European Climate Foundation

Potential options and technology pathways for delivering zero-carbon freight in Spain

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Final Report

Octobert
2021

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Contents

Tables

Figures

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 diesel vehicles 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.
Battery electric vehicle	BEV	This category refers to fully electric vehicles, with a battery but no internal combustion engine.
Fuel cell electric vehicle	FCEV	FCEVs are hydrogen fuelled vehicles, which include a fuel cell and a battery-powered electric motor.
Electric road system	ERS	Refers to electrified infrastructure to supply EV vehicles with a constant power supply across portions of the road network. BEV-ERS are vehicles with the required pantograph to enable them to draw charge from ERS.
Zero emissions vehicle	ZEV	Includes all vehicles with zero tailpipe emissions (e.g. FCEVs and BEVs).
Electric vehicles	EV	All vehicles which are fuelled directly via electricity (i.e. BEVs and PHEVs).
Vehicle types		
Light Heavy goods vehicles	LHGVs	Heavy goods vehicles with a gross vehicle weight of 3.6-7.5 tonnes.
Medium Heavy goods vehicles	MHGVs	Heavy goods vehicles with a gross vehicle weight of 7.6-16 tonnes.
Heavy Heavy goods vehicles	HHGVs	Heavy goods vehicles with a gross vehicle weight greater than 16 tonnes.
Heavy goods vehicles	HGVs	Goods vehicles with a gross vehicle weight greater than 3.6 tonnes. This acronym is used to refer to LHGVs, MHGVs and HHGVs altogether.
Other acronyms		
Original equipment manufacturers	OEMs	Equipment manufacturers of motor vehicles and their components.
Total Cost of Ownership	TCO	Total cost of purchasing, owning, and operating (fuel, maintenance, etc.) a vehicle over its lifetime.
Operating expenses	OPEX	Expenses a business incurs through its normal business operations.
Capital expenditures	CAPEX	Funds required to acquire and install a certain physical asset.

Operations and maintenance	O&M	The category of expenditure covering the operations and maintenance to provide a good or service.
Hydrogen refuelling station	HRS	Infrastructure for the dispensing of hydrogen for motor vehicles.

Executive Summary

The European Union has agreed to achieve climate neutrality by 2050. Such a transition will require a more rapid transition in the road freight vehicle fleet than implied in the previously agreed Regulation (EU) 2019/1242, which set CO_2 emissions standards for heavy-duty vehicles. This regulation aims to reduce the emissions of road freight transport by on average 15% and 30% by 2025 and 2030, respectively. There are a substantial proportion of older trucks operating in Spain, and rapid decarbonisation requires that these be phased out and replaced by zero carbon alternatives. This study therefore explores the potential options and technology pathways for delivering zero-carbon freight in Spain.

The aim of this study was to assess the techno-economic potential of different pathways to decarbonise road freight, considering the specific characteristics of the Spanish freight system, in terms of the nature of their freight transportation (use of different weight categories of vehicle, load factors, average trip lengths, etc.) and the infrastructure requirements to support the emerging fleet of zero carbon powertrains.

The analytical team at Cambridge Econometrics worked in coordination with the European Climate Foundation (ECF) and Transport & Environment (T&E), to understand in the specific Spanish case, what the potential pathways to decarbonisation are, and the relevant costs and benefits associated with these pathways (in terms of vehicle costs, fuel costs, infrastructure required) and the benefits of their deployment (in terms of CO_2 and other emissions).

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

The study shows that a rapid transition to zero carbon powertrains can substantially reduce the CO_2 emissions associated with the road freight fleet. As the power sector will also decarbonise and hydrogen will be produced locally by electrolysis using renewable energy sources, well-to-wheel CO_2 emissions will substantially decrease in such a scenario. However, there is a large gap between the existing policies and a trajectory consistent with the zero-carbon road freight in Spain.

