV – Long	Medium	451	609	647	679

[14] The projected efficiency under the NEDC are converted to WLTP equivalent as per the conversion of each efficiency measure given in Ricardo-AEA (2015). Starting conversion factors for 2015 were sourced from ADAC EcoTest laboratory results. The difference in kWh/km between NEDC and WLTP is typically around 5%.

BEV – Long	Large	523	710	754	791

The 2020 values in Table 3.11 reflect announced ranges of next generation models. For example, a Chevrolet Bolt or Tesla Model 3 with a range of 200 miles on the US EPA test cycle would have a range of 460-480 km on the NEDC, since the NEDC gives an approximately 40-45% increase in range for a given vehicle[15]. Ranges continue to increase after 2020 due to improvements in energy use per km (from light-weighting, improved ancillaries, aerodynamics etc.). PHEV ranges increase modestly beyond 2020 for the same reason, but it is assumed that the majority of reduced energy consumption is used to reduce the pack size and cost, since a range of 40-60 km is already sufficient for a large proportion of daily driving.

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.

3.5 Fuel cell vehicle assumptions

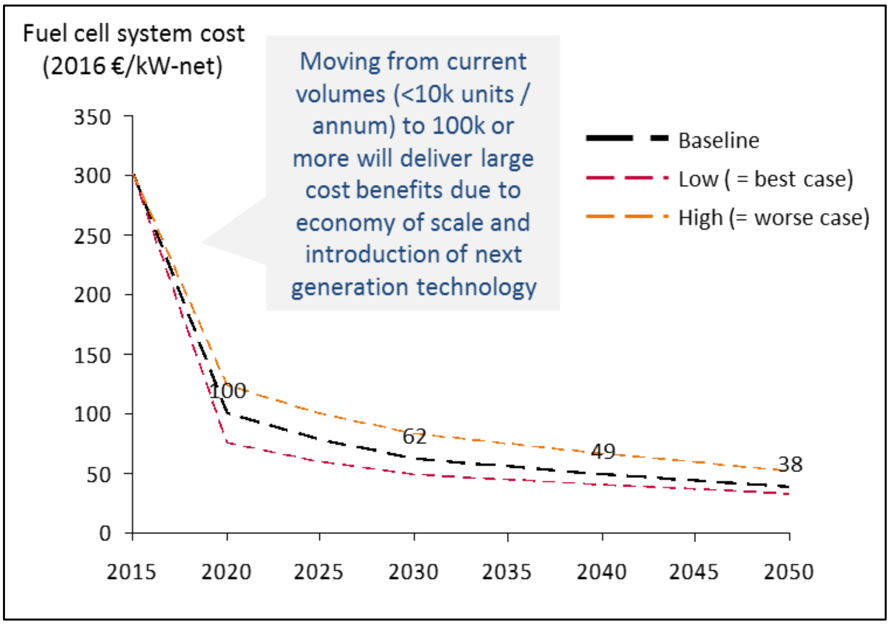
The assumptions regarding FCEVs build on work carried out by Element Energy for several national hydrogen mobility initiatives, as well as the cross-cutting Hydrogen Mobility Europe (H2ME) demonstration project funded by the Fuel Cells and Hydrogen Joint undertaking. They are based on aggregated and anonymised data provided by technology suppliers and vehicle manufacturers, data from real-world deployments and published data from the national hydrogen mobility initiatives and academic research.

Fuel cell system and hydrogen tank costs

The two largest components influencing the costs of FCEVs are the fuel cell system and the high-pressure hydrogen tank. Future values for these costs are subject to significant uncertainty, since they depend greatly on 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/kW are assumed as a central estimate. Figure 3.3 shows the assumptions.

[15] For example, the NEDC range for the Nissan Leaf 30kWh is 155 miles, compared with 107 on the EPA test.

Figure 3.3 Current and projected costs of fuel cell systems

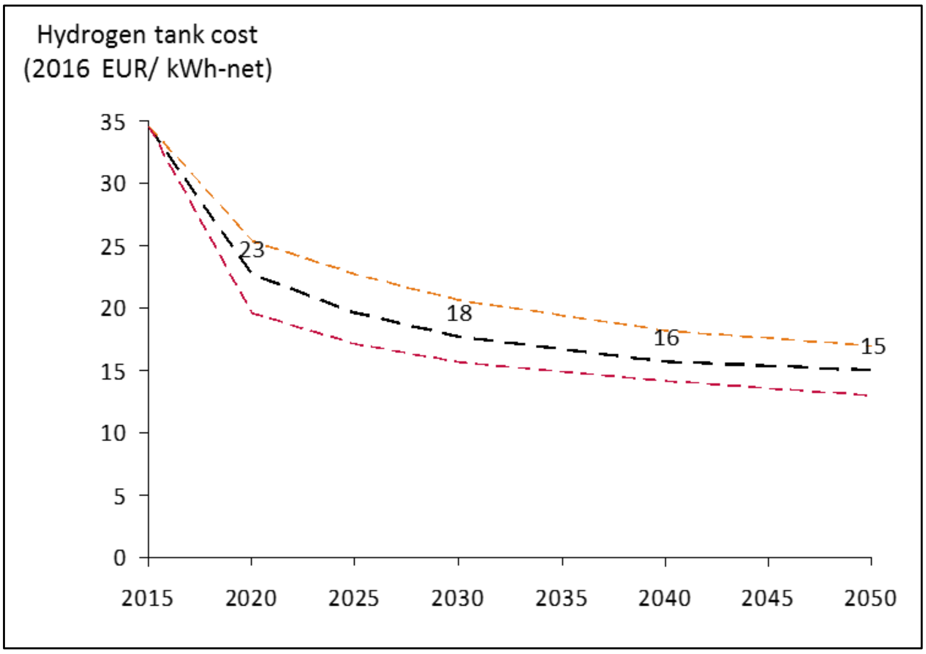


This is consistent with the 2010 values in the EU Powertrains study[16], reflecting the fact that FCEV commercialisation is occurring approximately five years later than assumed in that analysis. Recent discussions with fuel cell vehicle OEMs suggest that these costs reflect likely industry trends once this five-year delay is accounted for. A cost of €200/kW implies a system cost of €20,000 for a 100 kW system. This is broadly consistent with the retail price of the Toyota Mirai (approximately €66,000 plus taxes), but it is not possible to derive directly the 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, current fuel cell cost and margin assumptions have only a small impact on the economic modelling in the study. This uncertainty is lower by 2030 (when FCEVs are sufficiently numerous to have macroeconomic impacts), since the majority of OEMs have similar views on long-term fuel cell costs and the margins will converge with those of conventional vehicles once high sales volumes are reached.

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 (TINA) carried out by Element Energy and the Carbon Trust. These costs would result in a 100 kW fuel cell system costing €5000-6000 by 2030. Figure 3.4 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 at least 50% relative to today's prices by 2030.

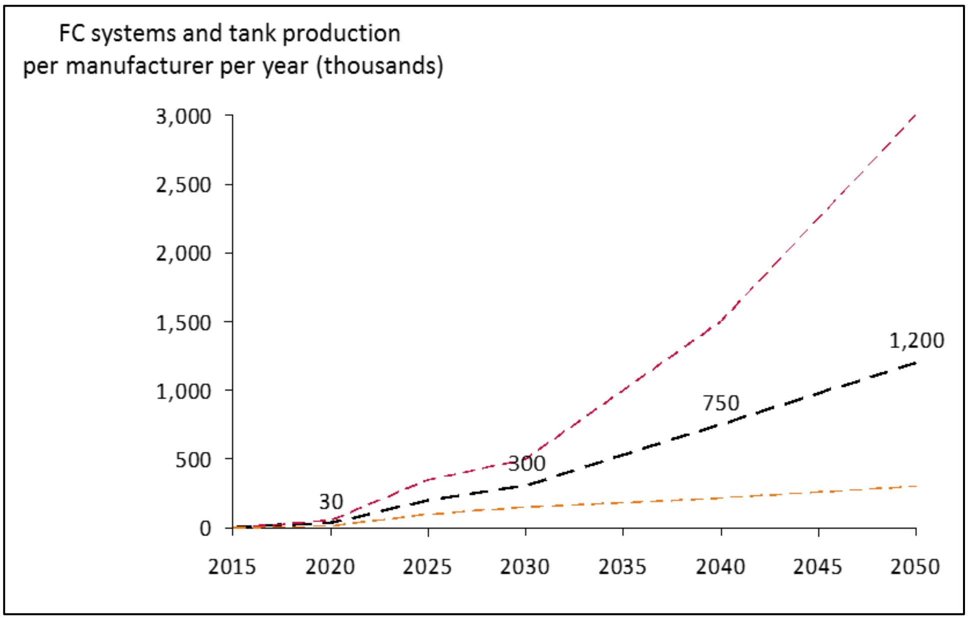
[16] FCH JU (2010): A Portfolio of Powertrains for Europe: A Fact-based Analysis

Figure 3.4 Hydrogen tank cost projections for full power fuel cell electric passenger cars



Low and high estimates of fuel cell and hydrogen tank trends (from the TINA) are also provided for use in sensitivity analysis, reflecting higher and lower sales volume assumptions from system manufacturers as shown in Figure 3.5.

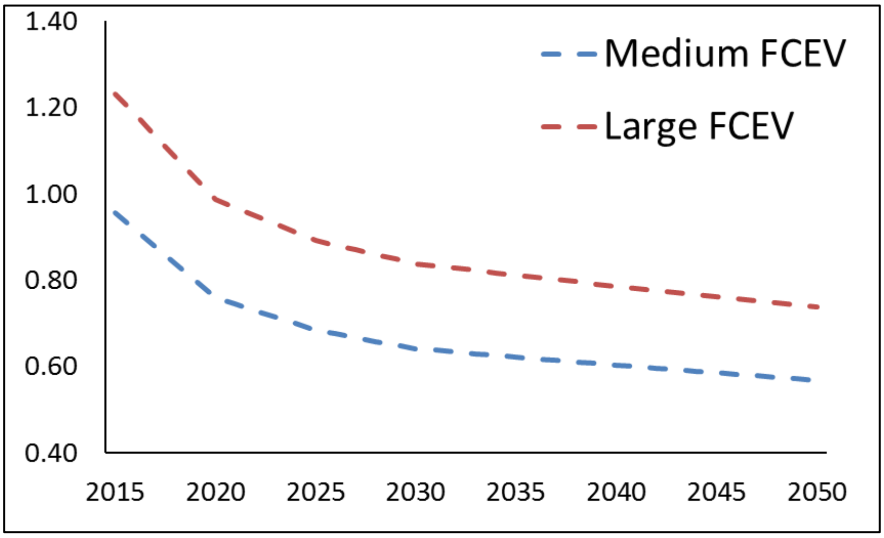
Figure 3.5 Assumed growth in global automotive fuel cell systems (units per manufacturer per year)



Hydrogen fuel consumption

Fuel consumption assumptions were developed from the stated New European Drive Cycle (NEDC) range and hydrogen tank size of current generation FCEVs (for example the Hyundai IX-35). This gives a current fuel consumption of c.1.1 kg/100km for a large car, and 0.85 kg/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 European Powertrains Study, and are equivalent to a 10% reduction per decade. The effect of non-fuel cell improvements (e.g. due to light-weighting or improved aerodynamics) is aligned with the assumptions for all other powertrains in this study.

Figure 3.6 Fuel consumption assumptions for medium and large FCEVs (kg/100km)

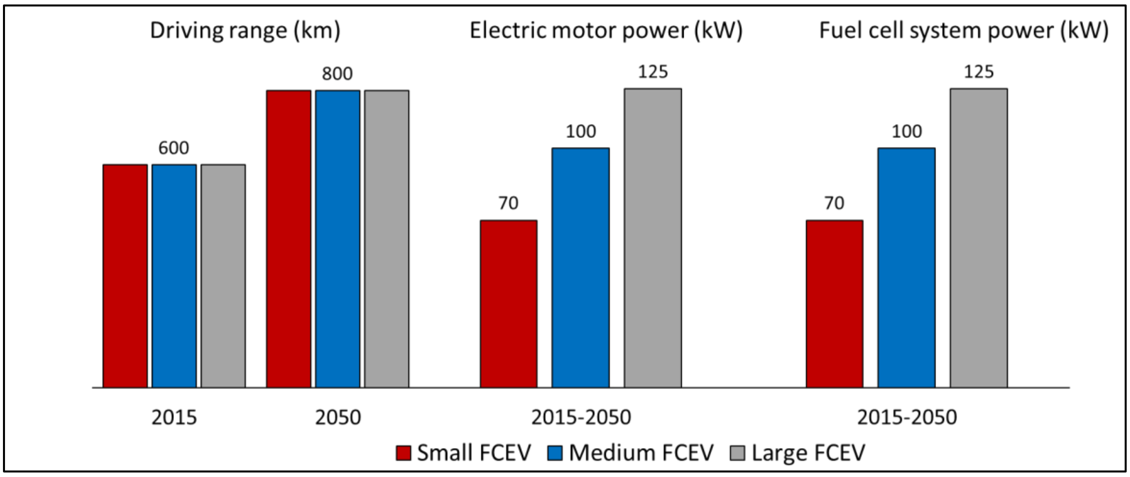


Driving range and system power outputs

The FCEV driving range between refuelling events is currently around 600 km which is significantly higher than current generation electric vehicles. Range assumptions and the assumed motor and fuel cell powers are shown below in Figure 3.7. 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. A similar trade-off exists for range-extended fuel cell vans, where the relative sizes of the battery and fuel cell stack can be optimised, based on the future rates of cost reduction in each technology.

As a simplifying assumption, motor/fuel cell powers are assumed to remain constant throughout the study timeframe. This is consistent with manufacturers favouring cost reduction to improve total cost of ownership relative to conventional vehicles, rather than 'spending' technology improvements on better performance. Fuel tank sizes are assumed to remain constant and therefore any fuel efficiency improvements result in an increased driving range. This increase in range is similar to a recent Hyundai prototype (800 km range), and also reflects the need to provide similar operating range to diesel cars and maintain an operational advantage compared with battery electric vehicles for long range duty cycles.

Figure 3.7 Modelling assumptions for hydrogen vehicle range and power outputs of drive motors and fuel cell systems



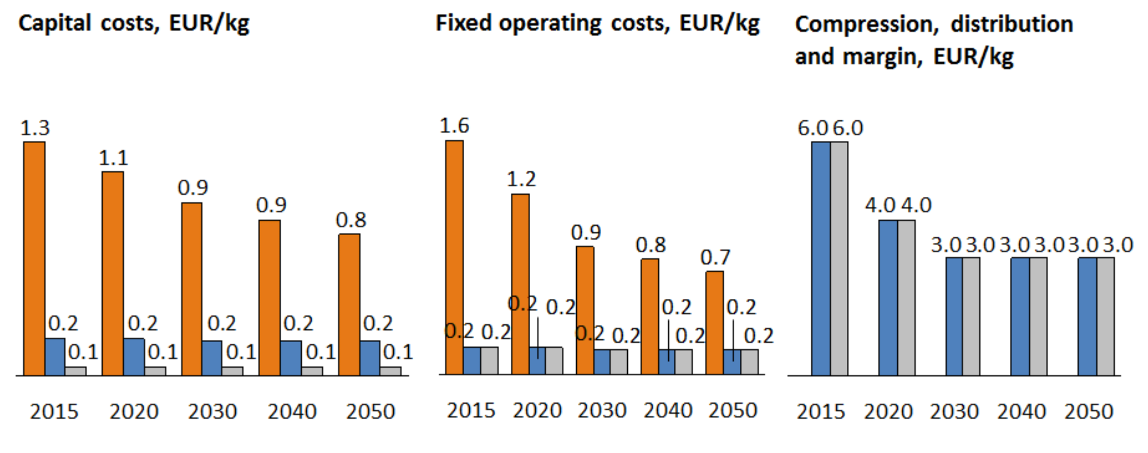
Hydrogen production

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 or economically 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 capital and fixed operating costs per kg of hydrogen produced are shown in Figure 3.8. 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-product are specific to each supplier, the number of stations served and the geographical distribution of refuelling stations. Values for compression costs, distribution and margin are consistent with observed prices in funded demonstration projects (which also show significantly higher and lower costs) and were agreed by industry participants for the French *En Route Pour un Transport Durable*[17] study.

[17] En Route Pour un Transport Durable, European Climate Foundation, 2016

Figure 3.8 Capital costs, fixed operating costs and compression, distribution and margin costs in EUR/kg

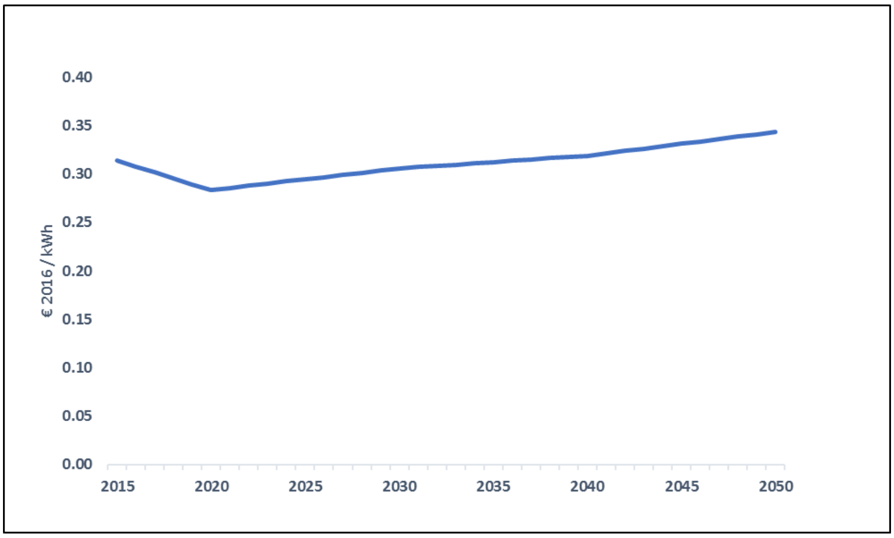


Notes:

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 electrolyser stack to be replaced once during the operating lifetime

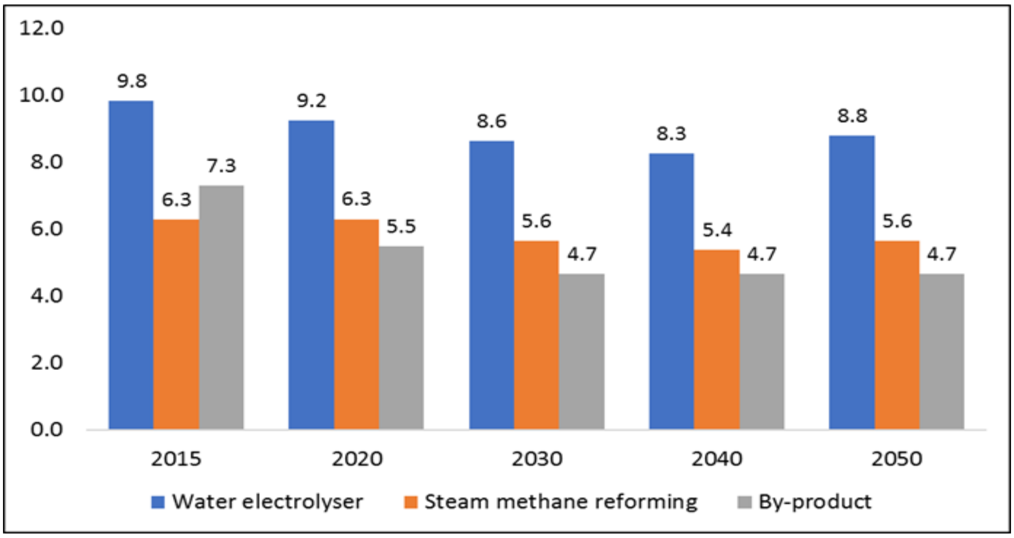
We include Spain-specific electricity and natural gas prices as inputs. Specifically, we assume that, to pay for the electricity used in the water electrolysis process, hydrogen producers are charged a price corresponding to the band ID (consumption between 2,000 MWh / year and 20,000 MWh / year) industrial price series from Eurostat. For natural gas, we rely on the band I3 (consumption between 10,000 GJ / year and 100,000 GJ / year) industrial price series.

Figure 3.9 Projected hydrogen price in Spain



The total production costs from each production route are shown in Figure 3.10. These costs include the feedstock costs assumptions for gas (€46/MWh in 2020 rising to €62/MWh by 2050) and electricity (€186/MWh in 2020 rising to €251/MWh in 2050). 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 or the provision of grid services. In some Member States such as France, electrolyser operators are able to access electricity prices of c. €65/MWh, which is sufficiently low to be competitive with hydrogen from SMR (once delivery costs for the latter are taken into account). The water electrolyser costs in Figure 3.10 does not include any revenue from the provision of balancing services to the electricity grid.

Figure 3.10 Total costs - production, compression and distribution included, € / kg

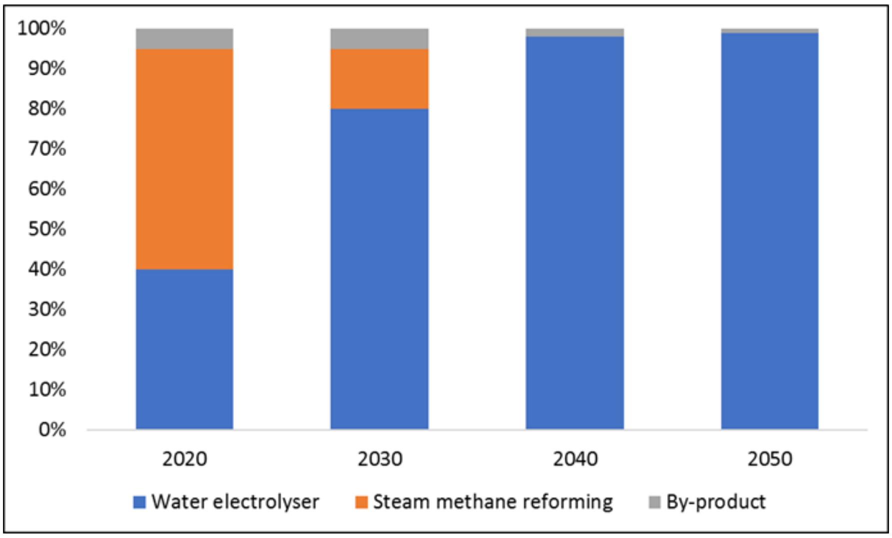


The hydrogen production mix in any given hydrogen market will be influenced by relative costs of each production source, customer demand (in terms of the carbon footprint of the hydrogen) and policies such as incentives for green hydrogen. The production mix already varies significantly between leading hydrogen markets in Europe. For example, most, if not all, of the first 100 stations deployed by H2 Mobility Germany will use hydrogen from steam methane reforming or industrial by-product hydrogen delivered by truck. In contrast, most of the recent stations deployed in the UK under the EU-Financed HyFIVE and H2ME projects are supplied by on-site water electrolysers. This is due in part to electrolysis specialists making significant investments in the UK (as they are in Scandinavia), but also due to the relative ease of guaranteeing hydrogen purity from electrolysers compared with SMR routes.

The production mix used to calculate the CO_2 footprint of hydrogen is shown in Figure 3.11, and shows a dominance of SMR-derived hydrogen in 2020. It should be noted that if the electrolyser market develops quickly, both in terms of technology cost reductions and the ability to provide grid services and take advantage of otherwise-curtailed renewable energy, green hydrogen could become the dominant production method during the 2020s.

We have used the production mix from the Italian National Plan on Hydrogen Mobility (MH2IT) as a proxy for the production mix in Spain, according to which the fraction of hydrogen from water electrolyses increases substantially over time, with an increasingly large proportion of the electricity used coming from renewable sources. This is driven by the necessity to decarbonise hydrogen production and deliver well to wheel emissions competitive with electric vehicles. The remaining part of the mix is dominated by steam methane reforming.

Figure 3.11 Assumed hydrogen production mix



3.6 Power sector assumptions

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

- it determines the net environmental impact of electrification of the vehicle fleet
- it determines the price of electricity that EV owners will be charged, which has implications for the Total Cost of Ownership (TCO) for an EV relative to a conventional ICE
- it could affect net electricity system costs negatively (distribution costs and additional power requirements) or positively (through synergies between EV and the power grid)

Our power sector projections are based on projections provided by the Spanish utility Iberdrola, in particular for:

- the future power generation mix / RES and fossil plant capacities
- future average EV charging rates paid by EV owners (retail price)

4 Infrastructure requirements

This section describes the definition, costs, deployment of electric charging posts and deployment of hydrogen refuelling stations. It also provides a breakdown of our calculation for total infrastructure requirements.