Furthermore, the deployment of zero carbon vans (vehicles with a gross weight up to 3.5 tonnes) and HGVs requires the simultaneous deployment of adequate charging and refuelling infrastructure to support the growing fleet of such vehicles. Scenarios dominated by hydrogen fuel cell vehicles require the greatest total investment in infrastructure followed by the scenario dominated by ERS-enabled vehicles. Investment in charging infrastructure is substantially lower in an equivalent scenario focussed on pure battery electric vehicles. There is also a major question around how quickly some of the infrastructure could be deployed; the need for front-loaded investment in ERS is likely to mean that any transition which favours this technology will take place more slowly than a switch to battery electric or hydrogen fuel cells, with the implication of greater cumulative emissions from the road freight fleet in the interim.

The analysis of the total cost of ownership of different options shows that zero emission trucks are likely to become cheaper than ICEs in the coming years; BEVs achieve cost parity with ICEs by 2025, while ERS-enabled BEVs are already expected to be cheaper than ICEs by that time. FCEVs become cost-competitive by 2030 as hydrogen prices fall. The cost of technologies will reduce over time as economies of scale are achieved and low electricity and hydrogen prices make vehicles with advanced powertrains more cost-efficient. Zero emission trucks can further benefit from additional policies which lower the cost of these technologies, or increase the costs of diesel vehicles.

However, phasing out ICE vans in 2035 and ICE HGVs in 2040 in the TECH scenarios does not lead to zero carbon emissions of the fleet by 2050, as a number of ICE vehicles sold before the phase out will still be part of the fleet. Additional policies or technologies are therefore needed to achieve net zero emissions across the sector. It is however important to highlight that conventional ICE vehicles will become less and less competitive over their lifetime compared to electric equivalents, with the likely result that hauliers will rely less and less on these vehicles. This has the potential to lead to a more rapid transition away from the use of existing ICE vehicles than is captured in this modelling.

1 Introduction

1.1 Background

Zero carbon freight transport policy

In 2019, the European Union agreed Regulation (EU) 2019/1242, which set CO_2 emissions standards for heavy-duty vehicles through to 2030. Compared to EU average CO_2 emissions per tonne-kilometre of new vehicles sold over the period 1 July 2019 to 30 June 2020, new vehicles sold in 2025 and 2030 will have to emit on average 15% and 30% less respectively. Initially, the standards apply just to larger trucks, but the scope will be extended as part of the review of the standards due in 2022.

These CO_2 standards are a key part of a wider aim to completely decarbonise freight transportation across Europe by 2050, itself one part of the overarching aim of climate neutrality (i.e. net zero greenhouse gas emissions) by that date. There are a wide range of potential measures which can reduce emissions, and ultimately a combination of these will be required to achieve a zero-carbon freight system, including modal shift (for example away from trucks and towards trains), logistics improvements (for example, employing hub-and-spoke models to ensure that vehicles are "right-sized" for specific purposes, rather than employing large trucks for start-to-end delivery), improved vehicle efficiency (both technology- and logistics-based) and zero carbon powertrains (i.e. moving away from combustion engines and towards battery electric or hydrogen fuel cell drivetrains).

Motivation for the study

The aim of this study is to explore the potential options and technology pathways for delivering zero-carbon freight in Spain. The study explores the techno-economic potential of different pathways to decarbonise road freight, taking into account the specific characteristics of the Spanish freight system, in terms of the nature of the freight transportation system (use of different weight categories of vehicle, load factors, average trip lengths, etc.) and the infrastructure needs at the country level (e.g. the required electric charging and hydrogen refuelling infrastructure requirements).

The aim of the work is therefore to understand, in the specific Spanish case, what the potential pathways to decarbonisation are, and the relevant costs and benefits associated with these pathways (in terms of vehicle costs, fuel costs, implications for maximum freight load, infrastructure required) and the benefits of their deployment (in terms of CO_2 and other air pollutant emissions).

1.2 Methodology

For this report, a set of scenarios were defined in which it was assumed that a certain zero carbon vehicle technology mix would be taken up. The particular factors affecting hauliers' decisions to purchase such vehicle technologies were not assessed.

The methodology involved distinct 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' (CE) vehicle stock model to assess the impact of zero carbon vehicle sales mixes on energy demand, CO_2 emissions, vehicle prices, and technology costs; and (ii) a Total cost of ownership (TCO) analysis to assess all the costs that hauliers face in the purchase, operation, and maintenance of vehicles during their lifetime.

Vehicle Stock Model

The vehicle stock model calculates vehicle fuel demand, vehicle emissions and vehicle prices for a given mix of vehicle technologies in each scenario. The model uses information about the efficiency of new vehicles and vehicle survival rates to assess how changes in new vehicles sales affect the characteristics of the stock. The model also includes a detailed technology sub-model to calculate how the efficiency and price of new vehicles are affected by changing uptakes of fuel-efficient technologies. The vehicle stock model is highly disaggregated, modelling 16 different technology types across four different classes of commercial vehicles (vans, LHGV, MHGV, HHGV).

TCO Analysis

Outputs from the vehicle stock model (including fuel demand and vehicle prices) are then used as inputs to the TCO analysis. The TCO analysis provides an in-depth comparison of the different vehicle types and shows the evolution of the cost components for each type of vehicle. The cost components considered in the central case are the following: depreciation, fuel cost, maintenance cost, infrastructure (private and public) and financial cost. These will be presented in more detail in the next sections of the report.

Scope of the analysis and the report

Much of the technical analysis presented in this report focuses on the van (0-3.5 t) and HHGV(> 16 t) segments; however, similar analysis has been carried out for LHGV and MHGV segments. The focus is primarily placed upon vans and HHGVs because these make up most of the Spanish stock of road freight vehicles, and as a result deliver the vast majority of freight tonne kilometres. They therefore highly influence the overall costs and environmental impacts of the sector.

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 Steering Committee.
- Section 3 presents the main modelling assumptions and technology cost data.
- Section 4 focuses on the new recharging and refuelling infrastructure requirements for the deployment of zero emission vehicles.
- Section 5 presents the results of the vehicle stock modelling exercise.
- Section 6 shows the environmental impacts of each scenario.
- Section 7 is devoted to an in-depth comparison of technologies through the TCO analysis.
- Section 8 sets out the conclusions of the study.

2 Overview of the scenarios

2.1 Scenario design

The analysis presented in this report is based on a set of scenarios developed in agreement with the Steering Committee[1], each assuming a different new vehicle sales mix. These represent a range of decarbonisation pathways and are designed to assess the impacts of a shift towards zero carbon powertrains; they do not necessarily reflect current predictions of the future makeup of the Spanish fleet of road freight vehicles. Uptake of each kind of vehicle is by assumption: implicitly we assume that this change is brought about by policy, but such policy is not explicitly modelled. The five core scenarios to be modelled for this study are summarised in Table 2.1.

Table 2.1: Description of the five core modelling scenarios

Scenario	Scenario description
REF (Reference)	• No change in the deployment of energy efficiency technology or powertrains in sales from 2020 onwards. • Some improvements in the fuel-efficiency of the vehicle stock, due to stock turnover.
CPI (Current Policy Initiatives)	• Deployment of fuel-efficient technologies in all new vehicles over the period to 2030 (e.g. light-weighting) and advanced powertrains, to meet the CO_2 emission performance standards targets in 2025 and 2030 for vans and HGVs. • No further changes after the year 2030.
TECH BEV (High Technology, BEVs dominate)	• Ambitious deployment of fuel-efficient technologies in all new vehicles over the period to 2030 (e.g. light-weighting). • Deployment of advanced powertrains, predominately BEVs for both vans and HGVs). • Phase-out of sales of new ICEs by 2035 for vans and 2040 for HGVs.
TECH ERS (High Technology, ERS system dominates)	• Ambitious deployment of fuel-efficient technologies in all new vehicles over the period to 2030 (e.g. light-weighting). • Deployment of advanced powertrains (predominately BEV for vans and BEV-ERS for HGVs). • Phase-out of sales of new ICEs by 2035 for vans and 2040 for HGVs.
TECH FCEV (High Technology, Fuel cell vehicles dominate)	• Ambitious deployment of fuel-efficient technologies in all new vehicles over the period to 2030 (e.g. light-weighting). • Deployment of advanced powertrains (predominately BEVs for vans and FCEVs for HGVs). • Phase-out of sales of new ICEs by 2035 for vans and 2040 for HGVs.