4.1 EV infrastructure

Definition and costs for EV charging points

Building on the definitions implemented in the previous Fuelling Europe's Future study, we adopt the definitions and costs for charging points as presented in this section. These definitions and costs were updated with inputs from several industry stakeholders part of the Steering Committee as well as recent publications (e.g. the EC Transport infrastructure development report).

Table 4.1 represents the range of available charge points to end users and illustrates the characteristics and costs of charging posts. Within each 'archetype' there is significant variation in price and features.

Table 4.1 Charging post definitions and costs

Main application	Charging point features	Power (kW)	Charge time - 25kWh battery (approx.)	Cost (€ Thousands)	
				Production 2017 (2030[c])	**Installation**
Residential - individual	Wall box (+ inductive pad in future) One socket User protection during charging Options for metering	3 kW /7kW	4-8 hours	0.6 (0.35)	0.4
Residential - collective	Wall box One socket Choice of access control systems	3 kW /7kW	4-8 hours	0.8 (0.45)	0.4
Workplace	Ground mounted Two sockets Choice of access control systems	7 kW	4-8 hours	0.8 (0.45)	0.4
Parking (on-street and shopping centres)	Ground mounted One socket High resilience Different access options	11 kW or 22 kW	2.5 hour (1 hour for 22 kW)	2.5 (1.4)	5
Rapid chargers on motorways site	Rapid charging Three connector types[a] High resilience	50 kW DC Likely to shift to 150kW by 2020 (and higher kW later)	30 minutes (50kW CP, 25kWh battery and 80% charge)	30 (22)	104.4[b]

a – only one car charging at the time (or several, at reduced kW)
b – includes grid connection, civils and greenfield site preparations costs, detailed later
c – Based on TECH uptake scenario

Residential charging posts

For the **residential sector**, the standard option is a wall box with a Type 2 connector and a charging rage of 3.7 kW (16 amp single phase) or 7.4 kW (32 amp), though some industry stakeholders believe the latter will make up the majority of residential wall boxes in the future. This solution is often offered through OEM dealerships either with an OEM-branded charging point or through a partnership with an independent provider. For example, BMW offers the Wallbox Pure (3.7 kW) and Wallbox Pro (7.4 kW) solutions for the i3. In some instances, consumers will choose not to install a wall box and simply charge their EVs from a standard socket to avoid paying capacity charges (this is the case in France).

For residential sites with no access to a private driveway or garage, solutions are similar to a private domestic charge point with the addition of options for metering electricity and controlling access to authorised users. In the workplace, we consider that double socket ground-mounted charging posts will prevail in the short term, but these could be replaced in the market by (double or single socket) 11 kW accelerated recharging posts in the medium term.

Public charging posts

For **public stations** in public places such as on-street parking spaces, dedicated car parks and retail car parks, a rate of 11kW or 22kW is assumed. This reflects the transition to 11kW on-board chargers observed among car OEMs. A 22kW rate is not relevant to many cars today because few EV models are compatible with this rate but this could increase, with the development of on-board chargers that can handle 3 to 43kW AC, such as those developed by Continental[18]. The installation rate of 22kW charging posts has been quite high in some countries, including France, Ireland and the UK. As the difference between 11kW and 22kW posts is not significant in terms of cost (both are based on a 3-phase connection, one at 16Amp, one at 32Amp), the distinction is not made in the model. An alternative to the 11kW or 22kW posts is the provision of double headed 7kW posts. The choice of power rate will depend on parameters such as parking time (the longer the customers typically spend in a retail, the lower the kW can be while still able to provide valuable range) and connection costs.

Rapid charging sites

For **stations on motorways**, a multi-standard AC/DC rapid recharging unit is proposed allowing for an 80% recharge in 20-30 minutes for a BEV with a c25kWh pack[19]. Future rapid charging power is likely to increase, given the agreement on a 150kW Combined Charging System standard in late 2015 and the announcement of the CHAdeMO standard revision from 50kW to 150kW in March 2017[20]. Higher power rates are necessary to maintain acceptable charging times for vehicles with large batteries (above 50kWh), expected in 2nd generation BEVs (e.g. the Tesla Supercharger is 145kW (although limited

[18] https://www.continental-corporation.com/en/press/press-releases/allcharge-technology-from-continental-makes-evs-fit-for-any-type-of-charging-station-63864

[19] The 43kW AC Type 2 outlet is not considered here, as no cars on the market, beyond the 1st gen Renault Zoe, can use it. The most likely users of 43kW outlets are small electric trucks used for urban deliveries (which are typically fitted with two 22kW on-board chargers).

[20] Whereas the standard maximum current for DC CHAdeMO had previously been limited to 125 Amp, the revised standard increases maximum current to 400 Amp, enabling an increase in charging output from 50kW to 150kW. https://www.chademo.com/wp2016/wp-content/uploads/2017/03/press0330en.pdf

to 120kW in operation). The Chargin initiative is aiming at developing and establishing the Combined Charging System (CCS) as the standard for charging battery-powered electric vehicles of all kinds[21]. It envisages using CCS for rates up to 350kW ('ultra-fast'). Chargin was launched in 2016 by BMW, Audi, VW, Porsche, Daimler, Ford, Mennekes, GM, Phoenix contact and TUV but has since grown to over 140 members (as of June 2017). A group of car OEMs, part of Chargin, announced in late 2016 their intention to form a Joint Venture and install 400 ultra-fast charging sites[22]. The first 350 kW station was unveiled by Porsche in July 2017 in Germany[23].

As the production volumes of charge points increase, production costs decrease due to advancements in manufacturing techniques and economies of scale. To model this we apply a learning rate to the product cost whereby the cost decreases by 10% for every doubling of annual production. The actual cost is therefore dependent on the uptake scenario modelled. This same learning rate has not been applied to the installation costs as they include fixed costs which will not be reduced with increased production.

The cost of preparing these sites will depend on the number of charging posts installed, the location and existing facilities of the site, and most significantly, the level of grid reinforcement needed to cope with the increased local electricity demand.

During the initial uptake of EVs the additional demand on the grid will be relatively low. The assumption is that in the short term, charging stations of a few 50 kW chargers will be installed with overall no major network upgrades needed (according to discussions with rapid charging networks). From 2020, as the uptake of EVs accelerates, the number of chargers at each site will increase and include 150 kW (and eventually 350 kW) posts, requiring upgrades to the local network.

The costs of developing a greenfield site with no pre-existing infrastructure will differ from developing a brownfield site which is located within a conventional fuel filling station. Although it is likely that 50 kW power may not be available in either case, the cost of developing a green field site will be significantly higher than a brownfield site, where the basic infrastructure already exists.

Table 4.2 also presents the site preparation costs that were assumed in the study 'Fuelling Europe's Future' and 'Fuelling Spain's Future', based on a recent study conducted for the European Commission[24]. Besides considering a different cost structure between recharging sites, we rely on a ratio between brownfield and greenfield sites of 6:1, therefore assuming that most of the rapid charging stations will benefit from pre-existing refuelling infrastructure. This ratio is taken from the analysis in Clean Power for Transport

[21] www.charinev.org

[22] http://media.daimler.com/marsMediaSite/en/instance/ko/BMW-Group-Daimler-AG-Ford-Motor-Company-and-Volkswagen-Group.xhtml?oid=14866747

[23] https://newsroom.porsche.com/de/unternehmen/porsche-zentrum-berlin-adlershof-schnellladepark-solarpylon-13955.html

[24] Clean power for Transport Infrastructure Deployment, Directorate-General for Mobility and Transport, European Commission, 2017

Infrastructure Deployment which calculates the charge points required to reach full mobility on the nine TEN-T corridors.

Sites that currently exist are assumed to be small sites (fewer than five charging posts), that will need to be upgraded to accommodate the demand for additional charge points. The upgrade costs are set to the 'mature state' brownfield costs and this upgrade cost occurs again for every ten additional charge points installed at a site

Table 4.2 Rapid charging sites preparation cost (per site). Source: SDG for the EC, Clean Power for Transport Infrastructure Deployment, 2017

	Item	Initial stage (2 chargers)	Mature stage (8 or more chargers)
Brownfield site	Grid connection	€ 10,000	€ 345,000
	Civils	€ 64,000	€ 82,000
Greenfield site	Access roads	€ 50,000	€ 50,000
	Site works	€ 100,000	€ 100,000
	Professional fees	€ 33,000	€ 33,000
	Grid connection	€ 5,000	€ 340,000
	Civils	€ 64,000	€ 82,000
Brownfield site	TOTAL	€ 74,000	€ 427,000
Greenfield site	TOTAL	€ 252,000	€ 605,000

Deployment of EV charging points

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 for every ten EVs on the road. Table 4.3 presents the deployment densities used in this study.

Table 4.3 Deployment of EV charging posts

		2020	2030	2040	2050
Charging posts per EV	**Residential**	0.8	0.8	0.8	0.8
	Workplace	0.2	0.2	0.2	0.2
	Parking	0.2	0.2	0.2	0.2
BEVs per rapid charging points		500	500	500	500

In this study, we assume that the number of rapid charge points is in proportion to the number of BEVs in the parc, with a ratio of 500 BEVs per charging point. This number is subject to significant uncertainty. There is also debate about whether rapid chargers will be used exclusively for long journeys, or whether they will provide a substantial fraction of a vehicle's annual energy demand during local trips, and even allowing people without access to dedicated home charging spaces to own an EV.

Changing the power of rapid chargers to 150kW may not have a large impact on the number of vehicles that can be supported by each charging point, because existing BEVs will not support the higher power and new vehicles are likely to have significantly larger batteries (e.g. 60kWh plus) that offsets any potential reduction in charging time. For this reason, the model does not differentiate 50kW and 150kW posts.

However, moving beyond this, higher powers of 350kW are likely to significantly decrease charging times as battery pack sizes are unlikely to continue to grow rapidly beyond 60kWh (or 80kW-100kW in larger vehicles). This means that 350kW chargers could potentially support larger numbers of vehicles, and hence fewer of them are required for a given EV parc, but the reduced number of sites is likely to be offset by the increased cost of the chargers and related grid connection costs.

Finally, a shift towards larger batteries and longer driving ranges between charges will make BEVs viable for longer range duty cycles, but could reduce proportion of annual energy use supplied by rapid chargers if the ranges were sufficient to allow long trips to be completed with charging before and after the journey. This trend is likely to be stronger if the prices of delivered energy from rapid chargers are higher than domestic or destination charging. The combination of very high-power charging in future and relatively high range BEVs mean that the estimated infrastructure numbers are likely to over-estimate rather than under-estimate the numbers needed to support a given fleet of BEVs.

The total number of residential, workplace and public slow charging posts required each year is calculated by multiplying the total number of EVs (PHEVs +BEVs) in the stock by the density assumptions outlined in Table 2. For rapid charging infrastructure, we assume deployment grows in line with the BEV fleet. The number of charging points (plugs) is then calculated based on our assumptions about the number of plugs on each post (see Table 1).

From the total infrastructure requirements, we calculate the net additional charging posts installed each year and add to this replacement of charging posts that are retiring from the stock. Note that all charging posts are assumed to have an active service life of 20 years, and to retire immediately once this age is reached.

To illustrate the resulting deployment levels, Table 4.4 combines the (B)EV per charging points assumptions with the EV stock for the TECH scenario.

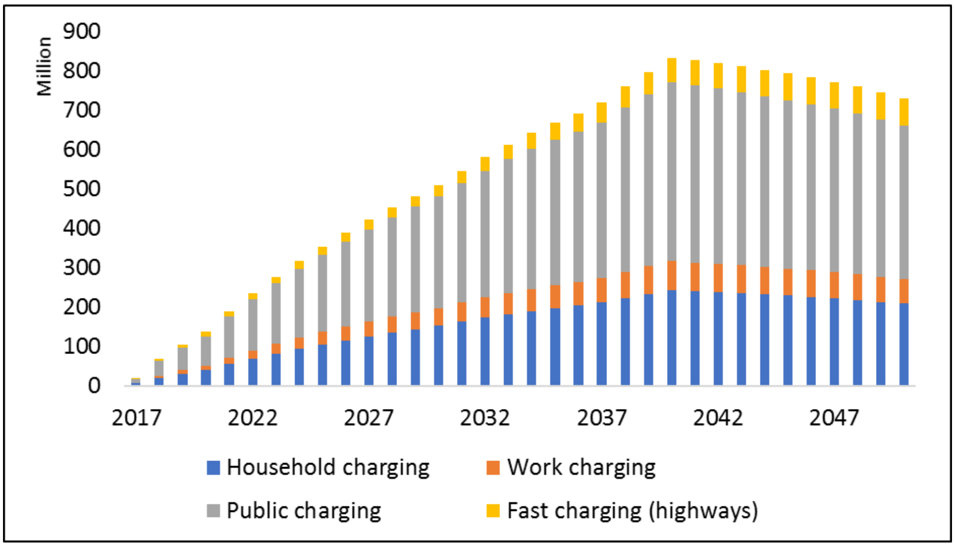
Table 4.4 Number of deployed charging points in the TECH scenario (for Spain)

Charging posts deployed (thousands of units)	2020	2030	2040	2050
Residential (1 plug)	140	2,574	8,158	12,977
Workplace (2 plugs)	35	644	2,039	3,244
Public (2 plugs)	35	644	2,039	3,244
Rapid charging posts (3 plugs)	0.3	3.6	12.3	24.1

Financing of EV charging point deployment

The additional charging requirements in each year are multiplied by the cost per post in that year. To project changes in charging infrastructure costs out to 2050, we apply a 10% learning rate per doubling of cumulative charging capacity, meaning that as the total capacity of installed chargers doubles, the cost of additional chargers comes down by 10%.

Figure 4.1 Total annual investment requirements to support the EV fleet in the TECH scenario



We assume that all private infrastructure spending (household and work charging points) are paid for upfront by the consumer when the vehicle is purchased. This is either explicit (e.g. consumers paying for chargers installed on their private property) or implicit (OEMs installing chargers as part of vehicle purchase and adding an appropriate premium to the purchase price of the vehicle to cover this cost). Investment in public infrastructure and rapid charging points is assumed to be paid for by owners of shopping centres, car parks and motorway service stations. We assume that these costs are fully passed on to customers: the cost of infrastructure in shopping centres and motorway services is ultimately paid for by an increase in prices for consumers in wholesale and retail markets.

Whilst recent studies suggest that there is no viable business case for site owners or private businesses to install chargers without public subsidies, this simplifying assumption is applied in the macroeconomic modelling, and does not have a large bearing on the economic results. If we had instead assumed that the public charging posts are publicly financed, then to balance the government budget in the scenario, tax rates would have to be raised elsewhere, and the cost would still ultimately be borne by businesses and consumers.

4.2 Hydrogen infrastructure

Refuelling station costs

Fuel cell vehicles are refuelled by hydrogen refuelling stations, dispensing high pressure gaseous hydrogen into the vehicles' on-board storage tanks. 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, varies according to the station supplier and the intended use.

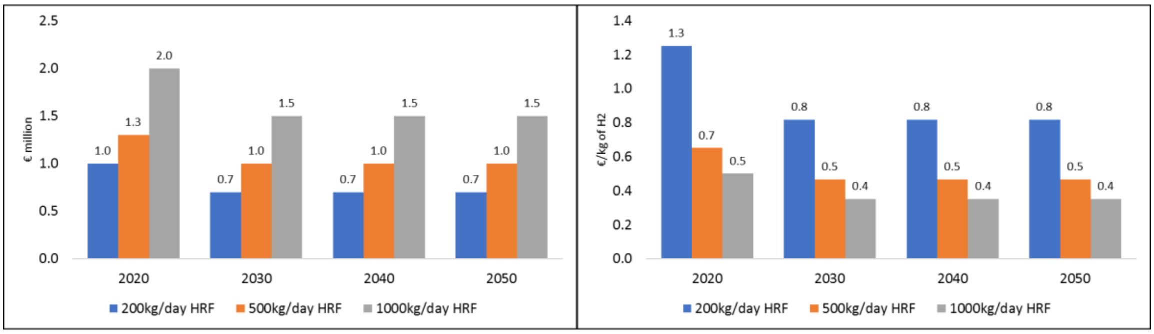
HRS costs in this study are based on three different station sizes (200, 500 and 1000 kg per day), dispensing 700 bar hydrogen and meeting the performance specifications set out in the SAE J2601 international standard. Cost assumptions are drawn from the various H_2 Mobility studies around Europe, the UK TINA, and quotations received directly from equipment suppliers. Current and projected installed costs are shown in Figure 4.2, 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[25]. 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 of suppliers. By 2030, capital costs represent a relatively small proportion of the expected hydrogen selling price (€7-10/kg), particularly for the larger station sizes. Hence, possible breakthroughs in HRS design that lead 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.

Costs shown in this document were validated by the stakeholders in 'En route pour un transport durable'. These numbers are broadly in line with recent funded deployments in lead markets such as Germany, the UK and Scandinavia, although we are aware of several HRS suppliers aiming to deliver significantly lower cost stations through modular designs and joint procurement mechanisms to allow investments in high volume manufacturing capacity.

Figure 4.2 Capital costs of HRF – installed costs (left) and capital costs per kg dispensed (right). Assumptions: 70% utilisation up to 2020, 75% afterwards, 7% cost of capital, 20-year operating lifetime

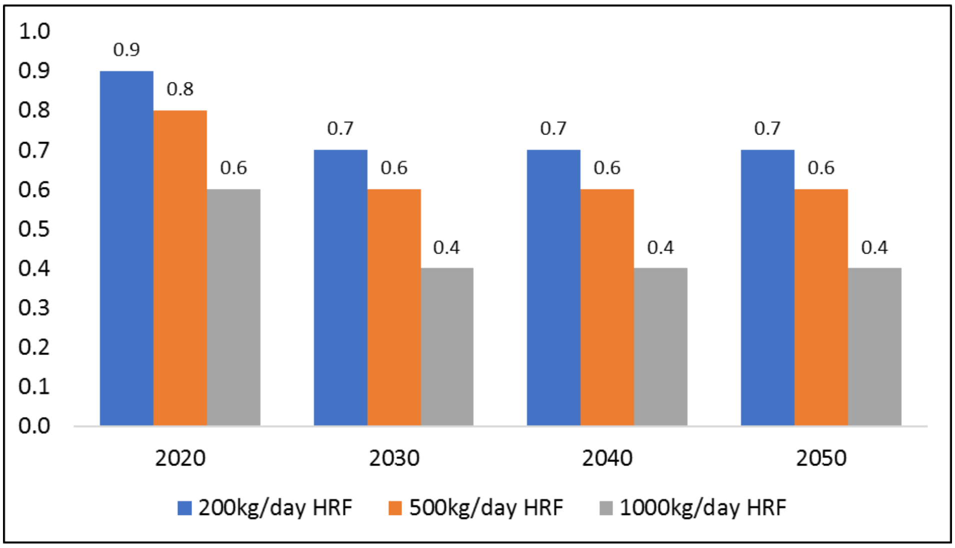


Operating costs for HRS are shown in Figure 4.3. Like capital costs, significant cost reductions are expected in future, due to more efficient supply chains, use of local labour for maintenance rather than engineering teams from the equipment supplier, and increased component lifetimes. Again, costs beyond 2020 are a relatively small proportion of the overall hydrogen cost structure, which is dominated by the cost of the hydrogen itself. This is similar to the

[25] An HRS with an on-site electrolyser producing hydrogen at 10-30 bar will require additional compression relative to a station receiving trucked-in and storing hydrogen at 200 bar. However, since some delivered hydrogen stations also use large volume, low pressure storage, we have not explicitly included an additional compression cost for electrolyser stations only

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 4.3 Fixed operating costs of hydrogen refuelling stations, EUR/kg



Deployment of hydrogen infrastructure

The future rate of deployment of HRS in lead European markets for hydrogen is strongly linked to the roll-out of FCEVs, particularly the step change in sales driven by lower cost, second generation vehicles beyond 2020.

For example, in the case of Germany, deployments beyond the first 100 stations will be explicitly tied to the number of vehicles on the road. In other markets, station deployments are based on current announcements by station investors and operators[26], and then linked to the actual number of hydrogen vehicles deployed. It should be noted since the national H2 Mobility strategies were published, the expected deployment volumes of fuel cell passenger cars have decreased. This is due to the decisions by car makers to produce limited volumes of first generation vehicles, before a significant ramp-up of next generation vehicles after 2020. For example, Toyota has stated that the second-generation fuel cell vehicle will be produced in volumes of 30,000 per year globally, with a further step change in production for a third-generation product in 2025[27].

In this study, the number of stations in Spain (and implied capital and operating costs) is directly linked to the projected uptake of fuel cell vehicles across scenarios and to the expected volume of vehicles that can be supported per refuelling station. The number of fuel cell vehicles in the TECH scenario is projected to increase to more than 130,000 in 2030. However, a more decisive deployment will start only after 2030 with the number of FCEVs increasing to 1.5 million in 2040 and about 4 million in 2050.

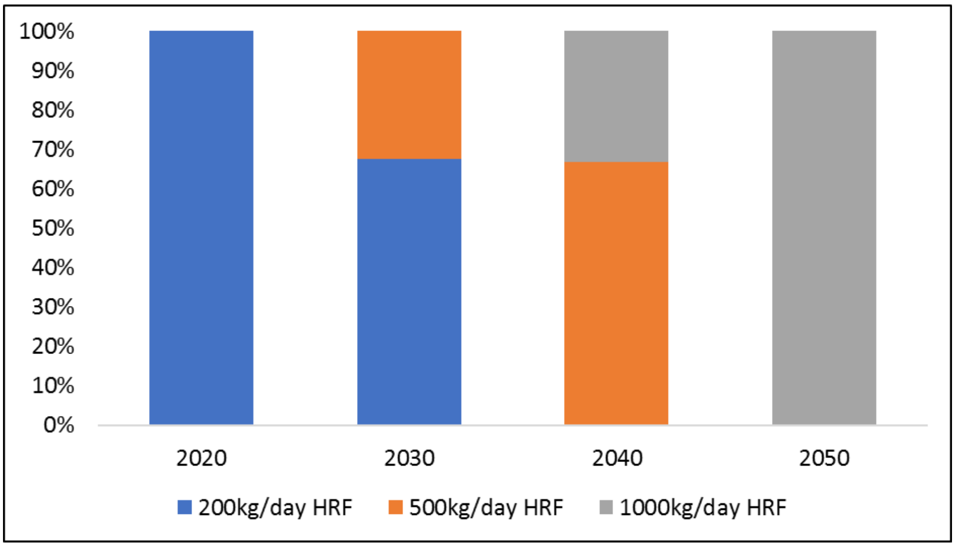
To model the uptake of larger stations as FCEVs market share grows, we assumed a gradual increase in 500 kg/day and 1000 kg/day stations through time where 500 kg/day stations become the dominant size in 2035.

[26] Based on the published strategies of the UK, German and French H_2 Mobility coalitions (EAS-HyMob & H2ME) and the Scandinavian Hydrogen Partnership

[27] http://www.reuters.com/article/us-toyota-environment-idUSKCN0S80B720151014

Thereafter, installation of 1000 kg/day stations starts and they become the most deployed stations after 2040. This is shown graphically in Figure 4.4.

Figure 4.4 Proportion of newly installed HRS stations by capacity



Besides defining the relative roll-out of each type of HRS, we estimated the total number of HRS that can support the fleet of hydrogen vehicles consistently with the density assumptions used in ‘Fuelling Europe’s Future’. Specifically, we assumed a ratio of 400 FCEVs per 200 kg / day HRS in 2020 increasing to 480 in 2030, and a ratio of FCEVs for each HRS with larger capacity of, respectively, 1,000 and 2,000 vehicles per 500 kg / day and 1000 kg / day HRS (see Table 4.5). Using the same logic as above, 500 kg/day and 1000 kg/day stations can support roughly 1,000 and 2,000 cars respectively.

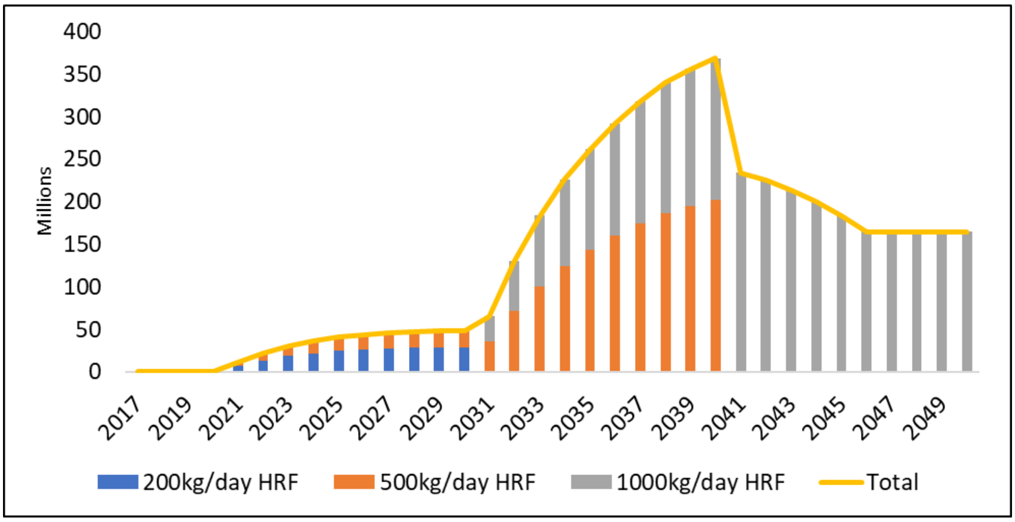
Table 4.5 Number of hydrogen refuelling stations in the TECH uptake scenario and the associated volume of FCEVs that can be supported per station

	2020	2025	2030	2030-2050
Number of HRS* 200kg/day 500kg/day	 - -	 96 46	 283 136	In relation to number of FCEVs in stock
Max number of FCEVs per HRS	400	400	480	1000 (500kg/day) 2000 (1000kg/day)

Financing refuelling station deployment

The number of additional hydrogen refuelling stations in each year – in line with the projected deployment of 200kg/day, 500kg/day and 1000kg/day HRF - are multiplied by the projected capital costs per station (see Figure 4.2) in each year to derive the annual investment requirements needed to support the FCEV fleet in the TECH scenario. This is shown in Figure 4.5.

Figure 4.5: Total annual investment requirements to support the FCEV fleet in the TECH scenario



As with public and rapid charging infrastructure, we assume that the costs of hydrogen infrastructure are fully passed on to customers: the cost of infrastructure in shopping centres and motorway services is ultimately paid for by an increase in prices for consumers in wholesale and retail markets. However, the number of stations deployed by 2020 and 2030 has minimal effect on the macro-economic modelling given the small numbers in relation to the overall car stock.

5 Consumers' Perspective

In this consumer perspective analysis, we outline what the different scenarios will mean for the consumer, or more specifically, for car owners. This is to see whether the costs assumptions that we have made in the vehicle stock model make sense, not just from a methodological point of view, but also from an economic perspective.

To that effect, a high-level assessment of the total cost of has been undertaken, although more detailed studies have been carried out, such as for example a study by Element Energy for the BEUC[28].

5.1 Terminology and assumptions

To calculate the total cost of ownership (TCO), we add up the larger different costs associated with owning cars. These include the costs of capital, finance, fuel, maintenance and infrastructure (for home-charging).

- Vehicle cost: the purchase price of a car (including VAT and excluding other taxes/subsidies) minus the sale price at the end of the TCO period
- Finance cost: the average cost of financing the capital cost
- Fuel cost: the cost of fuel/energy for the mileage driven over the TCO period
- Maintenance cost: the cost of maintaining and fixing the car
- Infrastructure cost: for plug-in electric cars we show the cost of household charging

Vehicle cost

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).

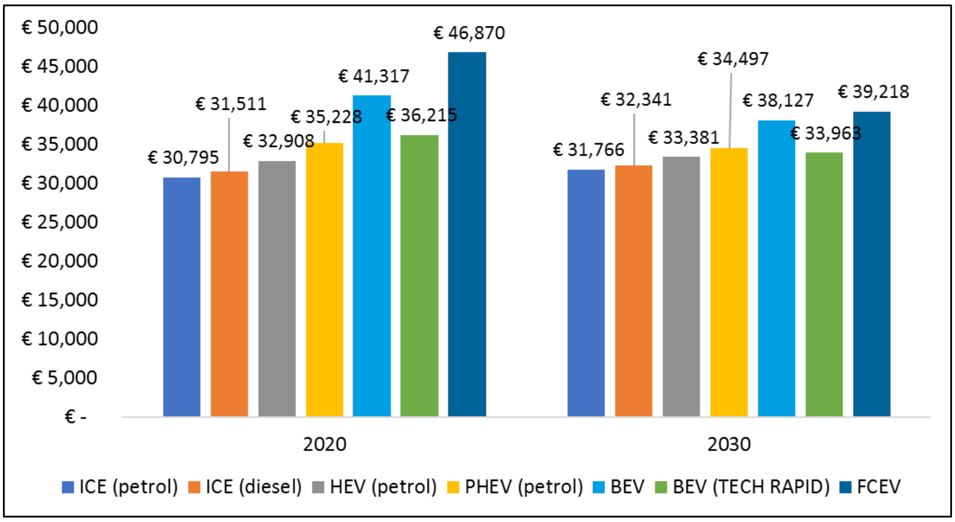
Margins, distribution costs and VAT are added to the vehicle production costs in order to derive the retail price. In 2030 it is assumed that, in monetary terms, the additional retail and distribution costs for ICEs, EVs, PHEVs and FCEVs are broadly equivalent.

VAT of 21% is charged on consumer sales of all vehicle types. As VAT is applied as a percentage of the final sale price, the VAT component for (more expensive) BEVs, PHEVs and FCEVs are higher than that for conventional petrol and diesel cars.

In Figure 5.1, we present the average capital cost of a new medium sized (segment C) vehicle by powertrain in the TECH and the TECH Rapid scenarios.

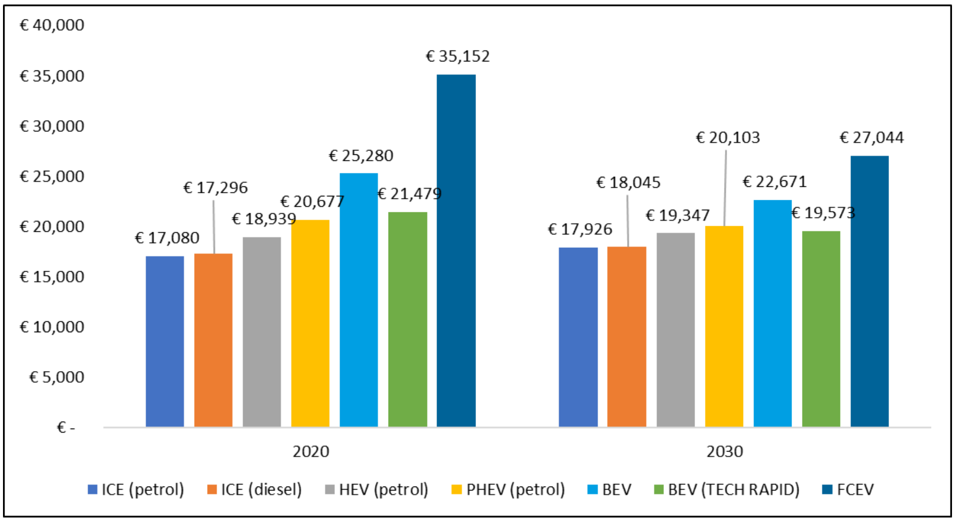
[28] http://www.beuc.eu/publications/beuc-x-2016-121_low_carbon_cars_in_the_2020s-report.pdf

Figure 5.1 Capital cost of a new medium sized vehicle by powertrain in the TECH and TECH Rapid scenarios



In Figure 5.2, we present the average capital cost of a new small vehicle (segment A + B) by powertrain in the TECH and the TECH Rapid scenarios.

Figure 5.2 Capital cost of a new small sized vehicle by powertrain in the TECH and TECH Rapid scenarios



When comparing total costs of ownership, we assume that car owners choose to lease the vehicles for a period of 4 years at a lease interest rate of 6.5%. However, when we model the capital expenditure in the vehicle stock we simply use the retail price of new vehicles.

The cost of technologies to reduce CO_2 from cars will reduce over time as scale economies are achieved, but the aggregate costs will increase as more technologies are added to reach tighter CO_2 limits. In 2020, battery-electric and fuel-cell electric vehicles are projected to be significantly more expensive than diesel and gasoline vehicles and their hybrid variants. But by 2030, the difference in price will be narrowed, as the cost of diesel and petrol cars increase to meet environmental goals and as zero-emissions cars get cheaper as they start being manufactured at scale.

Fuel cost

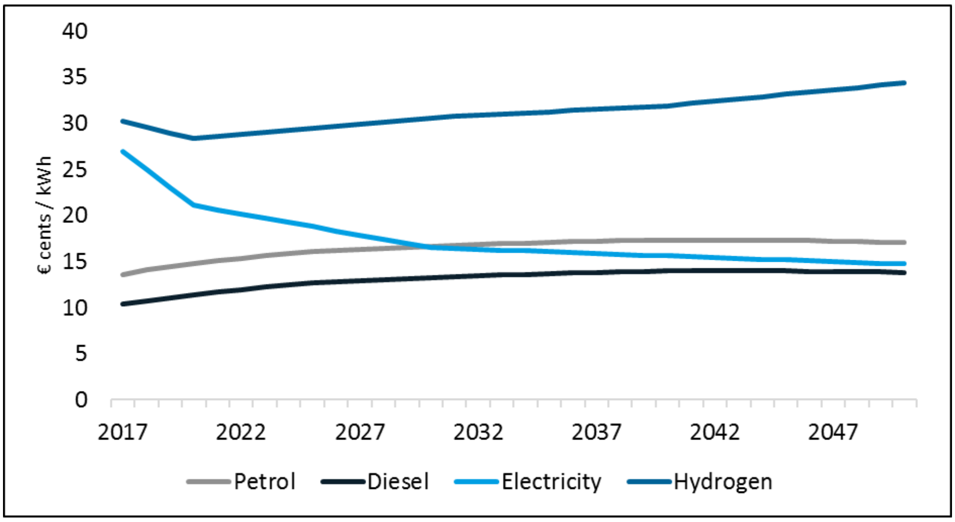
One feature of the TECH scenario is a substantial improvement to the efficiency of conventional ICEs, leading to fuel bill savings for owners of petrol and diesel cars. In addition, the transition towards an increase in the share of PHEVs, BEVs and FCEVs has implications for fuel bills in the TECH scenario 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 fuel cost for ICEs is calculated from historical fuel prices published by the European Commission in its Weekly Oil Bulletin and are in line with the prices data published by the Ministerio de Energía, Turismo y Agenda Digital of Spain. The oil price projections used for this analysis are taken from IEA's November 2017 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.

As PHEVs, EVs and FCEVs become more prevalent in the vehicle mix, assumptions about the price of electricity becomes more important. Future electricity prices for EV charging were taken from price projections developed by the Spanish utility Iberdrola for this study.

For the hydrogen prices and for the costs associated with a fuel cell electric vehicle (FCEV), we relied on data from the UK TINA report from the Carbon Trust and from a study on the development of water electrolysis in the European Union produced by E4tech and Element Energy. We include Spain-specific electricity and natural gas prices as inputs for hydrogen. Specifically, we assume that, to pay for the electricity used in the water electrolysis process, hydrogen producers are charged a price corresponding to the band ID (consumption between 2,000 MWh / year and 20,000 MWh / year) industrial price series from Eurostat. For natural gas, we rely on the band I3 (consumption between 10,000 GJ / year and 100,000 GJ / year) industrial price series.[29]

Figure 5.3 Price projections for petrol, diesel, electricity and hydrogen (€ cents / kWh)



[29] For more details on hydrogen, see section 4.2 of this report.

In the TECH scenario, we see a reduction in annual fuel costs across all vehicles though improved fuel efficiency. Savings vary substantially for vehicles for different powertrain types.

Maintenance cost The maintenance cost represents the lifetime expenditure on parts and servicing specific to each powertrain, and is taken from a report published by McKinsey & Company. Annual maintenance costs do not vary substantially across years and vehicle types, ranging from a maximum of 380 € for a medium ICE diesel to a minimum of 247 € for a medium BEV in 2020. In the case of a small sized vehicle, annual maintenance costs are lower and range from 200 € for an ICE petrol to 154 € for a BEV in 2020.

Infrastructure cost The infrastructure cost is the total cost for the deployment of a residential charging point for an electric vehicle. Specifically, it is calculated as the sum of the production and installation costs for a standard residential charging point with a Type 2 connector and a charging range of 3.7 kW (16 amp single phase) or 7.4 kW (32 amp). As the production volumes of charge points increase, the production cost decreases due to advancements in manufacturing techniques and economies of scale. Conversely, infrastructure costs for hydrogen refuelling stations are already included in the price of hydrogen.

Financing cost Finally, for the financing cost, we assume a 6.5% average interest rate in our central scenario to repay the cost of capital. As it will be presented in the next sections, a sensitivity test is performed to assess how much this assumption influences the final results.

The following table summarises the key assumptions used in our central case calculation.

Table 5.1 Central case assumptions

Variable	Central assumption
Fuel costs	
petrol	IEA oil price plus taxes
diesel	IEA oil price plus taxes
electricity	c. 21c/kWh in 2020 / c. 17c/kWh in 2030
hydrogen	c. 28c/kWh in 2020 / c. 31c/kWh in 2030
Financing cost (interest rate)	6.5%
Maintenance costs	380 € to 247 € in 2020 373 € to 240 € in 2030
Infrastructure costs (for plug-in electric cars)	Production & installation for a residential wall box: 1,000 € in 2020 750 € in 2030

5.2 Total cost of ownership (TCO)

To evaluate the impact of the low carbon transition on consumers, it is also important to look at the total cost of owning a vehicle for the first owner, whose purchasing decision will determine whether the low-carbon technologies enter the vehicle fleet or not.

We therefore analyse the total cost of ownership over two different time periods. One is the total average lifetime of a passenger car in Spain, which is approximately 13 years, and the other one is the cost of ownership for the first 4 years of life of a new vehicle.

This requires that over the initial ownership period we consider not only the purchase price, but also the costs of fuelling the vehicle, the financing costs, the charger cost if it is an electric vehicle, and the amount for which it can be resold at the end of the ownership period.

We also embed different battery cost projections. In the TECH scenario we use conservative cost estimates[30] and for the TECH Rapid we use more optimistic battery cost assumptions[31]. These two cost projections were presented earlier in this report. The following Table illustrates the conservative average cost assumptions that were used for full electric vehicles ('Bottom-up case').

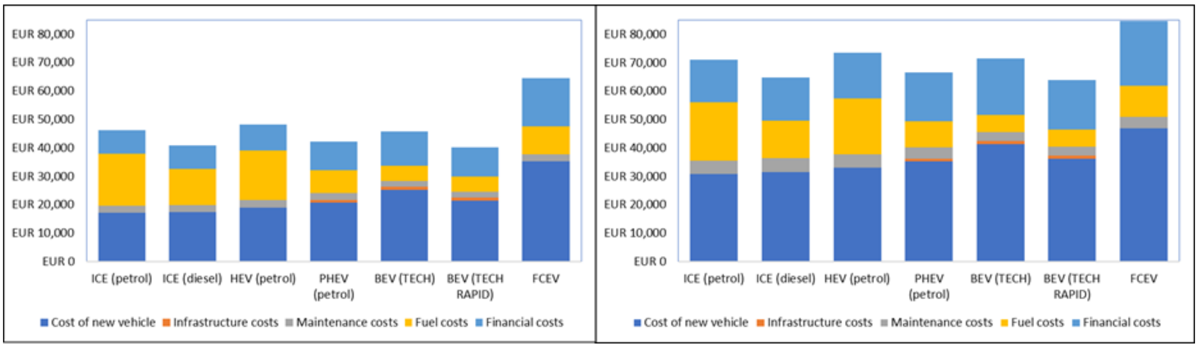
Table 5.2 Average announced costs for next generation battery electric vehicles.

Battery system costs (€/kWh)					
Powertrain	Market segment	2020	2030	2040	2050
BEV – Short	Small	279	194	143	106
BEV – Short	Medium	249	173	127	94
BEV – Short	Large	205	135	100	73
BEV – Long	Small	224	146	108	80
BEV – Long	Medium	224	146	108	80
BEV – Long	Large	205	135	100	73

Note: the values reflect the average range of new vehicles at state of charge (WLTP, not NEDC).

In this section, we present the results for the total cost of ownership analysis, for car segment A+B and for car segment C in the TECH scenario. We also compare these results with those for a BEV in the TECH Rapid scenario. The analysis covers two different time periods (4-year ownership versus full lifetime ownership) and results are presented for 2020 and 2030.

Figure 5.4 Lifetime TCO for all powertrains segment A+B (left) and C (right) in 2020



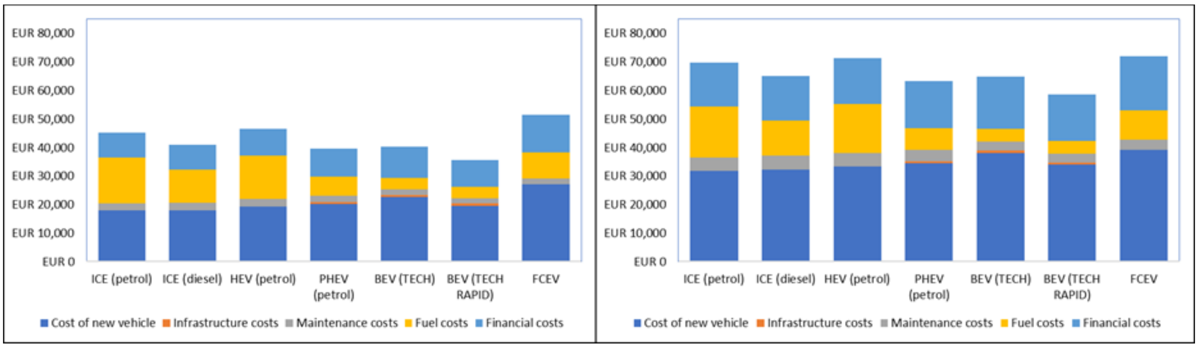
30 Based upon bottom-up estimates calculated by Element Energy for *Fuelling Europe's Future* (2018)
31 Based upon OEM projections of the development of battery costs, agreed as part of *Fuelling Europe's Future* (2018)

The total cost of ownership for a medium sized powertrain included in the model lies between about 64,000 € for a BEV in the TECH Rapid scenario and 84,500 € for a FCEV in 2020. Small vehicles have a lower total cost of ownership and, for the same powertrains, the lifetime costs range between 40,000 € to more than 64,000 €.

This TCO includes the different costs introduced in a previous slide: the dark blue area represents the average capital cost, which in this case is the average retail price of the new vehicle. The grey area represents the average maintenance costs over a car's lifetime. The orange area, very small here, represents the average infrastructure costs associated with battery charging. The yellow area represents the average fuel costs associated with each type of powertrain (and, in the case of FCEVs, includes the infrastructure costs associated with refuelling). The light blue area represents the financial cost of owning a car, meaning the interest paid on the borrowed capital costs over the period.

In 2020, the lifetime total cost of ownership for a medium BEV in the TECH scenario will be higher than that of an ICE of similar size. This is mainly because the capital cost for a BEV is considerably higher, due to high battery costs. However, in the TECH Rapid scenario, the total cost of ownership for a BEV is lower than that of petrol and diesel ICEs due to the more aggressive cost reductions assumed for batteries.

Figure 5.5 Lifetime TCO for all powertrains segment A+B (left) and C (right) in 2030.



In 2030, the lifetime total cost of ownership (compared with 2020) is lower for all powertrains with the exception of diesel ICEs. In the TECH scenario, reduced battery costs bring the total cost of ownership of a medium BEV down to a level close to that of medium diesel ICEs, while for smaller segments BEVs are even cheaper than both diesel and petrol ICEs. In the TECH Rapid scenario BEVs are always the cheapest type of car of all to own as a result of further battery cost reductions. Fuel cell technology costs have fallen substantially by 2030, but the TCO of FCEVs will still be the highest among all powertrains in 2030.

Figure 5.6 4-year TCO for all powertrains segment A+B (left) and C (right) in 2020.

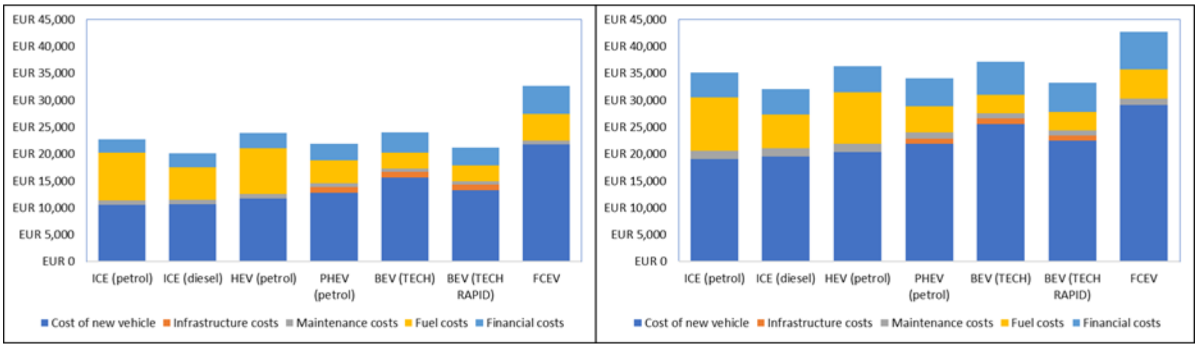
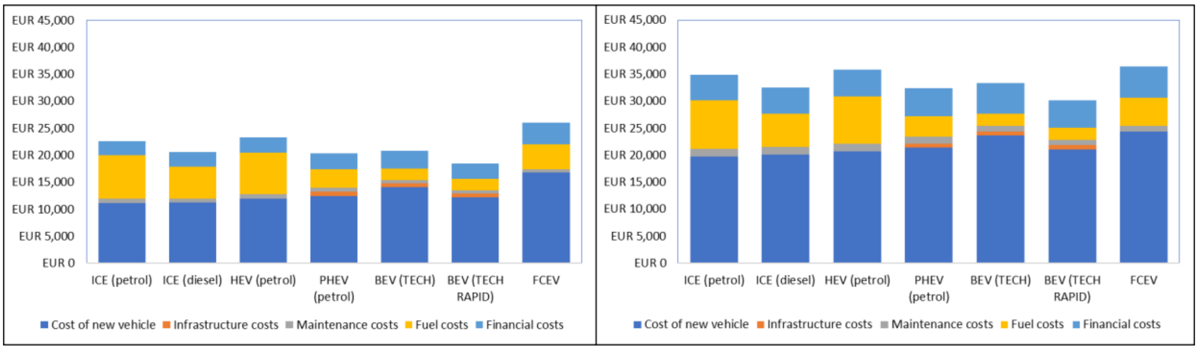


Figure 5.6 shows the 4-year cost of ownership for a car in 2020. The average capital cost for ICE cars is lower than the average capital cost for electric vehicles. The average capital cost for a BEV in the TECH Rapid scenario is lower than the average capital cost for a BEV in the TECH scenario. Average fuel costs for electric vehicles are considerably lower that the fuel costs for ICEs, but still not sufficient to compensate for the higher capital costs in the TECH scenario. However, in the TECH Rapid scenario small BEVs are already at parity with small petrol and diesel ICEs.

Figure 5.7 4-year TCO for all powertrains segment A+B (left) and C (right) in 2030



In 2030, average capital costs for electric vehicles have declined and, as a result, the overall cost of ownership for 4 years is broadly at the same level as the cost of ownership for ICE cars. In addition, the cost of fuel cell cars has dropped due to technological advancements, and the cost of ownership is now closer to the costs of ownership of other powertrains.

The main finding of the TCO analysis is that there is strong convergence in the cost of owning and running all types of vehicles in our central case, and this convergence is much stronger than for the purchase price alone.

Overall, the TCO analysis shows the following:

- ICEs are comparable with HEVs and PHEVs in 2020 and 2030, with PHEVs being less expensive than petrol ICEs in 2020
- BEVs in the TECH scenario have higher capital costs in 2020, but become competitive with petrol and diesel ICEs in 2030
- BEVs in the TECH Rapid scenario are already cheaper on a TCO basis than petrol and diesel cars in 2020 due to the assumed lower battery costs, and become the cheapest powertrain in 2030
- FCEVs are substantially more expensive than other powertrains in 2020 and remain the most expensive car to own in 2030. However, the

total cost of ownership for a FCEV gradually converges with that of other powertrains over time.