[1] The Consultation Group was a panel of experts drawn from different parts of the road freight transport industry, including OEMs, freight operators and civil society.

2.2 Scenario description

In this section we describe in more detail the key characteristics of the scenarios considered in the study.

Reference scenario

The reference scenario excludes any further improvements in new vehicle efficiency after the last year of history, 2020. This is the baseline against which all other scenarios are compared. Essentially, this scenario explores a potential future where existing legislation (i.e. the 2025 and 2030 CO_2 targets for new vans and HGVs) is removed, and in the absence of any fuel standards at the European or national level for vans and HGVs the characteristics of new vehicles do not change.

CPI scenario

The current policy initiatives (CPI) scenario considers the deployment of technologies to improve the energy efficiency of vehicles and of advanced powertrains (BEVs and FCEVs) to meet the CO_2 emission reduction targets for new vehicles sold in 2025 and 2030. No further improvements or changes in the sales mix are assumed after 2030 as no further policies have already been approved at the European or national level. This scenario therefore shows the impact of current policies.

The three TECH scenarios

Besides the reference and the current policy initiatives scenarios, the study considers three technology and policy scenarios. On one hand, these are aimed at exploring advanced technologies that could play a decisive role in decarbonising the road freight sector in Spain. On the other hand, these scenarios assess the impacts arising from the introduction of an additional policy at the European or Spanish level to continue to reduce the CO_2 emissions of new vehicles and ultimately phase-out the sales of new ICE vans by 2035 and ICE HGVs by 2040.

TECH BEV scenario

The first technology scenario considered is TECH BEV, which assumes that battery electric vehicles emerge as the dominant powertrain for vans and HGVs. Energy efficiency technologies are also increasingly installed in new vehicles in the period up to 2030, and a phase-out of ICEs is introduced in 2035 for vans and in 2040 for HGVs.

TECH ERS scenario

The second technology scenario is TECH ERS, which assumes that ERS-enabled vehicles emerge as the dominant technology thanks to the progressively increasing deployment of the ERS catenary infrastructure. Energy efficiency technologies are also increasingly installed in new vehicles up to 2030, and a phase-out of the sale of new ICEs is introduced in 2035 for vans and in 2040 for HGVs.

TECH FCEV scenario

The third technology scenario is TECH FCEV, which assumes that FCEVs emerge as the dominant powertrain. Energy efficiency technologies are also increasingly installed on new vehicles up to 2030, and a phase-out of the sale of new ICEs is introduced in 2035 for vans and in 2040 for HGVs.

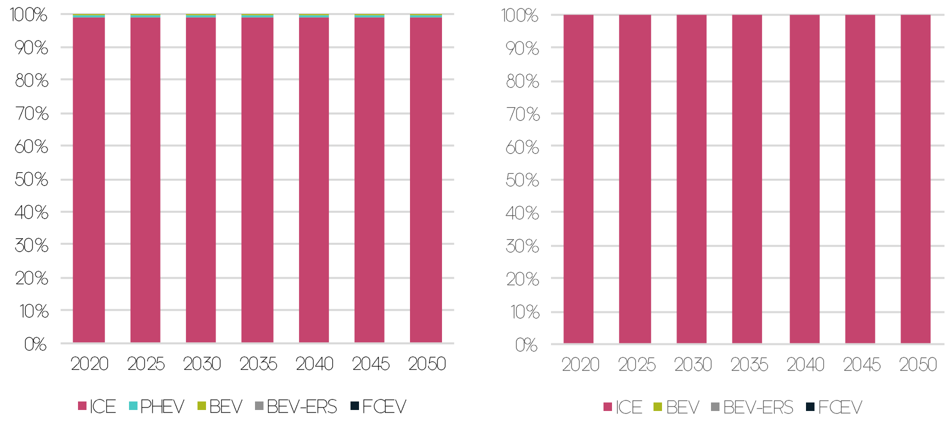
2.3 Vehicle sales mix

In this section we outline the sales mix by powertrain deployed across each of the scenarios and vehicle size classes. For vans, we assume that the deployment of advanced powertrains is the same across all TECH scenarios (i.e. BEVs become the dominant powertrain).