These results show that the faster take-up of BEVs is economically rational in the TECH Rapid scenario. They also provide an initial overview of the expected macroeconomic outcomes. For the average consumer, it will become cheaper to own and run a car over its lifetime as TCO for all cars will decrease between 2020 and 2030 in the TECH scenario, leading to higher spending on other goods and services. Given the likely evolution of the car fleet away from petrol ICEs, less money will be spent on fuel and more on car technology.

5.3 Sensitivities

There is fair degree of uncertainty around what will happen in the future, and as a result the total cost of ownership calculations are sensitive to the input assumptions. To deal with this uncertainty, we carry out several sensitivity tests with alternative assumptions (such as lower and higher fuel prices). This allows us to come to more robust conclusions about the suitability of certain powertrains versus other powertrains.

Please note we present the sensitivity analysis only for medium-sized cars (segment C).

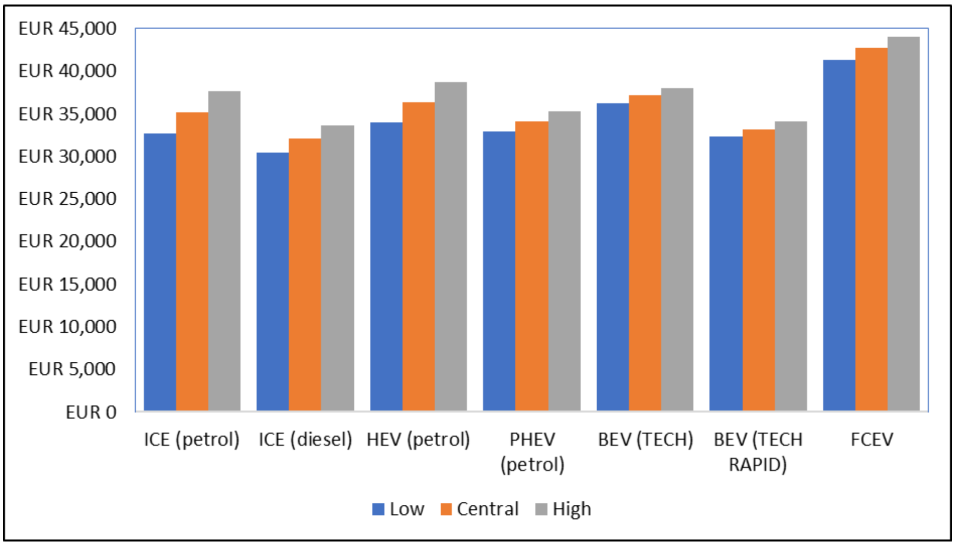
Sensitivity 1: Fuel costs

There is a fair degree of uncertainty around the future evolution of the prices for diesel, petrol, electricity and hydrogen. For this reason, we carry out a sensitivity using different projected prices. In the lower case, we reduce prices by 25%. In the higher case, we increase prices by 25%. All other assumptions remain the same in both cases.

Table 5.3 Fuel cost assumptions in lower case, central case and higher case

Variable	Low	Central	High
Petrol price	0.97€/litre in 2020 1.10€/litre in 2030	1.30€/litre in 2020 1.46€/litre in 2030	1.62€/litre in 2020 1.83€/litre in 2030
Diesel price	0.89€/litre in 2020 1.04€/litre in 2030	1.19€/litre in 2020 1.38€/litre in 2030	1.48€/litre in 2020 1.73€/litre in 2030
Electricity price	c. 16c/kWh in 2020 c. 12c/kWh in 2030	c. 21c/kWh in 2020 c. 17c/kWh in 2030	c. 26c/kWh in 2020 c. 21c/kWh in 2030
Hydrogen price	0.21€/kWh in 2020 0.23€/kWh in 2030	0.28€/kWh in 2020 0.31€/kWh in 2030	0.35€/kWh in 2020 0.38€/kWh in 2030

Figure 5.8 Fuel costs sensitivity analysis (car segment C)



This leads to variations in the 4-year cost of ownership for all types of cars. Looking at the impact of different electricity price assumptions on the 4-year cost of a new car in both the TECH and the TECH Rapid scenario, for example, a lower electricity price (-25%) could lead to a difference in the cost of ownership of 842 € over the course of 4 years.

The sensitivity analysis conducted here is meant to illustrate the impact of different fuel prices on the cost of ownership of a particular powertrain (e.g. EV). The same sensitivity is applied to all fuels at the same time and therefore one should be cautious of making a comparison across powertrains.

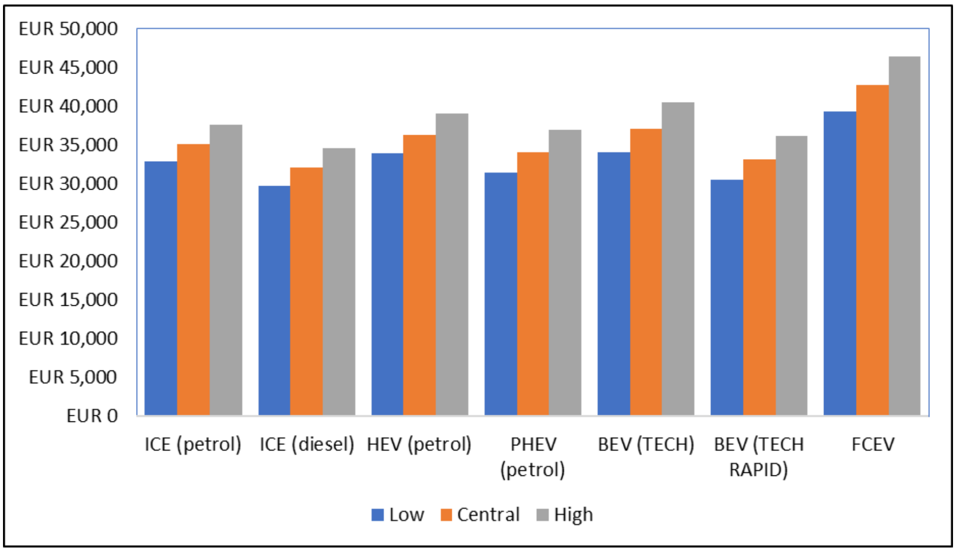
Sensitivity 2: Financing costs

We also carried out another sensitivity test in which we change the interest rates, therefore influencing total financing costs. All other assumptions remain unchanged.

Table 5.4 Financing cost assumptions in lower case, central case and higher case

Variable	Low	Central	High
Interest rate	3.5%	6.5%	9.5%

Figure 5.9 Financial costs sensitivity analysis (car segment C)



Changes in interest can lead to significant variations to the financing costs for cars, but this is of course the case for all types of cars, especially for those cars with a higher capital cost. The higher the interest rate, the more difficult it is for electric and hydrogen vehicles to compete on purchase price with ICEs.

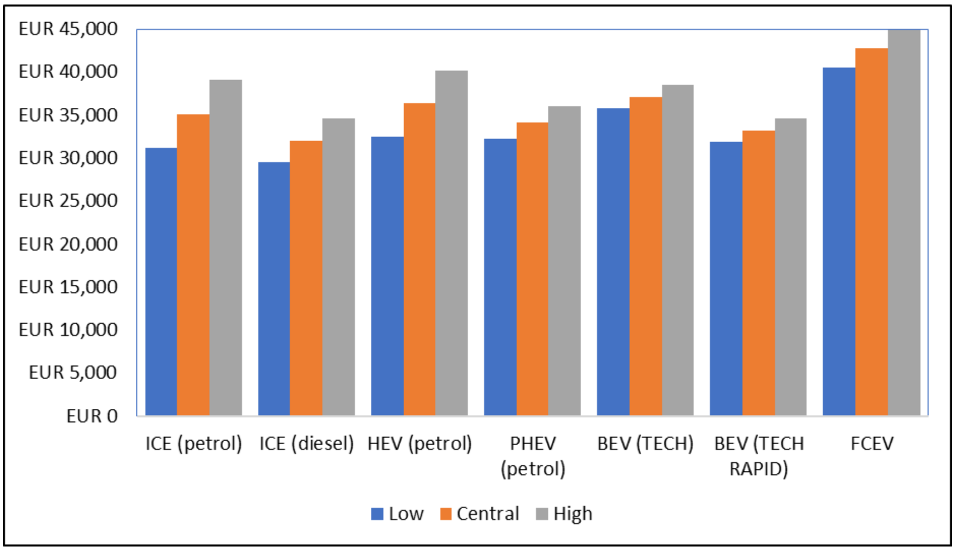
Sensitivity 3: Mileage

In this sensitivity test, we adjust the assumptions for the average annual mileage to examine the effect on the cost of ownership. For the first four years, we reduce the annual mileage to 15,000 km in the lower case and we increase it to 35,000 km in the higher case.

Table 5.5 Mileage assumptions for lower case, central case and higher case

Variable	Low	Central	High
Mileage	15,000 km	25,000 km	35,000 km

Figure 5.10 Mileage sensitivity analysis (car segment C)



In Figure 5.10, you can see the impact of different average annual mileage assumptions on the cost of ownership for the first 4 years. Higher mileage leads to higher fuel costs. The impact on the cost of ownership can therefore be considerable, and is larger on those vehicle with higher fuel costs (i.e. ICEs).

6 Synergies between EVs and the electricity grid

The impact that charging has on the electricity system will grow with the EV fleet. Choices made about how EVs are charged, can determine the extent of impact on the electricity grid, and whether these impacts, or Synergies, are negative (resulting in additional system costs) or positive (resulting in net system savings).

The three EV charging options we study are:

- Passive (uncontrolled) charging – which risks EV charging load adding to peak electricity system loads
- Smart (managed) charging – where EV charging times are managed so that peak times can be avoided; or in addition, to capture renewable energy that would otherwise be curtailed
- Vehicle to Grid – where energy from the EV battery is supplied back to the grid.

This chapter presents our assessment of the synergies between EVs and the electricity system. These include impacts at generation level (additional peaking plant capacity, additional fossil fuel use, increased integration of renewable energy sources by reducing curtailment) and distribution level impacts. The analysis also includes the potential to generate ancillary services for balancing the system, via controlled charging or Vehicle To Grid technology. Provision of ancillary services from fuel cell vehicles is also included.

While the E3ME modelling accounts for the electrical energy used in EVs, it does not account for the impacts upon the energy system of when this energy is used and so for example cannot distinguish between the three charging types identified above. Any net costs or benefits identified here, are in addition to the figures determined by Cambridge Econometrics in their E3ME modelling.

The analysis is based on vehicle deployment in the TECH scenario.

6.1 Methodology and scope

We model the impacts of EV charging (and H_2 generation for FCEVs) for the following items:

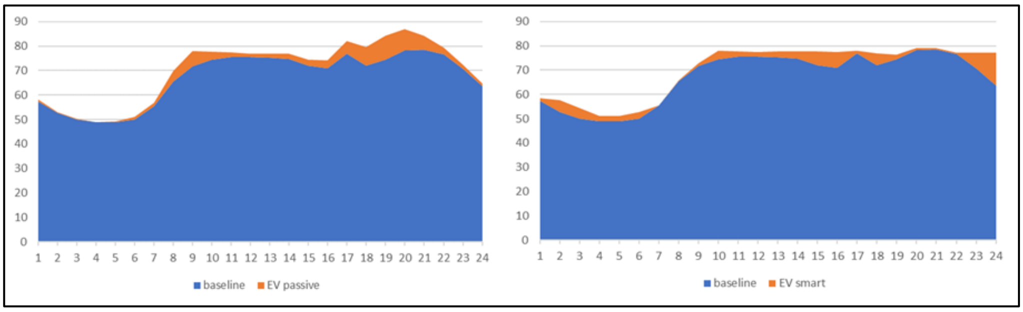
- Distribution network reinforcement (required if there is an increase in the peak load on the network)
- Electricity generation capacity investment (usually Peaking Plant capacity required to meet new peak loads on the network due to EV charging)
- Electricity generation production costs (for example additional fuel used in peaking or mid-merit plant to charge EVs)
- Electricity generation production savings (due to EVs absorbing energy that would otherwise be curtailed).

- Balancing services provision (revenues from the provision of these services, usually contracted or mandated by the transmission system operator)

We simulate the hourly dispatch of electricity generation as well as the capability of the EV fleet to provide grid balancing services and the revenue opportunity associated with that. The models are run in 2030 and 2050 to represent the differences in EV and RES deployment expected in those years. The E3ME/CE representation acts as our baseline scenario, which we modify to incorporate EV/energy system synergies. We compare scenarios of EV charging to this baseline scenario:

- Unmanaged charging is the result of vehicles beginning to charge as soon as they arrive at their destination (home or workplace) and are plugged in. This tends to increase peak loads on the network.
- Smart charging avoids (where possible) introducing new peaks on the network while ensuring vehicles have the required charging energy daily.
- Vehicle to grid allows the EV fleet to act as a storage capacity for the grid by charging at times of high renewable output and discharging at times of high electricity demand.

Figure 6.1 Unmanaged EV charging (left) vs smart charging (right) in Spain in 2050



These charging loads are added to the background electricity demand profiles, for each hour of the year. Renewable energy capacities are added to the model with an hourly generation profile determined from historical production datasets. An hourly dispatch model is used to determine the scheduling of fossil fuel plant in response to the applied electricity demand and renewable generation profiles. The dispatch model determines fuel use and energy prices.

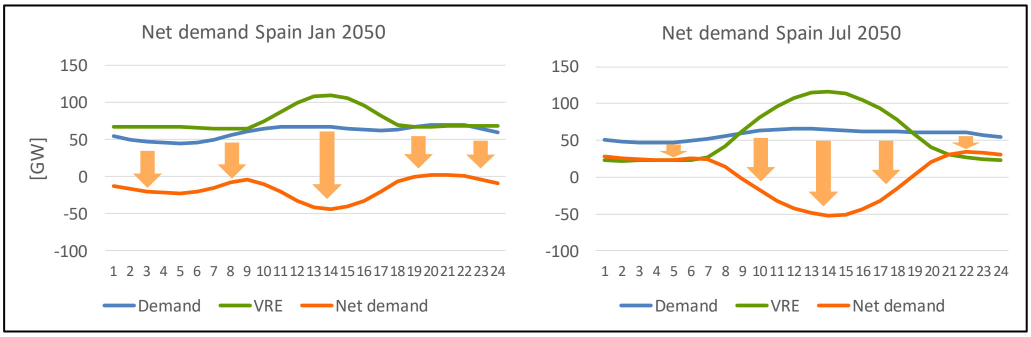
In addition, a revenue model also identifies annual value of providing grid services to the Transmission System Operator (TSO). An EV fleet can provide system services such as primary frequency response, by increasing or reducing the charging demand following a signal from the TSO. V2G technology enhances the system ability to provide these services. We include the costs of a smart system, battery degradation and round-trip losses in V2G operation to assess the net benefit of providing grid services using V2G.

As an alternative to EVs, the revenue model also estimates the revenues that could be generated through controlled dispatching of H_2 electrolysers providing H_2 for FCEVs.

Baseline electricity demand data is modified from ENTSO-E hourly data. Initial RES and fossil plant capacities are taken from a decarbonisation scenario by Spanish utility Iberdrola, which is in line with EU decarbonisation goals. The RES output profiles are based on European historical weather datasets.

As shown in the graphs below, the high levels of RES on the Spanish system in 2050 means that for significant periods of time, the net load (i.e. the residual demand after renewable generation) is less than zero, i.e. there is excess renewable generation. This presents an opportunity to schedule EV charging into these periods to absorb cheap, clean energy that would otherwise be wasted.

Figure 6.2 Future dispatchable generation must to respond to "Net Demand" – residual demand after Renewable Generation



6.2 Results: Total system costs and benefits

Passive charging causes significant costs

Passive charging leads to significant additional cost compared with the base case. The bulk of these costs are related to distribution network reinforcements and higher generation production costs (a combination of capital investments in peaking plant and additional fuel use in these low efficiency peaking plants).

The additional costs of passive charging amount to €150m a year in 2030, rising to €650m a year in 2050.

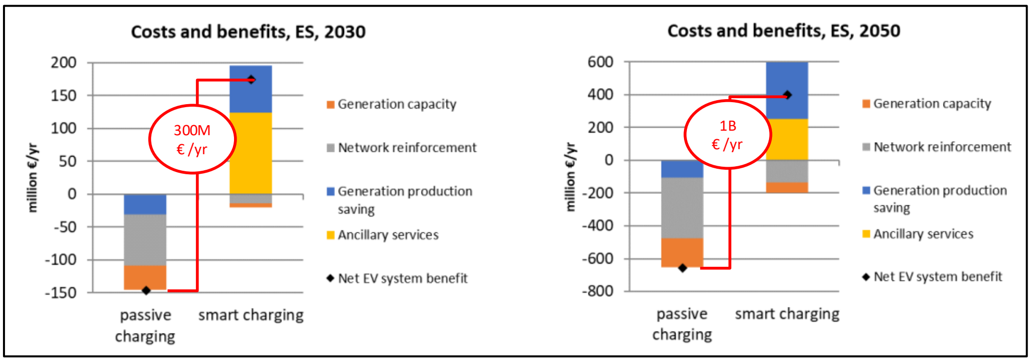
Smart charging avoids increase of peak demand

On the other hand, shifting the EV charging in time can largely avoid peak increases while still ensuring EVs are fully charged at the end of their charging window. As a result, most distribution system investments can be avoided with smart charging.

Furthermore, investments in generation capacity and fossil fuel costs can be largely avoided with smart charging.

Our analysis shows that deployment of smart charging would provide benefits of about €320m per year in 2030 compared to passive charging due to: fuel savings in the generation fleet, avoided infrastructure investment and ancillary services revenues (Figure 6.3). These benefits rise to about €1050m per year in 2050, mainly because the EV fleet grows as does the opportunity to support VRE production.

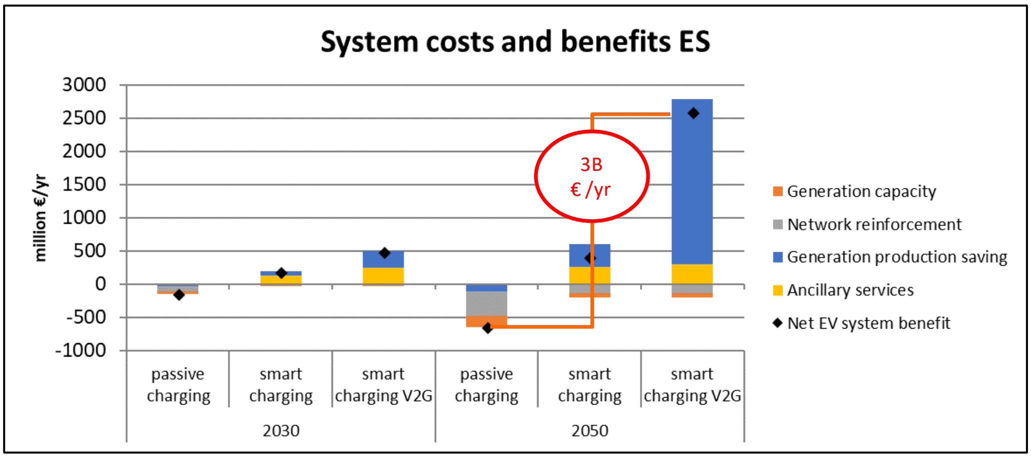
Figure 6.3:System costs and benefits of passive and smart charging in Spain in 2030 (left) and 2050 (right)



V2G provides significant system benefits

While smart charging already provides significant system benefits compared to passive charging, these benefits could be increased substantially if EV batteries were also used to store electricity and send it back to the grid. An additional scenario which assumes mass deployment of such vehicle to grid (V2G) technologies has been modelled and shows a much higher amount of generation savings than the smart charging scenario (Figure 6.4).

Figure 6.4 System costs and benefits in Spain in 2030 and 2050 of the three investigated scenarios, compared to the baseline scenario



The reason for this is the high solar output during the day in Spain which will often exceed demand in the future. EV charging events occur overnight (home charging) and during work time (daytime charging). V2G allows excess energy generated during the day to offset the renewable energy deficit at night. In such a scenario, EVs would be charged more than necessary to meet daily driving cycles; the additional PV derived energy would be fed back into the grid in the evenings to meet energy demands at these times. This would utilise significant amounts of energy from renewable sources which would otherwise have to be curtailed. By doing so, EVs would absorb an amount of renewable energy equivalent to 5% of total electricity demand, which would have been lost otherwise. Thereby they would help to reduce the carbon intensity of electricity by one third relative to non V2G operation and would also reduce electricity costs.

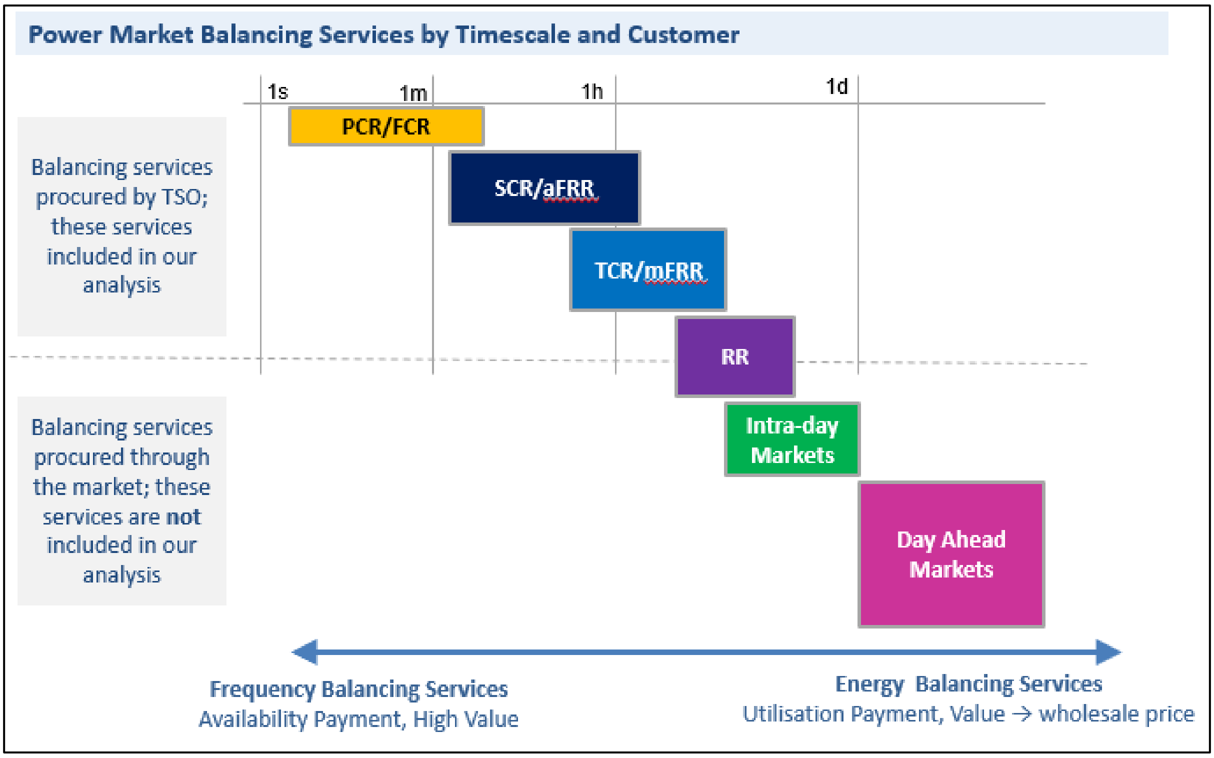
Utilising V2G technology in this way would require adequate deployment of charging infrastructure to ensure EVs can charge during the day and feed electricity back to the grid at night. In addition, more energy would be moving through the battery and so there may be some accelerated degradation. However, our analysis shows that investment into such infrastructure would facilitate significant increase in the penetration of renewable energy resources and make EVs an enabler of significant emission reductions.

EVs can provide the majority of balancing services

Electricity grids are stabilised with a range of services which balance supply and demand across a range of timescales. Rapid, "response" services (primary control reserve or frequency response) tend to attract higher values per MW of service delivered and are the main revenue streams for EVs. Slower responding services are longer in duration and their values approach that of bulk energy prices.

The demand for some ancillary services is expected to increase with additional RES capacity, because inertia on the system would decrease, and ramping up and down of net load will increase. On the other hand, it should be expected that the widespread deployment of devices using fast responding power electronics will reduce the market value for even rapid services, as has already been the case in the GB energy system for *Fast Frequency Response*.

Figure 6.5 Balancing services by timescale and market where they are procured



Currently procurement of these ancillary services differs significantly across the European member states. The technical specification for the services varies, but also some services are not commercially tendered; rather they are mandated to be provided by participants in the energy market.
However due to ongoing harmonisation initiatives at the European level, directed by ENTSO-E and ACER, it can be expected that technical specifications as well as commercial arrangements and the degree of liberalisation of balancing markets will converge across member states.

While in Spain, rapid response services are currently provided as a mandatory service by large thermal generators, this is expected to change in a decarbonised system where thermal plant will only be dispatched in hours of shortage of electricity supply from renewable energy and furthermore cheaper providers of balancing services such as grid scale batteries or aggregated EV batteries will be available.

The price values per service that we use in the modelling of revenues, is informed by current prices of this service in the Spanish market today, in the case of slower response services (so called secondary and tertiary control reserve). In the case of primary control reserve, we used values informed by recent price developments in European member states which have liberalised markets for this service.

Figure 6.6 Procurement methods of different grid services in investigated countries

MS	How Is the Ancillary Service Procured?			Procured Volume (MW)		
	Primary	Secondary*	Tertiary*	Primary	Secondary*	Tertiary*
PL	Mandated from generation (symmetric)			200-300	500-700	~2,800
ES	Mandated, symmetric	Tendered, distinct positive and negative products		500	2500	4,100
UK	Mandated (symmetric) and Tendered (distinct positive and negative products)	Tendered (distinct positive and negative products)		1200	NA	>3,000
FR	Tendered jointly, symmetric	Tendered at a fixed price, symmetric	Several Tendered products, most for low frequency only.	569	500-800	>3,600
DE	Tendered jointly, symmetric	Tendered, distinct positive and negative products		583	4,000	4,000

Increasing liberalisation of ancillary service provision (PL → DE)

Mandatory service provided by generators (yellow)

Optional service, procured through tender, that may be provided by load or DSM (blue)

The projected EV fleet in Spain in 2050 has the technical potential to provide the majority of ancillary services demand (about 90%) by way of controlled charging. Using bidirectional (V2G) charging, would enable the EV fleet to provide 85% of the demand for ancillary services already in 2030.

6.3 Revenues per EV

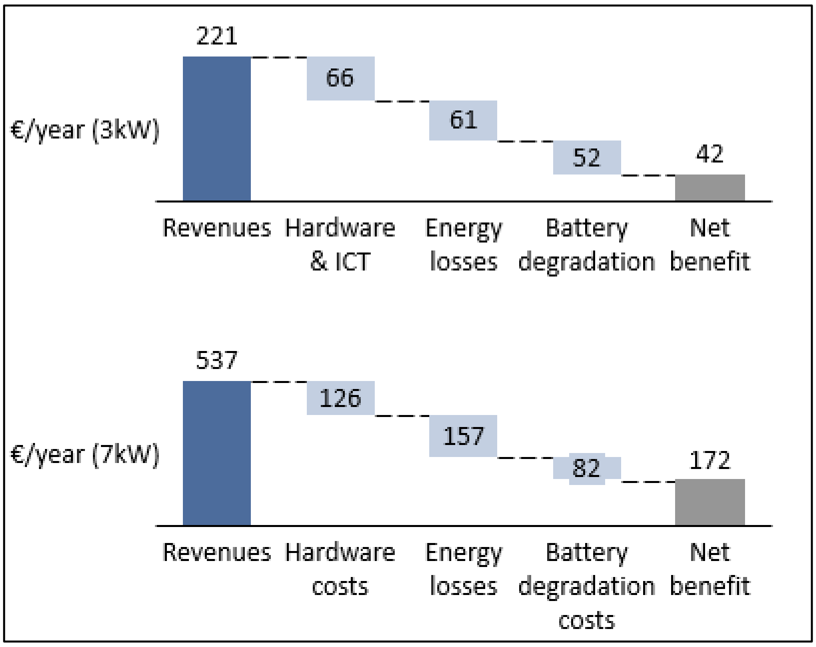
Balancing services can enhance net benefit for V2G

We model the revenues per EV with unidirectional (controlled charging) as well as bidirectional (V2G) charging, using 3kW or 7kW chargers to assess if such revenues are high enough to make the purchase of an EV more attractive.

Compared with controlled charging, V2G incurs additional costs. These are: additional hardware costs, energy round trip losses when power is put back into the grid, and enhanced battery degradation due to V2G induced additional cycling of the battery.

We found that, despite higher capital and operational costs, 7kW chargers offer much higher net benefit than 3kW.

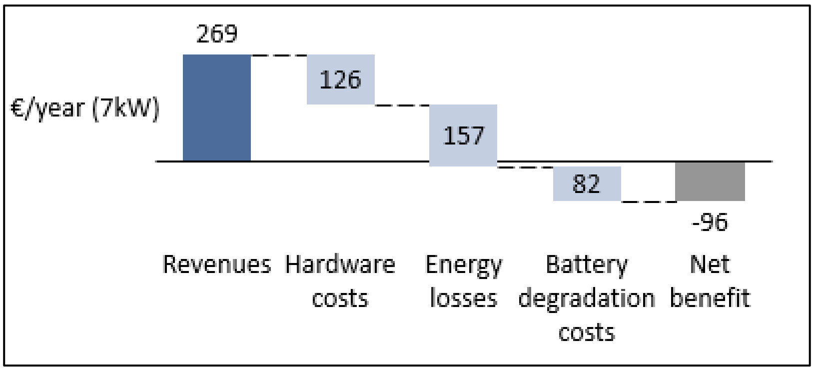
Figure 6.7 Net benefit of grid service provision with a 3kW vs 7kW bi-directional residential charger, in Spain in 2030.



Net benefit is very sensitive to future value of services

Furthermore, we also found that these net revenues are very sensitive to the value of ancillary services. A halving of service value (a sensitivity reflecting potential competition from other sources of frequency response) would eliminate any net benefit of 3kW V2G as well as 7kW V2G, while unidirectional service provision would remain barely profitable.

Figure 6.8 Net benefit of grid service provision with a 7kW bi-directional residential charger, in Spain in 2030, assuming 50% lower service prices than currently

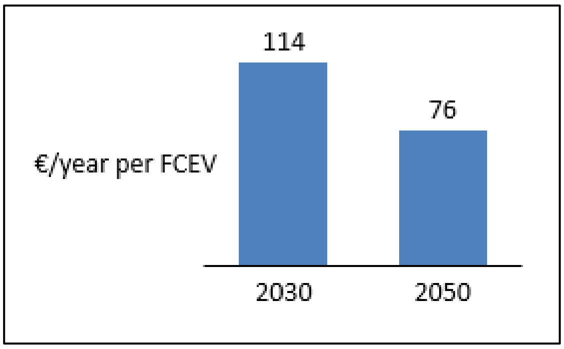


6.4 Services provision by electrolysers

Electrolysers supplying hydrogen to FCEVs could provide a significant amount of balancing services in Spain. This would enable a more attractive offer to FCEV owners, if the revenues of these services are passed on to them. It should be noted that the higher annual value of FCEV based services is because these vehicles consume more electricity than EVs.

Similarly to the case of EVs, the revenues per FCEV are moderate in European comparison due to comparably low value of secondary and tertiary control reserve in Spain.

Figure 6.9 revenues per FCEV from service provision by electrolysers in 2030



6.5 Conclusions

Passive charging would impose significant additional costs onto the electricity system, in addition to the cost and benefits determined by E3ME modelling. These costs, which are mostly avoidable via smart charging, arise from:

- Significant load growth at peak times requires additional investment in the distribution network, peaking generation plant and additional fossil fuel costs.
- These costs add up to more than €650m p.a. in Spain in 2050.

Smart charging of EVs could avoid these additional costs to a very large extent.

- Moving EV charging to times of lower electricity demand avoids significant network reinforcements or peaking plant investments.
- Smart charging of EVs would permit higher utilisation of renewable capacity as well as reduced utilisation of high polluting fossil plants.

Vehicle To Grid

- In addition, V2G technology could have a very significant positive impact on the Spanish electricity system in the long term. The (combined) battery capacity available for V2G in the 2050 EV fleet is very large, ca. 239 GWh.
- V2G allows EV to absorb excess PV energy during the day, released to the grid in evening.
- Using EV batteries as grid storage device would allow the absorption of about 26TWh additional VRE output (5% of annual demand). Relative to smart charging, the increased use of renewable energy displaces fossil fuel and reduces carbon intensity by 28%.

7 Economic impacts

The economic impact of decarbonising Europe's passenger vehicles, compared to a reference case (REF) in which cars remain unchanged from today, was modelled using E3ME[32].

7.1 GDP impacts

The impact comes from the shift in spending away from imported oil and towards a higher capital content in vehicles and spending on decarbonised fuels. The higher cost of vehicles raises prices to consumers and depresses real incomes and spending. It diverts spending towards the value chain for manufacturing vehicles and their component parts and away from other sectors of the economy. However, better fuel-efficiency lowers running costs for consumers, with positive consequences for the economy. It diverts spending away from oil supply chains and towards other areas of the economy. Since oil is imported into Spain while the decarbonised fuels are produced in Europe, the shift in spending on fuel boosts the Spanish economy and is reflected in an improvement in the balance of trade. A summary of the main economic indicators in presented in Table 7.1.

Table 7.1 Main macroeconomic indicators

	CPI	TECH	TECH Rapid
2030 Impacts		(relative to REF)	
GDP (%)	0.14%	0.21%	0.29%
Employment (000s)	27	23	45
Oil Imports (mboe)	-27	-34	-47
CO_2 emissions from passenger cars ($mtCO_2$)	-11	-14	-19
	CPI	TECH	TECH Rapid
2050 Impacts		(relative to REF)	
GDP (%)	0.31%	0.71%	0.74%
Employment (000s)	36	83	83
Oil Imports (mboe)	-54	-118	-123
CO_2 emissions from passenger cars ($mtCO_2$)	-22	-48	-49

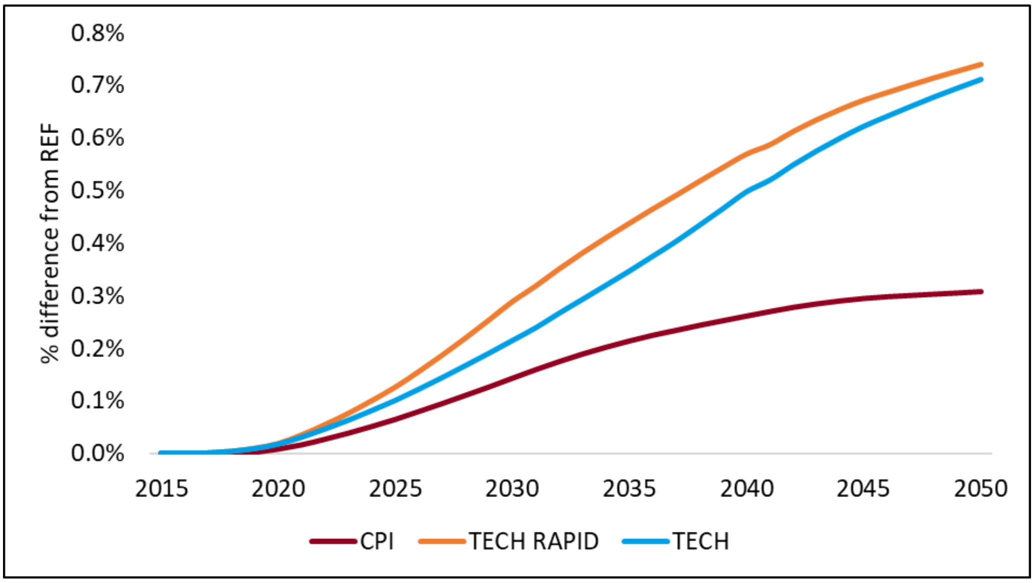
The scale of the long-term economic impact is uncertain, depending on a number of competing factors: the cost of vehicles, low-carbon technologies and EV batteries; the location of vehicle supply chains; and future oil prices, to name a few of the key uncertainties. However, the dominant impact arises

[32] https://www.camecon.com/how/e3me-model/

from the reduction in oil imports. This is evident in the macroeconomic results in which the GDP impact tends to follow oil imports in the CPI and TECH scenarios. The most ambitious scenario is TECH Rapid, and this also yields the greatest economic benefits in terms of the impact on both GDP and employment which comes mostly from the substantial reduction in oil imports.

Figure 7.1 below shows the GDP impacts under different scenarios. In the TECH scenario, by 2030, there is a modest (0.2%) GDP improvement, as the economic benefits of reduced spending on oil and petroleum imports outweigh the negative economic impacts associated with higher vehicle prices. However, by 2050 this has widened to almost 0.7%, as spending on imported fuels falls further due to continued improvement in efficiency of the stock and a continued shift away from ICEs and towards PHEVs, BEVs and FCEVs.

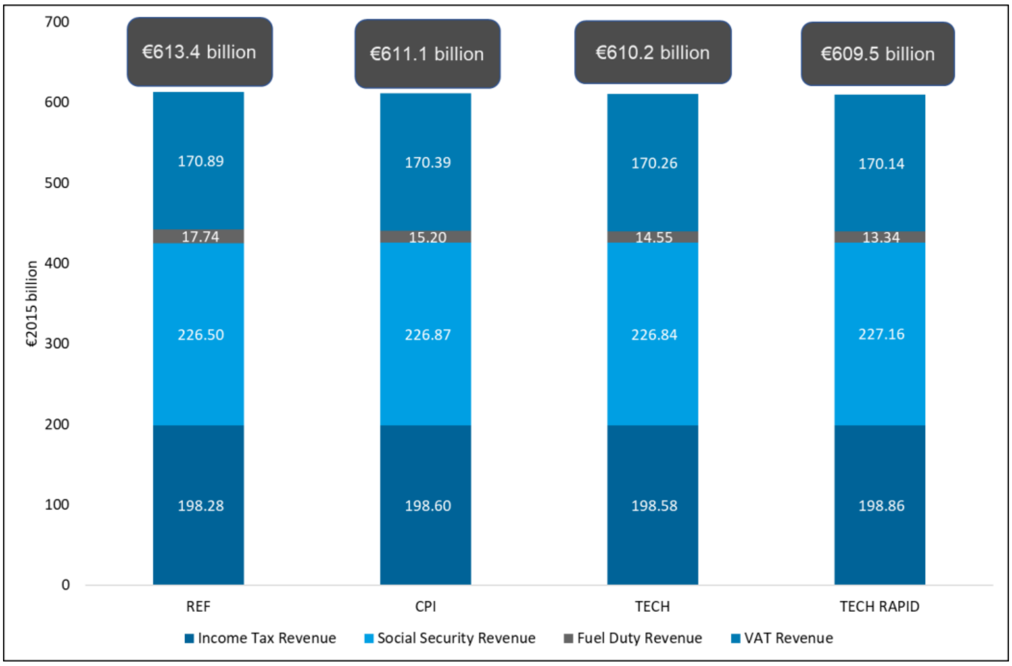
Figure 7.1 GDP results relative to the reference scenario



7.2 Government revenues

In many European countries, fuel tax is levied to raise general revenue and to pay for road infrastructure improvements. Vehicle efficiency improvements and a switch to low-carbon vehicles will reduce spending on petrol and diesel fuels with consequent impacts on tax revenues and the model for financing road maintenance and road infrastructure improvements.

Figure 7.2 Total government revenues in 2030 (€2015bn)



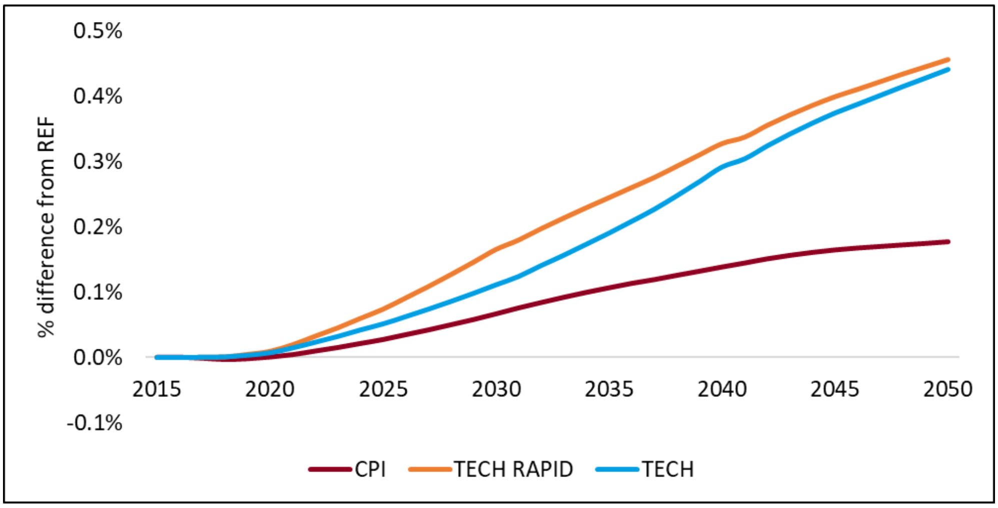
Our analysis shows that in the TECH scenario fuel tax revenue will be reduced by around €3.2 billion by 2030, due to the deployment of more advanced fuel efficient technologies and advanced powertrains. The Spanish government could attempt to recoup the lost revenue directly through other taxes on the same group of consumers, for example through increases in excise duties (where they exist) or road charging. The net economic effect would depend on which taxes are changed. This highlights the importance of industry, government and civil society working together to find consensus on the optimal approach.

Government Revenue Balancing

In E3ME, the macroeconomic model used for this study, it is possible to introduce a revenue balancing mechanism to model the transition towards more advanced powertrains without impacting on public finances. This is done by allowing the model to increase the current VAT rate (21% in Spain) to cover the losses in fuel duty revenues over future years. As it is reasonable to assume that final consumers will ultimately bear the cost to close the gap arising in the public budget, an increase in the applied VAT rate represents a good approximation of the change in tax policy that the decision maker will introduce.

Figure 7.3 illustrates the obtained GDP results after introducing revenue balancing in the model.

Figure 7.3 GPD results relative to the reference scenario, with revenue balancing



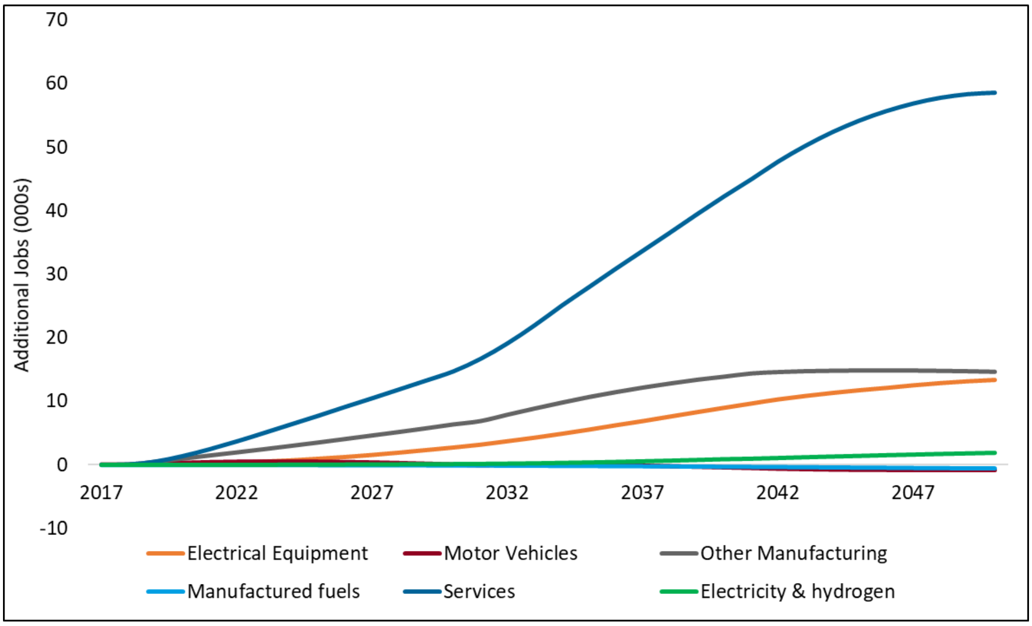
Overall, revenue balancing (i.e. a higher VAT rate) would still lead to a positive net economic impact in both the TECH and TECH Rapid scenario in the case of can be observed, but the impact is lower than in the case without revenue balancing.

7.3 Employment

The pattern of impacts on employment, while related to the output impacts, are somewhat different. To assess the impact on employment, we also need to take account of the different employment intensities in the various sectors that are affected. The trend towards greater automation in the auto industry is expected to reduce the number of jobs, regardless of the low-carbon transition. Building battery-electric vehicles is expected to be less labour intensive than building the gasoline and diesel vehicles they will replace, while building hybrids and plug-in hybrids is expected to be more labour intensive. Our modelling for the Fuelling Europe's Future study confirmed that the net employment impact for the auto sector from the transition depends on the market shares of these various technologies, and the degree to which they are imported or produced in Europe.

Figure 7.4 shows the evolution of jobs in Spain as a result of the transition to low-carbon cars in 2030 and 2050 under our central TECH scenario, relative to the Reference case. There is a net increase in employment in the following sectors: electricity, hydrogen, electrical equipment, services and most manufacturing sectors. Employment in the fuel manufacturing sector is reduced. Employment in the automotive manufacturing sector is very slightly higher until 2030, but is slightly lower thereafter in our central TECH scenario.

Figure 7.4 The employment impact per sector of the transition to low-carbon cars (TECH compared to REF)

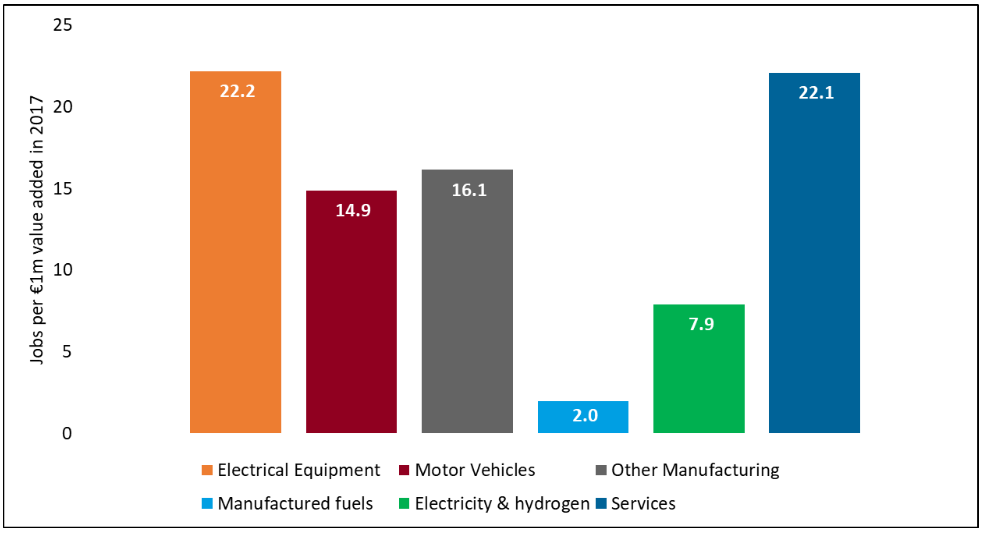


In our TECH scenario, net auto sector jobs increase through to 2030, because diesel and gasoline engines are built to greater levels of sophistication and efficiency to meet climate goals, and because of the increasing deployment of hybrids, plug-in hybrids and fuel-cell vehicles, with their greater technological complexity. However, by 2050, the net impact on auto jobs is negative – if only to a small extent - because hybrids are increasingly replaced by battery-electric vehicles, which are simpler to build and therefore generate fewer jobs.

It can be deduced from analysing employment by sector that, if the amount of employment in a sector of the economy is measured as jobs by added value of € 1 million, the fuel production sector has a lower intensity of employment, much lower than the service and electrical equipment sectors. Figure 7.5 presents the employment intensities used to project sectoral employment impacts, based on historical data for 2017 from Eurostat and the Spanish national accounts[33].

[33] In E3ME the relationship between value added and employment is not fixed over time. Employment is not tied to value added in a linear fashion due to the cointegrating equations. These employment intensities give a snapshot of the relative intensities of the different sectors.