Reference scenario

As discussed above, the REF scenario has no deployment of advanced powertrains, therefore the dominance of ICEs remains in the whole projected period. ICEs make up the entirety of sales and stock of HGVs up to 2050, and only 0.65% of new vans are BEVs as showed in Figure 2.1.

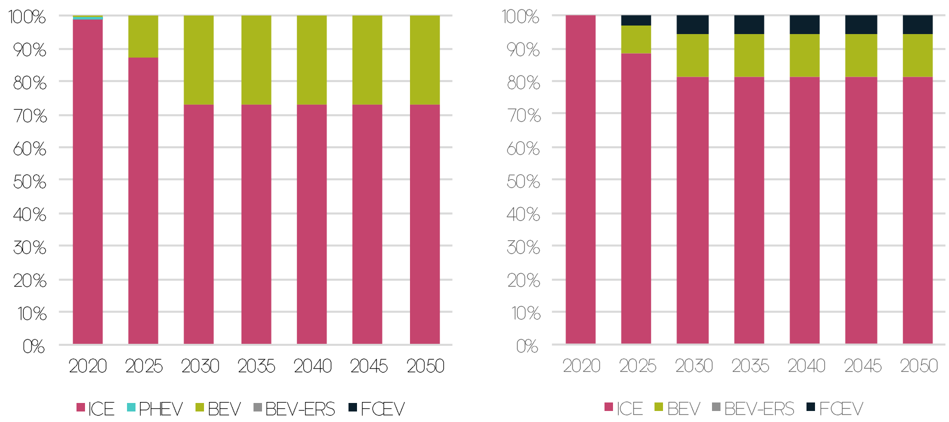
Figure 2.1: Sales mix of vans (left) and HGVs (right) in the REF scenario (% of annual new vehicle sales)



CPI scenario

The CPI scenario reflects the achievement, by 2025 and 2030, of the current emission reduction targets for newly registered vehicles as set at the European level. To meet the target of 31% reduction in new vans' CO_2 emissions by 2030, energy efficiency technologies are introduced, and BEVs reach 27% of the yearly new sales in 2030 (Figure 2.2). Furthermore, in this scenario, it is assumed that BEVs and FCEVs play a more prominent role in the HGV sales mix, reaching respectively 13% and 6% of new sales in 2030. Moderate improvements to the energy efficiency of HGVs are also realised in this period. Since no further targets have been announced and formally introduced, we do not assume any additional deployment of advanced powertrains or improvements in the efficiency of new vehicles beyond 2030.

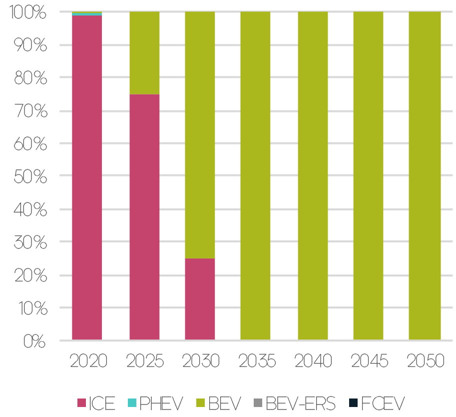
Figure 2.2: Sales mix of vans (left) and HGVs (right) in the CPI scenario (% of annual new vehicle sales)



Van powertrain deployment in the TECH scenarios

Van sales in the TECH scenarios are outlined in Figure 2.3. BEVs reach 75% of new sales by 2030, and ICEs are phased out of new sales from 2035. All new vans are electrified thanks to improved battery technology and the deployment of adequate depot recharging infrastructure. FCEVs and ERS enabled BEVs are not considered in this scenario as vans are used for short range urban transport where the limited range of BEVs is not a major factor.