Figure 7.5 Employment intensity per sector (jobs per €1m value added in 2017)

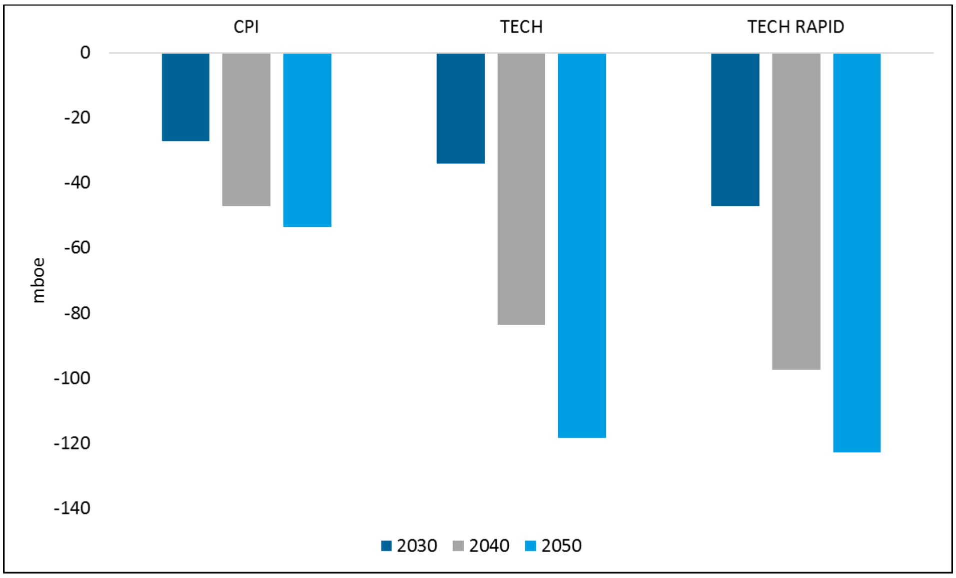


Employment impacts within the auto sector are an important issue. The benefit of using a macro-economic modelling approach is that it allows us to assess the economy-wide impacts of this transition, but there are limits to the level of detail that can be provided. For the low-carbon transition to be successful, care will need to be taken to support those who lose their jobs in technologies that are phased out. Managing the switch in the motor vehicles industry, to ensure a "just transition", should be a key focus of policy, particularly against an overall background of increasing automation.

7.4 Oil imports

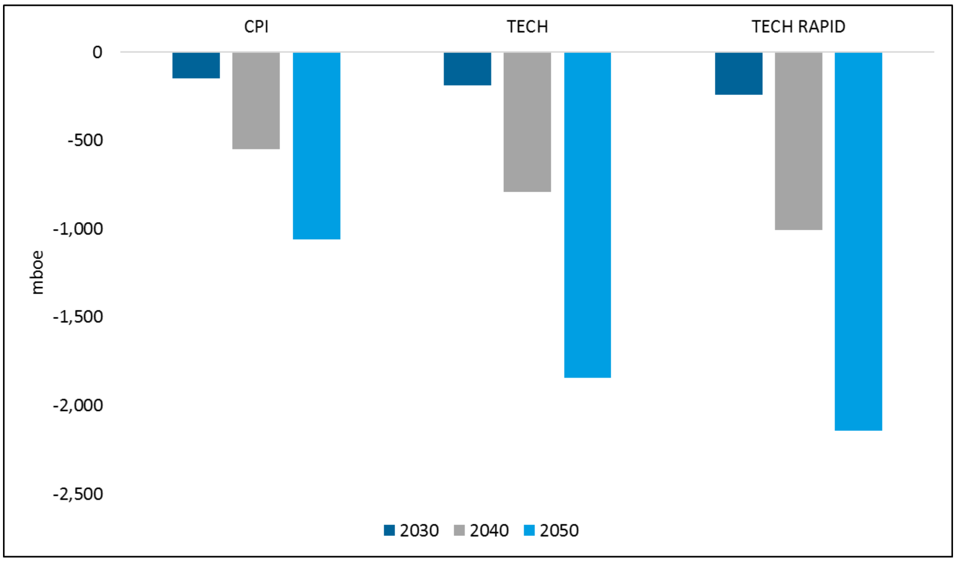
By 2030, in the core TECH scenario, annual oil imports are reduced by around 34 mboe annually. By 2050, the reduction in annual oil imports compared to the Reference case increases to 118 mboe. In the most ambitious TECH Rapid scenario, this reduction happens more quickly, with a reduction of over 47 mboe by 2030 (see Figure 7.6).

Figure 7.6 Annual oil import savings (difference from REF)



Over the time period of this study, this will lead to cumulative oil import savings of around 186 mboe by 2030 in the TECH scenario. By 2050, the cumulative reduction in oil imports compared to the Reference case increases to 1,843 mboe. In the most ambitious TECH Rapid scenario, the reduction in cumulative oil import savings is even higher (see Figure 7.7).

Figure 7.7 Cumulative oil import savings over time (difference from REF)



The reduction in oil imports is the main economic driver and explains the levelling off of economic benefits in the CPI scenario from 2030 onwards (oil savings are lowest in the CPI), compared to the increasing GDP benefits in the TECH and TECH Rapid scenarios out to 2050.

8 Environmental impacts

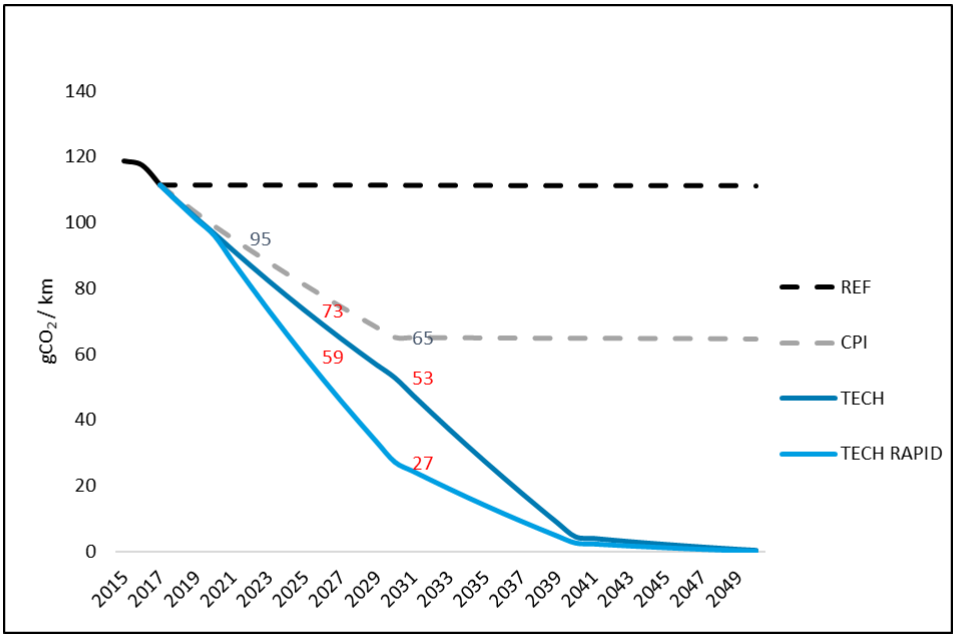
8.1 Impact on CO_2 emissions

Average emissions

The trend in average CO_2 emissions for new cars under each scenario, in terms of NEDC test cycle, is shown in Figure 8.1.

Apart from the REF scenario, all scenarios meet the 95 gCO_2/km NEDC target for 2021, and further reduction of at least 15% by 2025 and 30% by 2030 (relative to CO2/km in 2021), in line with the current proposal from the European Commission for post-2020 CO_2 standards. For the TECH scenario, new cars achieve a NEDC average of 73 gCO_2/km in 2025 and 53 gCO_2/km in 2030. For the TECH Rapid scenario, new cars achieve a NEDC average of 59 gCO2/km in 2025 and 27 gCO_2/km in 2030. By 2050, average tailpipe emissions of new vehicles drop to nearly 0 gCO_2/km.

Figure 8.1 Average CO_2 emissions (NEDC) of new cars from 2015-2050



Because the TECH Rapid scenario is characterised by a faster deployment of BEVs after 2020, the average vehicle emissions fall faster in the TECH Rapid scenario. However, the TECH Rapid pathway is very similar to the TECH scenario from 2040 onward, as PHEVs and BEVs are replaced by FCEVs.

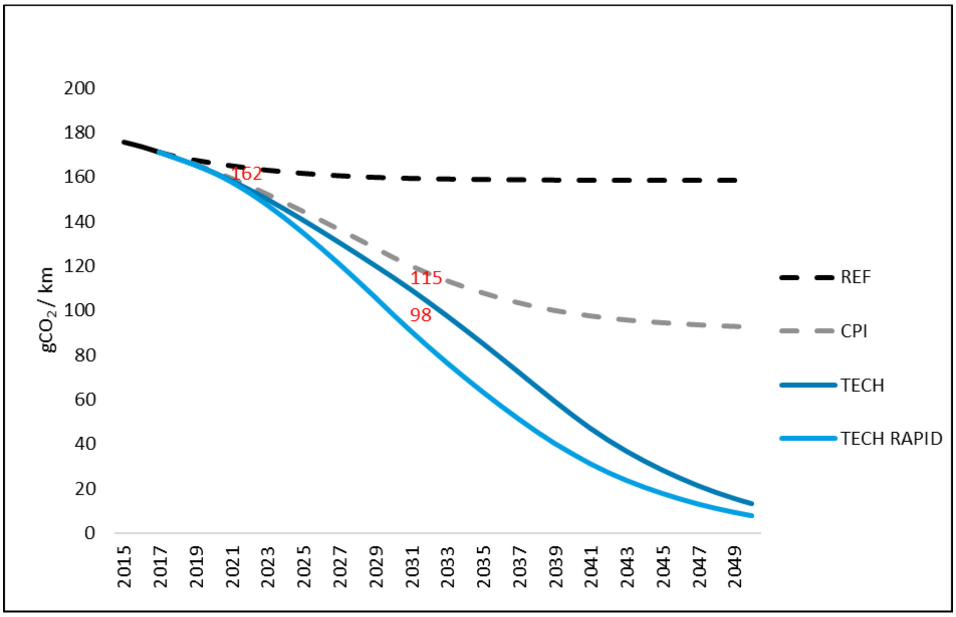
Figure 8.2 shows the average real-world tailpipe emission for all cars in the vehicle stock, under all scenarios. Average tailpipe emissions are higher for two reasons:

- There is a gap between NEDC emissions and real world emissions for new vehicles entering the stock. NEDC emissions of new vehicles are estimated to be around 42% lower than real world emissions[34].

[34] https://www.theicct.org/publications/laboratory-road-2017-update

- The average real world emissions presented in Figure 8.2 relate to the entire passenger vehicle stock and not just new vehicles. Older vehicles in the stock are gradually being replaced with more efficient new vehicles.

Figure 8.2 Average vehicle emissions (real-world, stock)

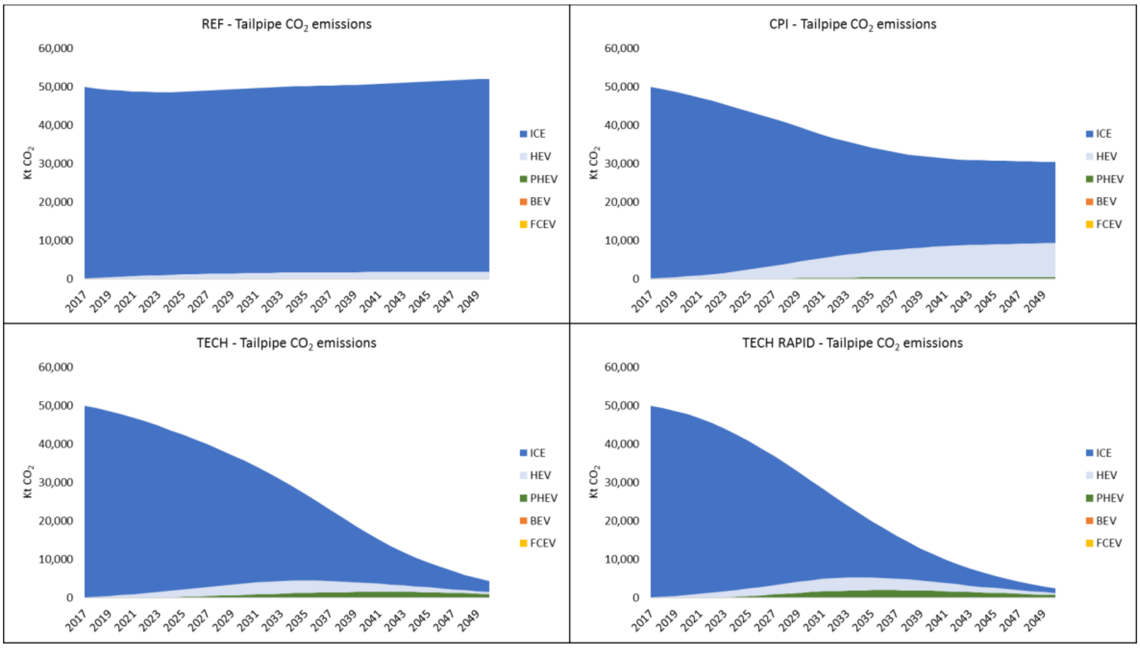


Total emissions

Figure 8.3 shows the vehicle stock's CO_2 tailpipe emission in each of the scenarios. Total tailpipe emissions in the TECH and TECH Rapid scenario drop considerably between 2020 and 2050.

In the central TECH scenario, CO_2 emissions from cars are reduced from around 50,000 Kt CO_2 per annum in 2017 to about 5,000 Kt CO_2 per annum in 2050. This is achieved via a combination of increased fuel efficiency and switching the energy source from diesel and gasoline to low-carbon electricity and hydrogen.

Figure 8.3 Total EU vehicle stock CO_2 tailpipe emissions



Note that the TECH scenario and the TECH Rapid scenario emission pathways are relatively similar. This is because ICEs leave the respective vehicle stocks at similar rates.

8.2 Impacts on emissions of particulate matter and nitrogen oxides

Particulate matter (PM_{10}) and nitrogen oxides (NO_x) emitted from road transport have a substantial impact on local air quality with harmful consequences for human health in many urban centres. The reduction of both pollutants is a substantial co-benefit of decarbonising passenger cars.

In the central TECH scenario, particulate matter emissions from vehicle exhausts are cut from around 3,613 tonnes per year in 2017 to around 54 tonnes in 2050 (see Figure 8.4) and NO_x emissions from vehicle exhausts are cut from 115,162 tonnes in 2017 to 5,672 tonnes in 2050 (see Figure 8.5).

Figure 8.4 Total particulate matter (PM_{10}) tailpipe emissions in the CPI, TECH and TECH Rapid scenarios (Tons)

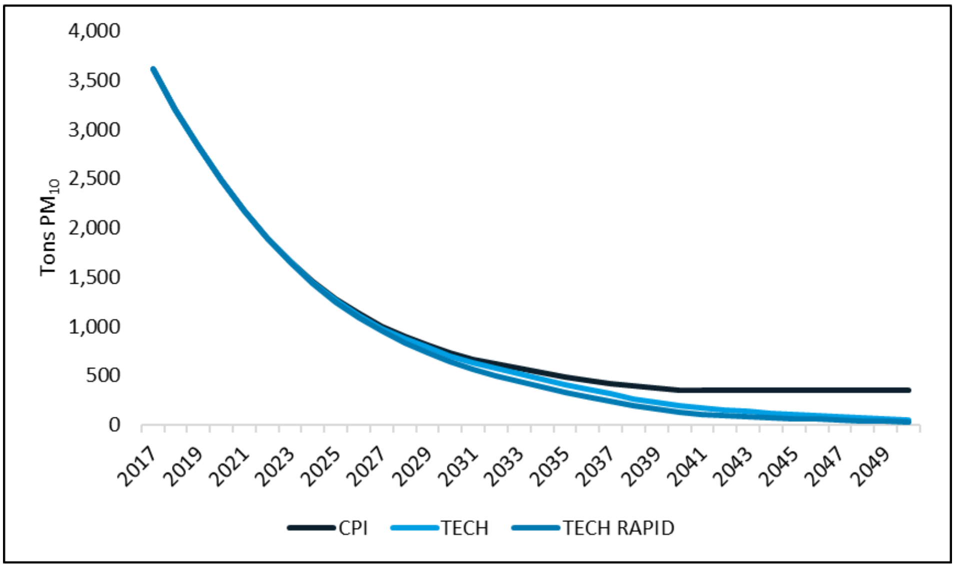
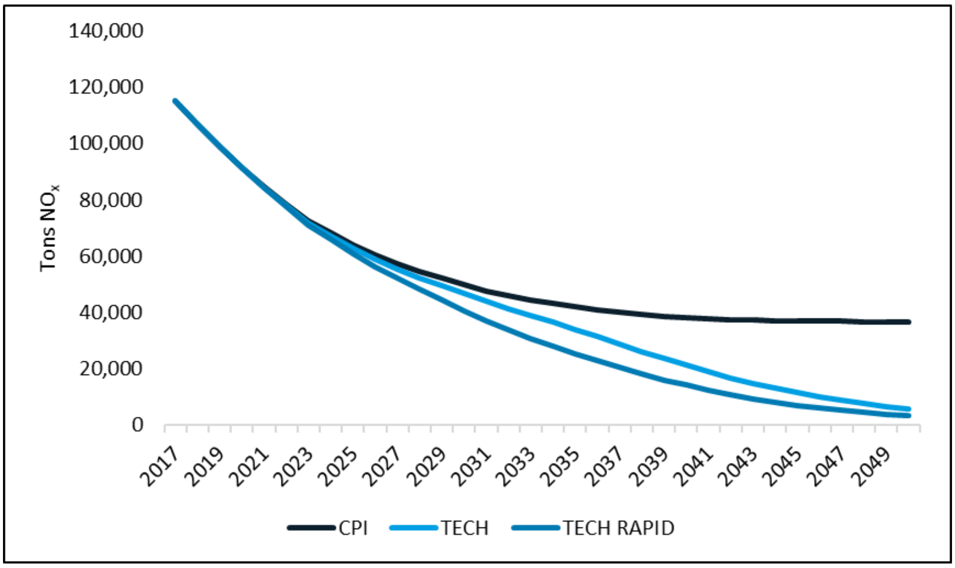


Figure 8.5 Total NO_x tailpipe emissions in the CPI, TECH and TECH Rapid scenarios (Tons)



In the short to medium term, much of the reduction seen across all scenarios is from the impact of the Euro 5 and Euro 6 emissions standards. As these standards are already in place and set out to 2020 for ICEs, the reduction to 2030 is through the replacement in the vehicle stock of the least efficient older ICE-based vehicles by more efficient newer ICE-based vehicles. However, beyond 2030, tailpipe emissions in the CPI scenario decrease at a slower rate compared to the TECH and TECH Rapid scenario. This is mainly achieved by the transition away from petrol and diesel vehicles towards zero emissions electricity and hydrogen.

It is worth noting that the particulate emissions that we model only refer to *tailpipe* emissions. While substantial, they are only one source of local air pollutants from road transport. The largest source of emissions of particulates from road transport is tyre and brake wear and road abrasion which have been shown to account for over half of total particulate matter emissions.

9 Using gas to decarbonise transport

An additional scenario (TECH Gas) was developed to assess the role gas cars could play in the decarbonisation of the passenger vehicle fleet in Spain. Because this scenario is not considered to as plausible as the TECH and TECH Rapid scenario, the TECH gas is presented separately in this section of the report.

The section presents an overview of the narrative and assumptions that underpin the TECH GAS scenario, as well as its main environmental and economic impacts, similar to the results presented for the TECH (and TECH Rapid scenario) presented above.

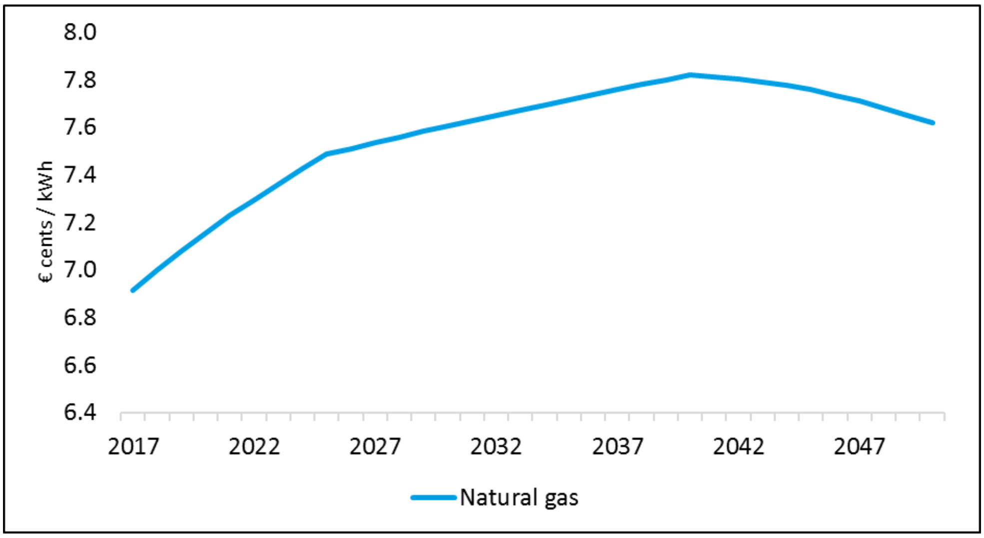
9.1 Narrative and assumptions

In the TECH GAS scenario, the EC's proposed 2025 and 2030 CO_2 emission standards for passenger vehicles are met based on a rapid deployment of CNG/biomethane cars. The aim of this scenario is to assess whether a deployment of gas cars can represent a realistic alternative to the deployment of advanced powertrain, and as such act as a bridge-technology towards the full decarbonisation of the vehicle fleet post 2030.

Natural gas

To create a projetion of natural gas prices for the period up to 2050, we rely on the average CNG price in the Spanish refuelling stations in 2017 and on the natural gas price projections developed by the IEA in its November 2017 World Energy Outlook. The price of CNG is therefore assumed to grow in line with the IEA's projections and is presented in Figure 9.1.

Figure 9.1: Price projections for natural gas (€ cents / kWh)



Biogas

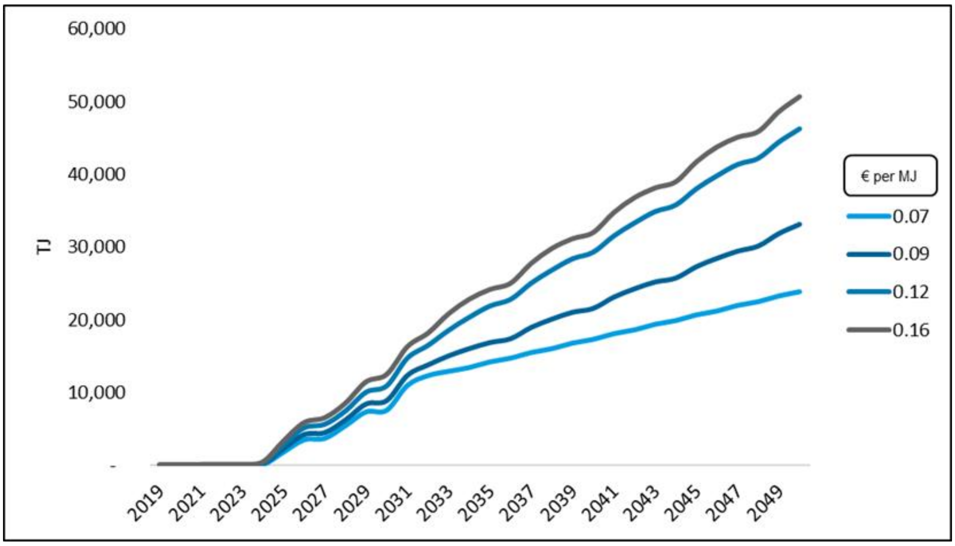
We consider the potential role of domestically-produced biogas as a vehicle fuel that can be blended with natural gas to reduce its climate change impact. This is based on data from a recent study[35] produced by the International Council on Clean Transportation (ICCT), in which the total technical potential

[35] Baldino, C., Pavlenko, N., & Searle, S. (in press). The potential for low carbon renewable gas as a transport fuel in France, Italy, and Spain. Washington, DC: International Council on Clean Transportation.

for additional sustainable, low-carbon biogas production in Spain from 2019 to 2050 is assessed.

In the ICCT's study, projections of total technical potential are made using different cost assumptions for biogas[36], as presented in Figure 9.2.

Figure 9.2 Total technical potential (cost-supply curves) for low-carbon biogas production in Spain



Source: ICCT

In the TECH Gas scenario, we assume that the maximum economical biogas potential (i.e. biogas potential at the highest cost point included in ICCT's analysis) in Spain will be realised (around 50,000 TJ in 2050) and that all of the obtained biogas – additional to existing capacity - will be used as an engine fuel for passenger cars.

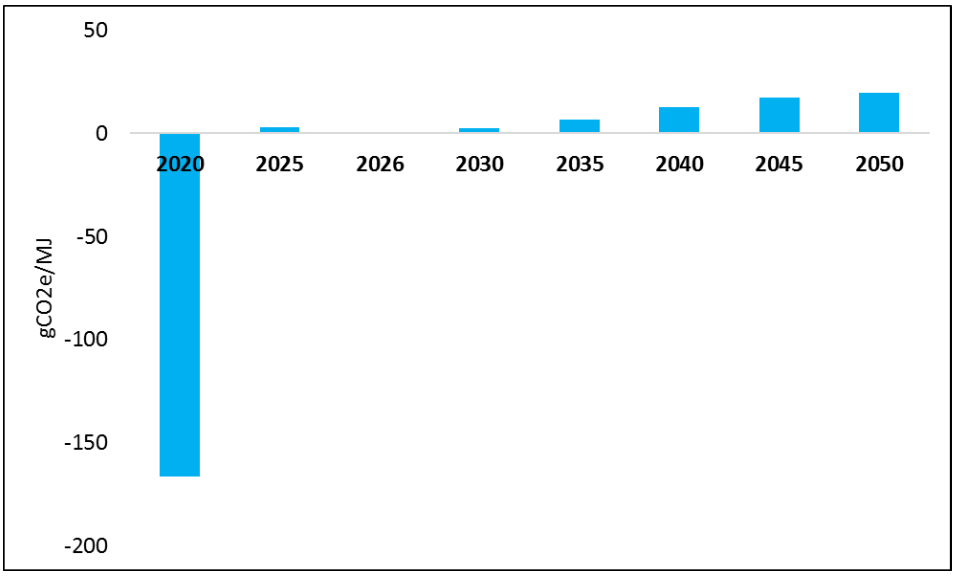
The ICCT considered four different production pathways, namely:

- livestock manure
- wastewater treatment sludge
- gasified bio-waste
- renewable power-to-gas (P2G)

Depending on the production process, biogas can have different GHG intensities. We therefore estimated a weighted average emission factor for the biogas to be blended with natural gas: Figure 9.3 shows the evolution of the derived biogas emission intensity according to the projected biogas production mix.

[36] The ICCT estimated a) the total technical potential for additional sustainable, low-carbon biogas production and b) cost supply curves for additional sustainable low-carbon biogas to be supplied as a transport fuel in Italy and Spain from 2019-2050. The cost supply curves are based on retail gas prices and do not include any policy support.

Figure 9.3 Biogas GHG intensity (2019 – 2050)



Source: CE using ICCT data.

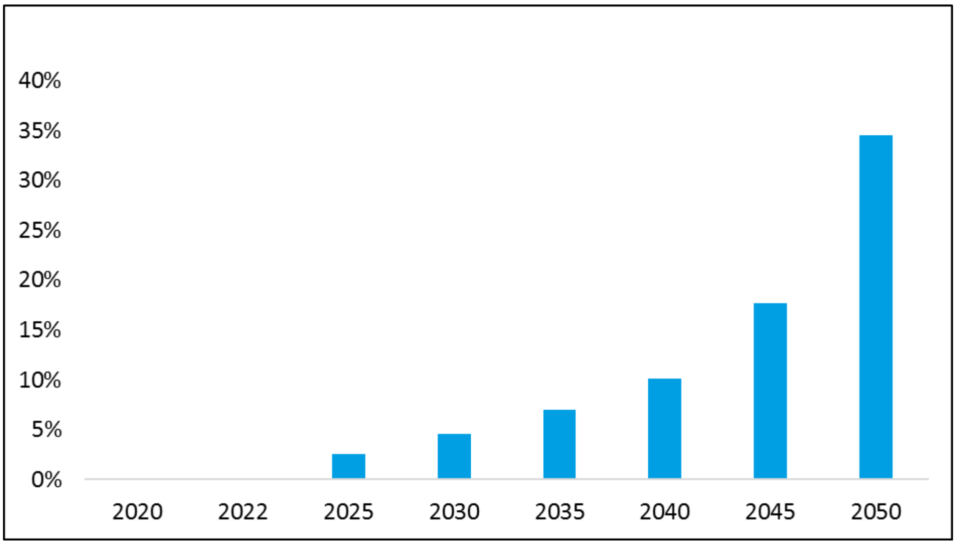
As most of the sustainable biogas will be produced using livestock manure in 2020, a negative emission intensity has been calculated[37]. However, as the production potential of this pathway is projected to be very limited by cost, most of the biogas in the following years will be produced using gasified bio-waste and, especially, renewable power-to-gas technology. This evolution for the biogas production mix will lead to a positive average GHG emission intensity of approximately 2.4 gCO_2e/MJ in 2030 and 20 gCO_2e/MJ in 2050[38].

It is assumed that all of the future additional nationally-produced sustainable biogas is blended with natural gas and used as engine fuel for passenger cars. Given the estimated production levels and fuel requirements from the increasing fleet of natural gas cars, we calculated the maximum blending share in each of the projected years. Figure 9.4 depicts these shares.

[37] ICCT's analysis assumes negative lifecycle CO2 emissions of -264 gCO2e/MJ for livestock manure biogas following the California Air Resources Board

[38] ICCT assumes positive lifecycle CO2e emissions for renewable power-to-gas of 32 gCO2e/MJ following their previous analysis.

Figure 9.4 Share of biogas blending with natural gas (2019 – 2050)



Source: CE using ICCT data.

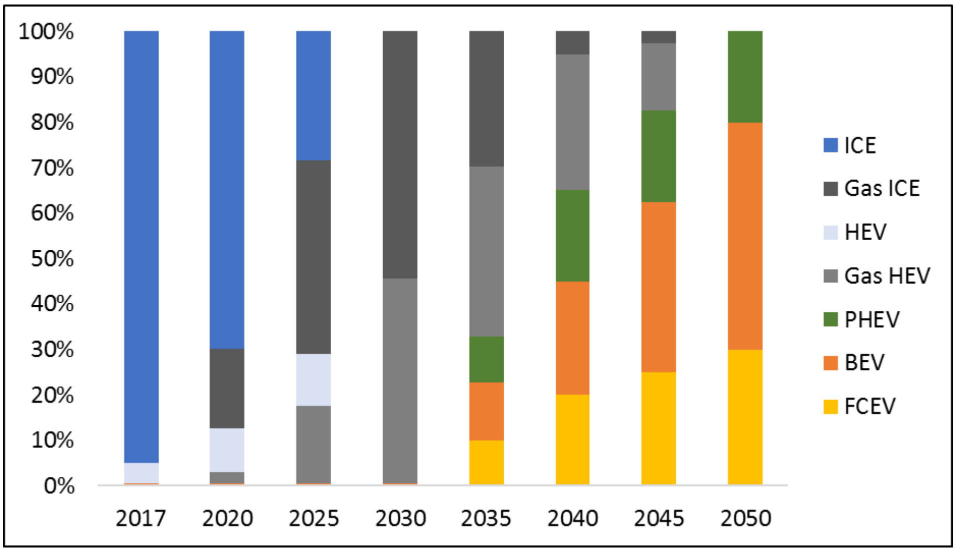
Given the fairly limited production potential of low-carbon biogas, the percentages at which natural gas can be blended with biogas up to 2030 are very modest. However, given the progressive introduction of biogas produced using P2G and the reducing demand of gas as engine fuel post 2030, the blending share could increase up to 35% in 2050.

9.2 Vehicle sales mix and stock

As in the CPI, TECH and TECH Rapid scenarios, the TECH GAS scenario is defined by the rate of deployment of different powertrains. In other words, the scenario is defined by a specific sales mix, which leads to a particular composition of the vehicle stock.

Figure 9.5 gives an overview of the assumed sales mix and the resulting projected composition of the vehicle stock in the TECH GAS scenario.

Figure 9.5 Sales mix for the TECH GAS scenario (2017 – 2050)



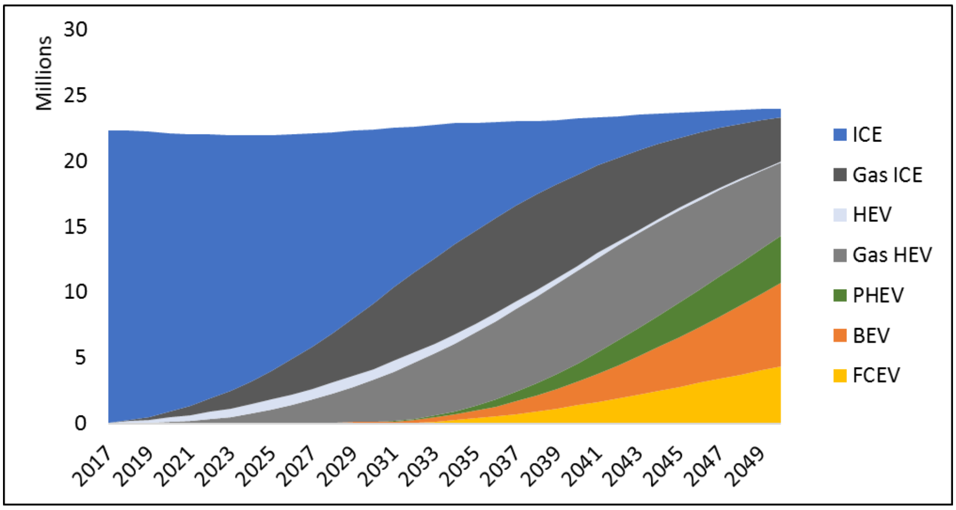
A scenario in which average emissions of new cars are reduced in line with the EC's proposed emission standards - and in which the take-up of electric vehicles remains very marginal up to 2030 - requires a very rapid deployment of CNG cars:

- By 2020, around 20% of new cars sold on the Spanish market would have to be CNG cars
- By 2025, around 60% of new cars sold on the Spanish market would have to be CNG cars (including a 24% share of CNG HEVs)
- By 2030, the share of new gas cars being sold on the Spanish market would have to rise to almost 100% (of which 45% would be CNG HEVs)

The same technology improvements as for petrol and diesel ICE vehicles are applied to CNG cars. Post 2030, further efficiency improvements to CNG cars would however be insufficient to generate the emission reductions required to arrive at a drastically decarbonised vehicle fleet in 2050. A very rapid and unrealistic deployment of more advanced powertrains (BEVs, PHEVs, FCEVs) post 2030 would therefore be required.

Figure 9.6 shows the projected evolution of the stock of passenger cars in Spain following the described sales mix of new cars.

Figure 9.6 Vehicle stock for the TECH GAS scenario (2017 – 2050)

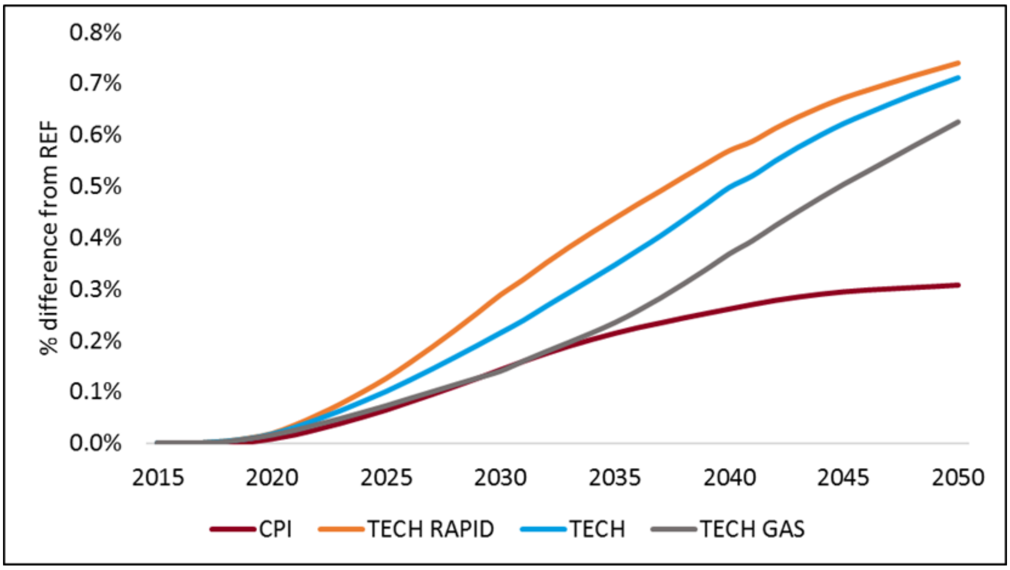


The increasing deployment of new CNG cars in the first projected decade inevitably has an impact on the composition of the vehicle stock, with the result that in 2030 CNG vehicles (including CNG HEVs) represent more than 35% of the total stock. Despite the rapidly increasing sales of more advanced powertrains like BEVs, PHEVs and FCEVs post 2030, the stock only adjusts gradually and the number of circulating CNG cars increases to almost 14 million in 2040. By 2050, sales of CNG cars are phased out, but ICEs still amount to 17% of the car stock.

9.3 Economic impacts

The rapid introduction of CNG cars into the Spanish sales mix has a double effect on the national economy. On the one hand, consumers who buy a CNG car will face a lower total cost of ownership (TCO) compared to conventional petrol and diesel cars, in particular due to lower fuel costs. This has a beneficial effect on the economy as households will be able to switch part of their spending from fuel to other goods and services. On the other hand, oil imports are progressively substituted with imports of natural gas which is cheaper than crude and refined oil. Overall, this results in a beneficial effect for the Spanish economy compared to the reference (REF) scenario, and in 2030 GDP is projected to be 0.1% higher in the TECH Gas scenario.

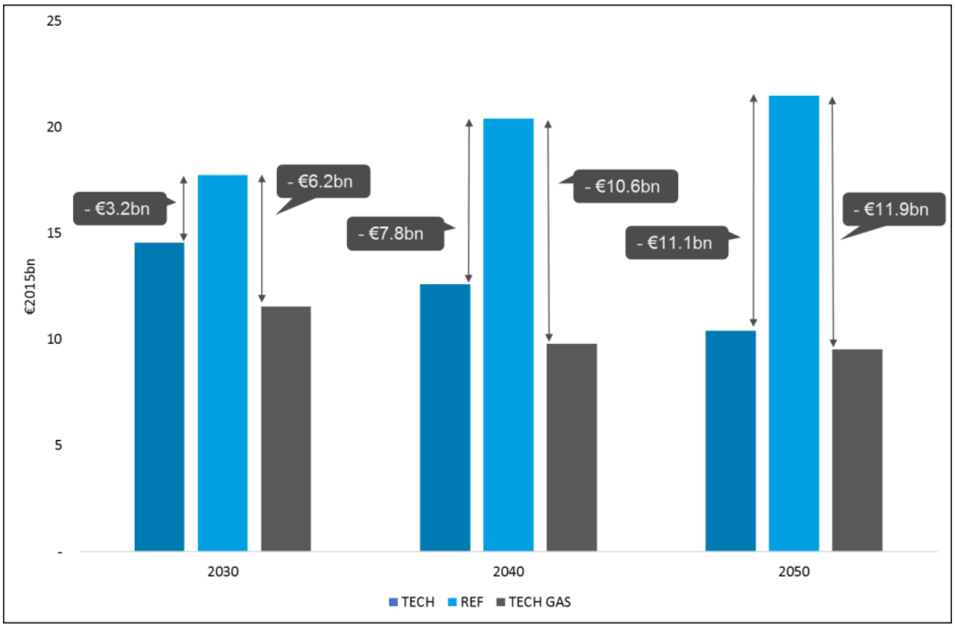
Figure 9.7 GDP in CPI, TECH, TECH Rapid and TECH Gas scenarios compared to REF



Despite the positive economic outcomes highlighted above, the TECH GAS scenario does not achieve the same increase in GDP as in the TECH scenario and, in particular, the TECH Rapid scenario. In the TECH and TECH Rapid scenario there is a steep reduction in fuel imports due to a rapid substitution of ICEs with BEVs and PHEVs running on nationally produced electricity, while in the TECH Gas scenario fuel (natural gas) continues to be imported. As advanced powertrains enter into the car stock from 2030 onwards in the TECH GAS scenario, fuel imports progressively decline, and the economic benefit becomes bigger. However, in 2050 the increase in GDP is still smaller than in the TECH and TECH Rapid scenarios.

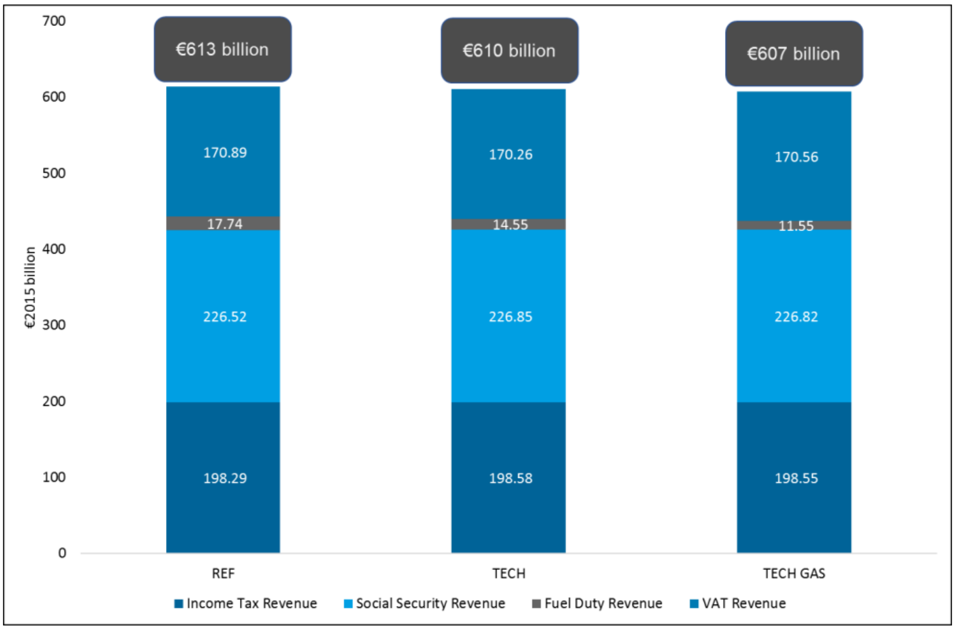
The switch from petrol and diesel to natural gas as the main fuel for the Spanish stock of passenger cars will also have a significant impact on fuel duty tax revenues. The rapid deployment of CNG cars at the expense of petrol and diesel cars in TECH GAS (faster than in the TECH and TECH Rapid scenarios) results in a steeper reduction in revenues from petrol and diesel taxes compared to the other scenarios. Although natural gas is subject to taxation, this is at a much lower rate than conventional vehicle fuels. The impact is demonstrated in Figure 9.8, which shows the public revenues from fuel taxes in the Reference case, the TECH scenario and the TECH Gas scenario.

Figure 9.8 Annual fuel duty tax revenues in REF, TECH and TECH GAS (2030, 2040, 2050)



Fuel duty revenues do not represent the biggest source of revenues for the Spanish government. As a result, the impact on total government tax revenues is estimated to be fairly limited in 2030. Figure 9.9 shows the projected total government tax revenues in the Reference case, the TECH scenario and the TECH Gas scenario in 2030.

Figure 9.9 Total government tax revenue in REF, TECH and TECH GAS in 2030



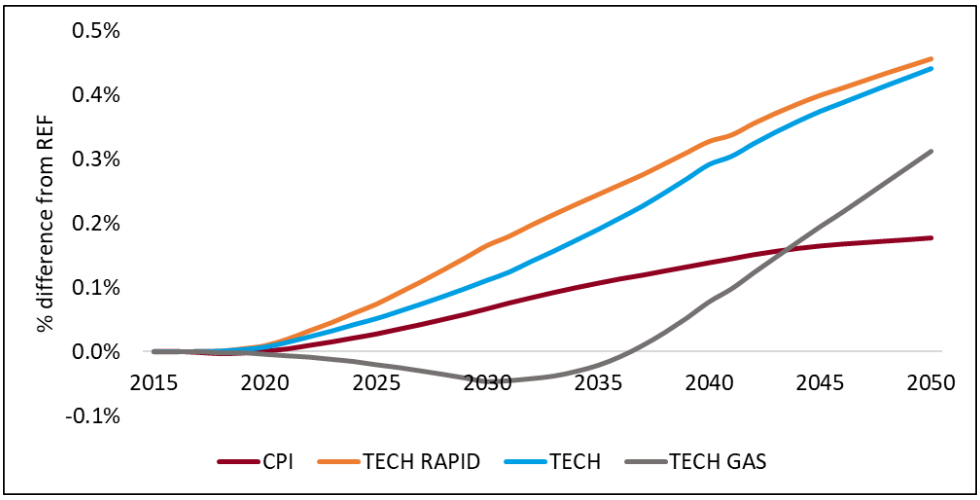
Government revenue balancing

The reduction in fuel duty revenues would need to be balanced by tapping into other sources of revenue or a reduction in public spending (assuming that the government does not wish to expand their borrowing). The government could decide to recoup the lost revenue directly through other taxes on the same group of consumers, for example through increases in excise duties (where they exist) or road charging.

As in the TECH and TECH Rapid scenarios, revenue balancing was introduced to model the transition towards more advanced powertrains without impacting on public finances. This is done by allowing the model to increase the current VAT rate (21% in Spain) to cover the losses in fuel duty revenues over future years. As it is reasonable to assume that final consumers will ultimately bear the cost to close the gap arising in the public budget, an increase in the applied VAT rate represents a good approximation of the change in tax policy that the decision maker will introduce.

Figure 9.10 shows the GPD results with revenue balancing. The results for the CPI, TECH and TECH Rapid are the same as in Figure 7.3, but Figure 9.10 also includes the TECH Gas scenario. While in the CPI, TECH and TECH Rapid scenarios there will be a positive economic impact even with revenue balancing, the TECH GAS scenario is the only scenario in which there will be a negative economic impact.

Figure 9.10 GDP in CPI, TECH, TECH Rapid and TECH Gas scenarios compared to REF, with revenue balancing



In TECH GAS the 2021, 2025 and 2030 CO2 reduction targets are achieved through a rapid and substantial introduction of CNG cars and gas HEVs, and petrol and diesel cars are phased out much more rapidly than in the other scenarios. This leads to a more sudden and pronounced fall in fuel duty revenues, which needs to be balanced with an increase in the VAT rate. Overall, the rapid shift away from a heavily-taxed fuel (gasoline) to a less-taxed fuel (natural gas) results in a net negative effect on the Spanish economy (even as compared to the REF scenario).

9.4 Environmental impacts

This section presents the results from the vehicle stock model on fuel consumption, total and average carbon emissions for the TECH GAS scenario.

The total energy demand of the vehicle stock for each scenario is defined in terajoules (TJ). In the model, this is converted into demand values for the respective energy sources (petrol, diesel, gas, electricity, hydrogen). As Figure 9.11 illustrates, total fuel consumption falls over the projected period. This is due to the deployment of more efficient advanced powertrains like electric and fuel cells vehicles after 2030.

In a marked contrast to the other scenarios, natural gas becomes the most prominent fuel for the Spanish fleet of passenger cars. As CNG cars have a similar efficiency levels to conventional petrol and diesel cars, total fuel consumption does not rapidly decrease as in the TECH and TECH Rapid scenarios and, by 2050, the overall reduction is less pronounced compared with the TECH and TECH Rapid scenarios.