Figure 2.3: Sales mix of vans in the TECH scenarios (% of annual new vehicle sales)



HGV powertrain deployment in the TECH BEV scenario

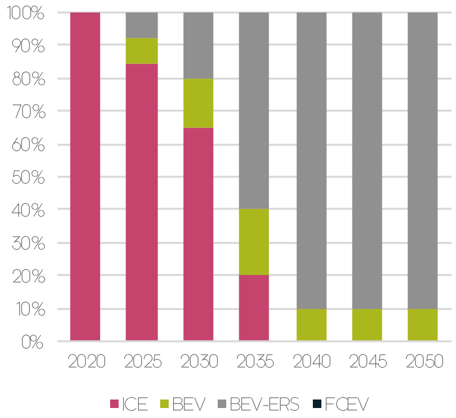
In the TECH BEV scenario, 16% of new sales are BEVs in 2025. Those who purchase BEVs do so because the technology is sufficient to meet their current requirements (e.g. range between distribution centres can be met by one full charge of a BEV). As shown in Figure 2.4, BEVs reach 100% of new sales by 2040 (up from 35% in 2030) due to continuous improvements in the technology and reductions in the battery pack's costs.

Figure 2.4: Sales mix of HGVs in the TECH BEV scenario (% of annual new vehicle sales)

HGV powertrain deployment in the TECH ERS scenario

In this scenario, ERS-enabled vehicles emerge as the dominant technology, but take some time to emerge due to their dependence upon ERS infrastructure being in place. BEV-ERS vehicles are only 20% of sales in 2030; however, their market share rapidly expands thereafter, reaching 90% in 2040. As the deployment of ERS roads increases (see Chapter 5 for more detail), ERS-enabled vehicles become more attractive to hauliers. Vehicle costs are relatively low (as compared to non-ERS zero carbon powertrains), because the ERS variants do not need large batteries.

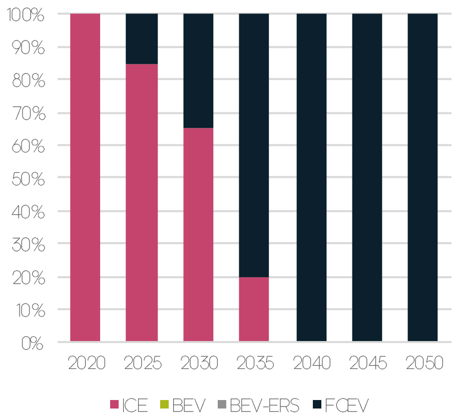
Figure 2.5: Sales mix of HGVs in the TECH ERS scenario (% of annual new vehicle sales)



HGV powertrain deployment in the TECH FCEV scenario

In the TECH FCEV scenario, FCEVs emerge as the dominant powertrain and by 2040 they make up 90% of new sales. The deployment of FCEVs in this scenario matches that of BEVs in the TECH BEV scenario. FCEVs achieve rapid deployment thanks to cost reductions.

Figure 2.6: Sales mix of HGVs in the TECH FCEV scenario (% of annual new vehicle sales)



3 Modelling assumptions

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

The scenarios are defined by (i) the new sales mix of vehicles by powertrain type, (ii) the uptake of energy efficiency technologies, and (iii) the CO_2 emission reduction policies. Key assumptions that are common to all scenarios are briefly outlined in Table 3.1. The subsequent sections provide information about our assumptions for technology costs and deployment, battery costs, fuel cell vehicle and the power sector.