Figure 9.11 Energy demand in the TECH GAS scenario (2017 – 2050)

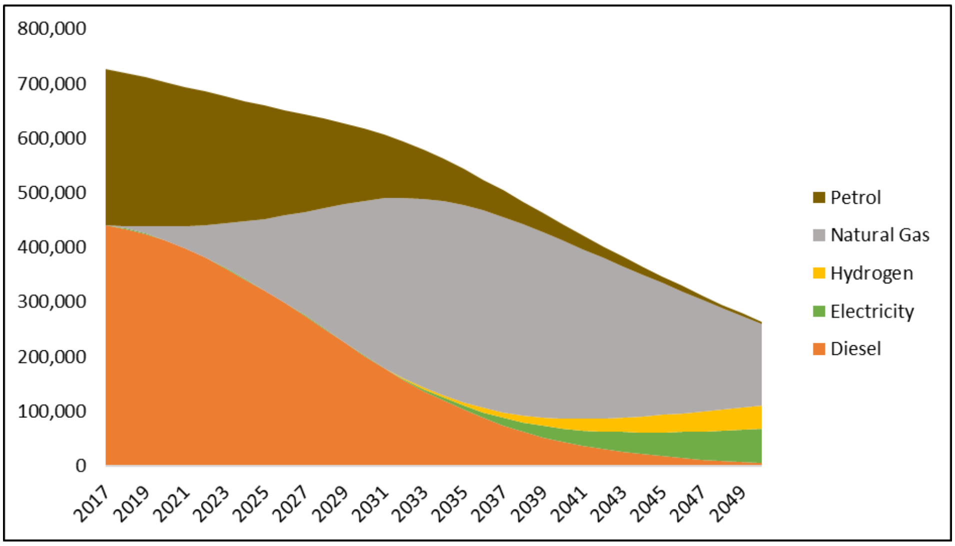
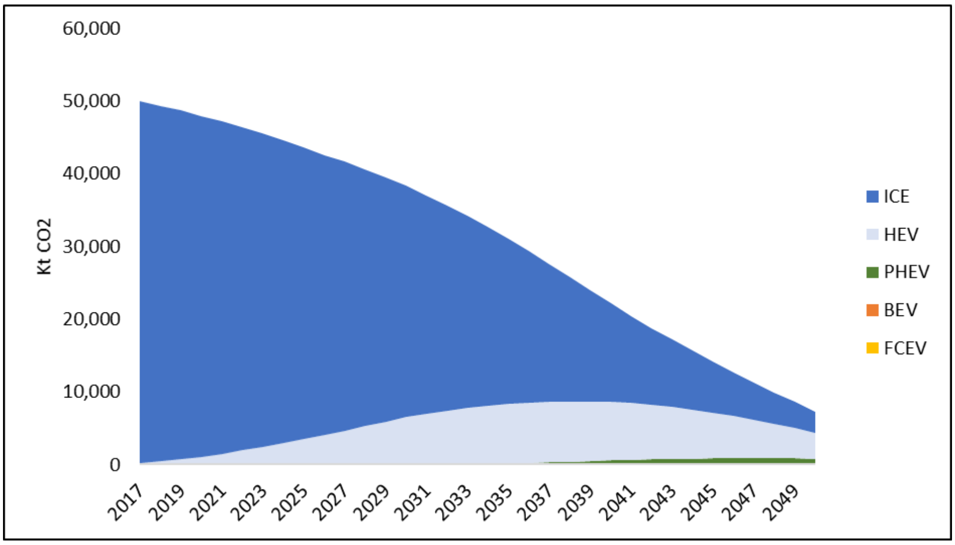


Figure 9.12 shows the total tailpipe emission pathway in the TECH GAS scenario. Total tailpipe CO_2 emissions drop considerably between 2017 and 2050. However, the overall emission reduction is slower and not as pronounced as in the TECH and TECH Rapid scenarios due to the extended presence of ICEs (including CNG cars) in the vehicle stock.

Figure 9.12 Total tailpipe CO_2 emission in the TECH GAS scenario (2017 – 2050)



Because the TECH GAS scenario has been designed to meet the 2021, 2025 and 2030 EU emission targets[39] for new passenger cars, the average vehicle emissions fall in line with the CPI scenario up to 2030. As the sales shares of

[39] In line with the proposal of the European Commission, new cars meet the 95 gCO2/km (NEDC) target in 2021 and achieve further reductions by 15% in 2025 and by 30% in 2030 compared to the average emissions in 2021.

electric and hydrogen vehicles grow thereafter, average emissions continue to decrease and finally converge towards the average emissions for the TECH and TECH Rapid scenarios in 2050.

Figure 9.13 Average new vehicle emissions (gCO_2/km) in all the scenarios developed (2000 – 2050)

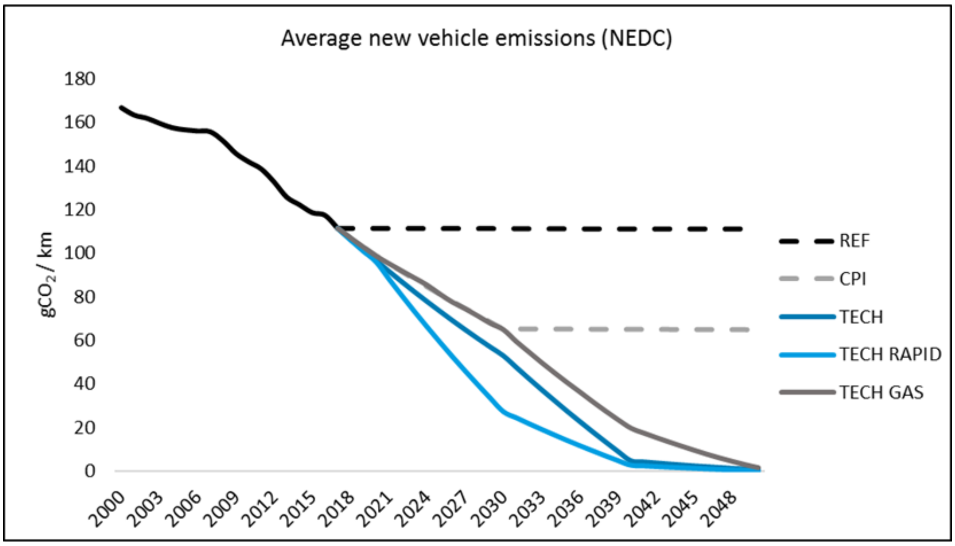
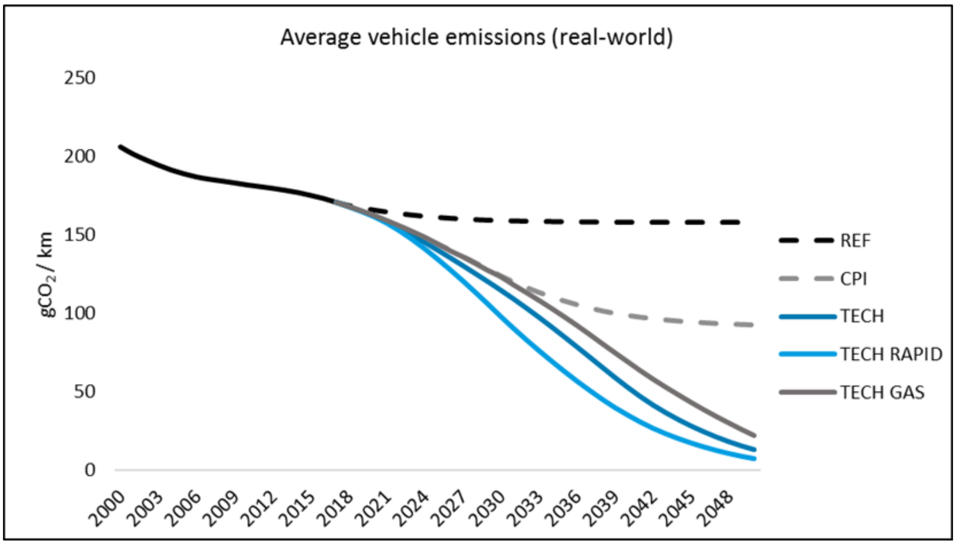


Figure 9.14 Real-world average vehicle emissions (gCO_2/km) in all the scenarios developed (2000 – 2050)



When looking at the average carbon emissions of the circulating fleet as depicted in Figure 9.14, we see how the deployment of gas cars first and electric and hydrogen vehicles after 2030 lead to a progressive decarbonisation of the fleet.

9.5 Infrastructure requirements

As part of this study, the deployment of the CNG refuelling stations that are required to supply the growing stock of CNG cars and gas HEVs was modelled.

We considered one type of CNG refuelling station with a capacity of 500kg / day of natural gas. To estimate the total number of stations required in each year, we relied on a density assumption of 600 gas vehicles per refuelling station which corresponds to the threshold level for the natural gas infrastructure suggested by the European Commission[40].

To estimate the investment costs required to build the new gas refuelling infrastructure, we relied on capital costs estimates from Ricardo-AEA[41] as presented in Table 9.1.

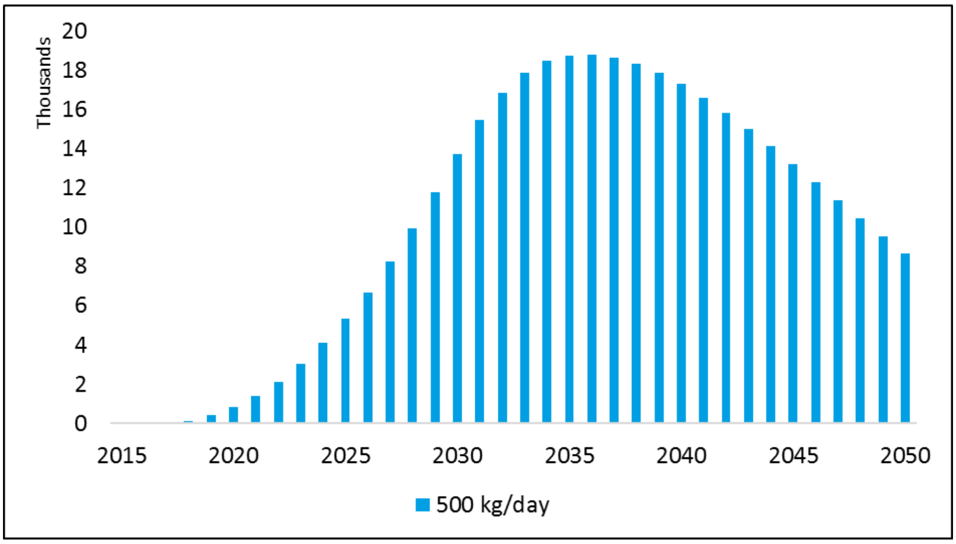
Table 9.1 Cost assumptions for a CNG refuelling station

Station size	Capital costs (€)	Civil engineering costs (€)
500 kg / day	184,000	57,500

Source: Ricardo-AEA.

Figure 9.15 and Figure 9.16 show the modelled deployment of CNG refuelling stations and the estimated annual investment requirements in the TECH GAS scenario. As the sales of gas vehicles will progressively decline post 2030 as well as the number of circulating CNG cars, no more investments will be required to build new gas refuelling stations from about 2040 onwards. The gas stations built before 2030 will be sufficient to satisfy the gas demand from the existing stock post 2030, and the total number of stations will slowly decline once the progressively older stations will be phased out.

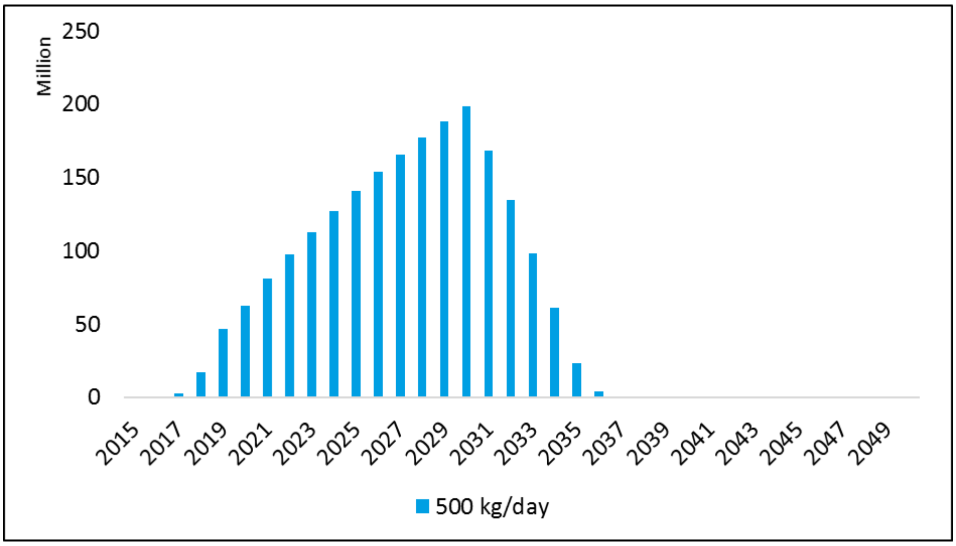
Figure 9.15 Deployment of CNG refuelling stations in TECH GAS (2015 – 2050)



[40] The European Commission presented a detailed assessment of the National Policy Framework of each Member State on the infrastructure deployment for alternative fuel vehicles. The document is available at: https://eur-lex.europa.eu/resource.html?uri=cellar:d80ea8e8-c559-11e7-9b01-01aa75ed71a1.0001.02/DOC_1&format=PDF.

[41] Ricardo-AEA (2016), The role of natural gas and biomethane in the transport sector. Available at: https://www.transportenvironment.org/sites/te/files/publications/2016_02_TE_Natural_Gas_Biomethane_Study_FINAL.pdf.

Figure 9.16 Annual investment required for the CNG refuelling infrastructure in TECH GAS (2015 – 2050)



10 Conclusions

This study focused on the potential benefits of decarbonising passenger vehicles in Spain.

A transition to low carbon mobility is technologically feasible. We know that technological solutions exist and even though there is some uncertainty about what will happen in the future, we have a good sense of trends and estimates, associated costs and potential for the development of these technologies, and have explored different assumptions around these. BEVs are expected to achieve cost parity with conventional petrol and diesel cars by 2030.

A transition to low carbon mobility is economically desirable. The technology transitions of the TECH and TECH Rapid scenario yielded net positive economic outcomes, which is made possible by the reduction in spending on imported oil as well as less overall spending by households on car ownership and more on other goods and services.

The economic benefits are positive in the short, medium and long term. The economic benefit increases over the period to 2050 as oil imports are further reduced through the build-up of efficient vehicles in the stock. The implication of this finding is that a transition towards low carbon cars to meet the European Union’s climate goals can be adopted without fear of substantial economic damage in Spain. Lowering Spain’s dependence on imported oil also contributes to its energy security.

A transition to low carbon mobility is also environmentally desirable. In the TECH and TECH Rapid scenario, CO_2 emissions would be substantially reduced and local air quality improved.

Our analysis did not look into specific policies that would bring about the transition. Participants agreed that considerable transition challenges remain to be overcome:

- While this study has not sought to analyse impacts on competitiveness in the sector, the Spanish auto industry needs to remain at the cutting edge of clean technology innovation to remain competitive and thereby to maintain its share of a rapidly evolving market.
- Employment in the motor vehicles sector would likely fall post 2030 as advanced powertrains dominate the market, since they require fewer people to manufacture and assemble the components. There is time to plan for this within the sector by looking at natural rates of retirement and retraining, but affirmative action will be required. Efforts must be made to ensure workers who are currently producing legacy technologies are retrained for quality jobs in producing technologies for which demand is expected to increase in the future.
- The transition depends on the rapid deployment of charging infrastructure at considerable scale and cost. Active support for the deployment of sufficient infrastructure is needed to inspire consumer confidence. Without this, uptake of EVs will be limited.

- Even though the fiscal impact of the loss of fuel duty revenues is marginal, revenue balancing may require collecting revenues elsewhere. Policy-makers could opt to introduce other taxes on road users to recoup the shortfall from the same group of consumers.
- Even if generating the additional electricity in the coming decades is not a challenge, the mass adoption of electric vehicles would imply that the electricity grid needs to be adapted to recharging needs. A shift to electric vehicles could put some strain on the electricity generation and distribution system by exacerbating peak loads. However, our research suggests that there are technologies that could manage this by helping to spread out the demand (e.g. smart-charging). Moreover, such technologies could afford benefits to EV owners by offering flexibility services back to the grid.

Despite the challenges, the transition towards zero emission vehicles will financial advantages to the public, improve air quality, reduce CO_2 emissions, and benefit the Spanish economy in general.

Appendix A E3ME model description

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.

Recent applications

Recent applications of E3ME include:

- a global assessment of the economic impact of renewables for IRENA
- contribution to the EU's Impact Assessment of its 2030 climate and energy package
- evaluations of the economic impact of removing fossil fuel subsidies in India and Indonesia
- analysis of future energy systems, environmental tax reform and trade deals in East Asia
- 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.

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 1970-2014 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.

The main dimensions of the model

The main dimensions of E3ME are:

- 59 countries – all major world economies, the EU28 and candidate countries plus other countries' economies grouped

- 43 or 69 (Europe) industry sectors, based on standard international classifications
- 28 or 43 (Europe) 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.

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

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.

E3ME as an E3 model

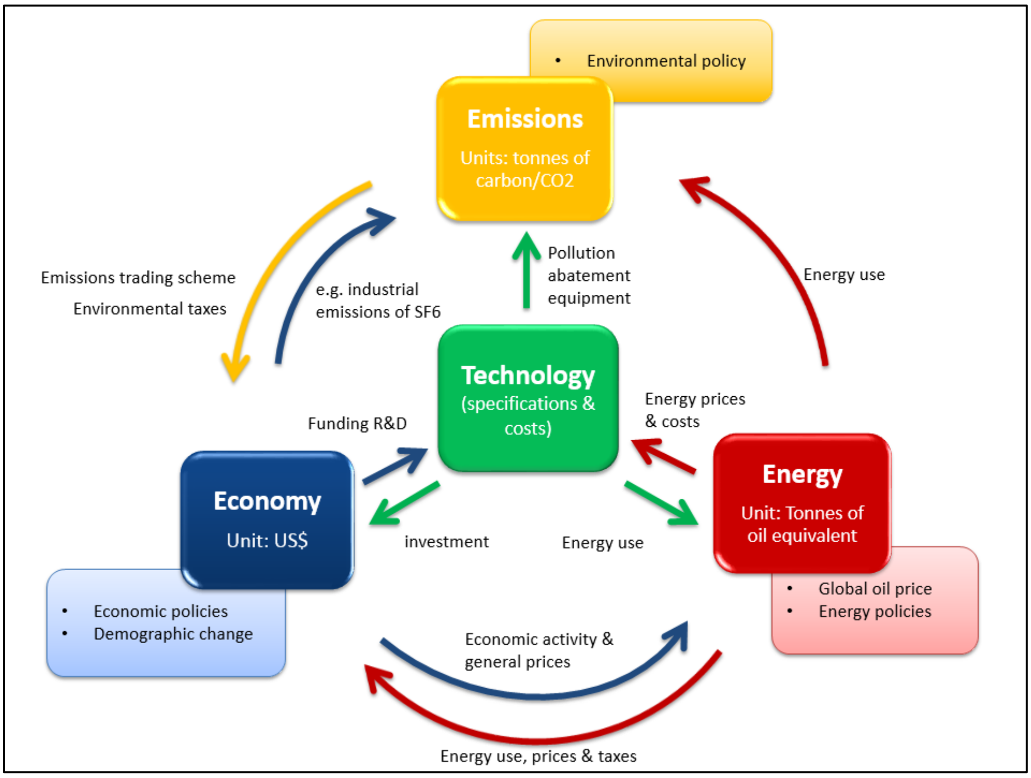
The E3 interactions

The figure below 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[42].



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

[42] See Mercure (2012).

- 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.

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.

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[43], which are included as standard in the model's results.

Key strengths of E3ME

In summary the key strengths of E3ME are:

[43] 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. See Barker et al. (2009).

- 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

Applications of E3ME

Scenario-based analysis

Although E3ME can be used for forecasting, the model is more commonly used for evaluating the impacts of an input shock through a scenario-based analysis. The shock may be either a change in policy, a change in economic assumptions or another change to a model variable. The analysis can be either forward looking (ex-ante) or evaluating previous developments in an ex-post manner. Scenarios may be used either to assess policy, or to assess sensitivities to key inputs (e.g. international energy prices).

For ex-ante analysis a baseline forecast up to 2050 is required; E3ME is usually calibrated to match a set of projections that are published by the European Commission and the IEA but alternative projections may be used. The scenarios represent alternative versions of the future based on a different set of inputs. By comparing the outcomes to the baseline (usually in percentage terms), the effects of the change in inputs can be determined.

It is possible to set up a scenario in which any of the model's inputs or variables are changed. In the case of exogenous inputs, such as population or energy prices, this is straight forward. However, it is also possible to add shocks to other model variables. For example, investment is endogenously determined by E3ME, but additional exogenous investment (e.g. through an increase in public investment expenditure) can also be modelled as part of a scenario input.

Price or tax scenarios

Model-based scenario analyses often focus on changes in price because this is easy to quantify and represent in the model structure. Examples include:

- changes in tax rates including direct, indirect, border, energy and environment taxes
- changes in international energy prices
- emission trading schemes

Regulatory impacts

All of the price changes above can be represented in E3ME's framework reasonably well, given the level of disaggregation available. However, it is also possible to assess the effects of regulation, albeit with an assumption about effectiveness and cost. For example, an increase in vehicle fuel-efficiency standards could be assessed in the model with an assumption about how efficient vehicles become, and the cost of these measures. This would be entered into the model as a higher price for cars and a reduction in fuel consumption (all other things being equal). E3ME could then be used to determine:

- secondary effects, for example on fuel suppliers
- rebound effects[44]
- overall macroeconomic impacts

Table 1: Main dimensions of the E3ME model

	Regions	Industries (Europe)	Industries (non-Europe)
1	Belgium	Crops, animals, etc.	Agriculture etc.
2	Denmark	Forestry & logging	Coal
3	Germany	Fishing	Oil & Gas etc.
4	Greece	Coal	Other Mining
5	Spain	Oil and Gas	Food, Drink & Tobacco
6	France	Other mining	Textiles, Clothing & Leather
7	Ireland	Food, drink & tobacco	Wood & Paper
8	Italy	Textiles & leather	Printing & Publishing
9	Luxembourg	Wood & wood prods	Manufactured Fuels
10	Netherlands	Paper & paper prods	Pharmaceuticals
11	Austria	Printing & reproduction	Other chemicals
12	Portugal	Coke & ref petroleum	Rubber & Plastics
13	Finland	Other chemicals	Non-Metallic Minerals
14	Sweden	Pharmaceuticals	Basic Metals
15	UK	Rubber & plastic products	Metal Goods
16	Czech Rep.	Non-metallic mineral prods	Mechanical Engineering
17	Estonia	Basic metals	Electronics
18	Cyprus	Fabricated metal prods	Electrical Engineering
19	Latvia	Computers etc.	Motor Vehicles
20	Lithuania	Electrical equipment	Other Transport Equipment
21	Hungary	Other machinery/equipment	Other Manufacturing
22	Malta	Motor vehicles	Electricity
23	Poland	Other transport equip	Gas Supply
24	Slovenia	Furniture; other manufacture	Water Supply
25	Slovakia	Machinery repair/installation	Construction
26	Bulgaria	Electricity	Distribution
27	Romania	Gas, steam & air cond.	Retailing
28	Norway	Water, treatment & supply	Hotels & Catering
29	Switzerland	Sewerage & waste	Land Transport etc.
30	Iceland	Construction	Water Transport
31	Croatia	Wholesale & retail MV	Air Transport
32	Turkey	Wholesale excl MV	Communications
33	Macedonia	Retail excl MV	Banking & Finance
34	USA	Land transport, pipelines	Insurance
35	Japan	Water transport	Computing Services
36	Canada	Air transport	Professional Services
37	Australia	Warehousing	Other Business Services
38	New Zealand	Postal & courier activities	Public Administration
39	Russian Fed.	Accommodation & food serv	Education
40	Rest of Annex I	Publishing activities	Health & Social Work
41	China	Motion pic, video, television	Miscellaneous Services
42	India	Telecommunications	Unallocated
43	Mexico	Computer programming etc.	

[44] In the example, the higher fuel efficiency effectively reduces the cost of motoring. In the long-run this is likely to lead to an increase in demand, meaning some of the initial savings are lost. Barker et al (2009) demonstrate that this can be as high as 50% of the original reduction.

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	Indonesia	Architectural & engineering	
51	Rest of ASEAN	R&D	
52	Rest of OPEC	Advertising	
53	Rest of world	Other professional	
54	Ukraine	Rental & leasing	
55	Saudi Arabia	Employment activities	
56	Nigeria	Travel agency	
57	South Africa	Security & investigation, etc.	
58	Rest of Africa	Public admin & defense	
59	Africa OPEC	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		Households as employers	
68		Extraterritorial orgs	
69		Unallocated/Dwellings	

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