3.1 Common modelling assumptions

Table 3.1: Key assumptions used in the stock model

	Details of assumptions used
Vehicle sales	• Historical stock of vans and HGVs (total number) is taken from the statistics provided by the Dirección General de Tráfico (DGT). • Historical sales of new vehicles by size (vans ≤3.5t, LHGVs 3.6-7.5t, MHGVs 7.6-16t, HHGVs >16t) and fuel type (petrol, diesel, natural gas, electricity, hydrogen) are available at Dirección General de Tráfico (DGT), and ACEA Motor Vehicle Registrations (1990 – 2020). • The annual number of second-hand vehicles imported (and for the first time registered in Spain) is taken from Table 18 of COWI and Ökö-Institut report on second-hand car market in Europe (2011). • Average age of imported second-hand vehicles is also taken from COWI and Ökö-Institut report on second-hand car market in Europe (2011). • Total new registrations beyond 2021 are calculated to ensure the stock meets freight demand through accounting for both demand from replacing de-registered vehicles and demand from growing freight demand.
Mileage by age cohort	• We assume that average annual mileage falls gradually over the lifetime of a vehicle and varies depending on size and powertrain. • From the TRACCS[2] database we have derived mileage factors which show the annual mileage of each vehicle. Mileage factors were calibrated to meet the total tonne kilometres travelled (exogenously defined).

[2] Transport data collection supporting the quantitative analysis of measures relating to transport and climate change, European Commission, 2013.

Road freight activity	• Projections for road freight transport activity (expressed in Gtkm[3]) for heavy goods and light commercial vehicles are taken from the PRIMES 2020 Reference Scenario.
Vehicle survival rates	• Yearly registrations and de-registrations (or data on the composition of the current stock by year of registration of the vehicles) to create the survival rate curves by type of vehicle are taken from the TRACCS database. The survival rate curves for each type of vehicle (vans, LHGVs, MHGVs, HHGVs) are derived from the analysis of the age distribution of the total Spanish HGVs stock between 2005-2010.
Sales mix	• Sales mix of recent years of history by powertrain type (2019 and 2020) is taken from Dirección General de Tráfico (DGT), and ACEA press releases. • Projections of sales mix by powertrain type (2025, 2030, 2040, 2050) for each scenario were agreed during the meetings of the Steering Committee.
Load	• Specific payloads (% of max payload) are calibrated and assumed to be 50% for all vehicle size classes (for vans, LHGVs, and MHGVs, this is in line with the Trucking into a Greener Future (2018) study of Cambridge Econometrics). • Load factors are applied to define the Gross Vehicle Weight (t) and the Unladen weight (t) of considered archetypes. Gross vehicle weight of vans is based on ICCT Pocketbook mass in running order statistics; while Gross vehicle weight of MHGVs is based on the study of ICCT and weight profiles for LHGVs and HGVs based on archetypes from 2017 Ricardo AEA study.
Technology packages	• Technology packages to model the take-up of energy efficiency technologies and calculate the future powertrain costs and fuel economies for each vehicle type are in line with the Trucking into a Greener Future (2018) study of Cambridge Econometrics (see technical report for more details, section 3.2).
Fuel prices	• Historical data on fossil fuel prices (diesel, petrol and LPG) is taken from the Weekly Oil Bulletin database of the European Commission. • For projections, we assume oil prices to grow in line with the IEA World Energy Outlook 2020 Stated Policies Scenario and then we project forward the price of petrol and diesel in line with the oil price projections.
Electricity prices	• We use data on electricity prices paid by non-household consumers (Band IE : 20 000 MWh < Consumption < 70 000 MWh) from Eurostat.

[3] Gtkm (Gross tonne-kilometre) is a unit of measure of freight transport which represents the transport of one tonne of goods (including packaging and tare weights of intermodal transport units) by a given transport mode over a distance of one kilometre.

	• For projections we assume electricity prices to grow in line with the electricity price projections for Spain from the PRIMES 2020 Reference Scenario.
Hydrogen price	• Hydrogen price projections are taken from the European forecast of Hydrogen Council (2020).
Price level	• All costs are deflated by the gross domestic product deflator for the Euro Area of FRED to 2020 price level.

3.2 ICE efficiency gains

Fuel-efficient technologies for HGV segments were collected from four different sources:

- Ricardo-AEA 2011, Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles – Lot 1: Strategy
- TIAX 2012, European Union Greenhouse Gas Reduction Potential for Heavy-Duty Vehicles
- Ricardo-AEA 2012, A review of the efficiency and cost assumptions for road transport vehicles to 2050 for UK CCC
- Ricardo-AEA 2017, Heavy Duty Vehicles Technology Potential and Cost Study for ICCT Technology

Where there was overlap in technologies, data from the latest Ricardo-AEA (2017) took precedence.

Technology costs and energy savings

Aerodynamic technologies

Three aerodynamic technologies from R-AEA (2017) have been included in the technology list for HGVs (see Table 3.2). These technologies include several aerodynamic technologies, for example, *aerodynamic bodies/trailers* and *box skirts*, which when deployed together give the percentage *reduction in aerodynamic drag*. However, the report by R-AEA (2017) is not explicit in terms of which specific aspects are included; aerodynamic technologies from older studies have therefore been removed to avoid double counting.

Table 3.2: Aerodynamic technologies

	Energy saving			Cost (€, 2020)		
	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
10% reduction in aerodynamic drag	0.6%	-	-	267	-	-
15% reduction in aerodynamic drag	-	6.3%	-	-	401	-
25% reduction in aerodynamic drag	-	-	10.6%	-	-	2,137

Light-weighting technologies

Light-weighting technologies were taken from R-AEA (2017), most of this saving (R-AEA, 2017) occurs due to material substitution. Thus, *material substitution* (TIAX, 2012) has been removed. Note that the *light-weighting* technologies (*light-weighting 1, 2 and 3*) are additive, rather mutually exclusive.

Table 3.3: Light-weighting technologies

	Energy saving	Cost (€, 2020)

	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
Light-weighting 1	0.5%	0.2%	0.3%	0	0	0
Light-weighting 2	0.03%	-	0.1%	1	-	57
Light-weighting 3	0.7%	0.7%	0.3%	97	320	320

Tire and wheel technologies

Energy saving and costs for *Low rolling resistance tires* are from R-AEA (2017) whereas data on *single-wide tires* is from R-AEA (2012).

Table 3.4: Tire and wheel technologies

	Energy saving			Cost (€, 2020)		
	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
Low rolling resistance tires	2.5%	4.8%	5.1%	688	1,944	6,282
Single wide tires	4.0%	4.0%	5.0%	925	925	1,457
Automatic tire pressure adjustment	1.0%	1.0%	2.0%	10,802	10,802	15,633
Tire Pressure Monitoring System (TPMS)	0.4%	0.4%	0.4%	267	267	507

Transmission and driveline technologies

Transmission friction reduction (TIAX, 2012) and improved controls with aggressive shift logic and early lockup (TIAX, 2012) can be deployed alongside automated manual.

Table 3.5: Transmission and driveline technologies

	Energy saving			Cost (€, 2020)		
	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
Transmission friction reduction	0.5%	1.3%	1.3%	218	218	218
Improved controls, with aggressive shift logic and early lockup	2.0%	-	-	52	-	-
Automated manual	7.0%	5.0%	1.7%	2,457	2,457	1,602

Engine efficiency technologies

Improved diesel engine (TIAX, 2012) has been removed from our technology list as it overlaps with nearly all the other technologies included in this category. In fact, the sum of all the other engine efficiency technologies (16%) is roughly the same energy saving percentage as the *improved diesel engine. Mechanical* and *electrical turbocompound* are mutually exclusive.

Table 3.6: Engine efficiency technologies

	Energy saving			Cost (€, 2020)		
	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
Controllable air compressor	-	-	1.0%	-	-	213
Mechanical turbocompound	0.7%	0.7%	2.0%	2,557	2,557	1,923
Electrical turbocompound	1.0%	1.0%	2.0%	6,412	6,412	1,923
Turbocharging	1.9%	2.0%	2.5%	1,122	1,122	1,122
Heat recovery	1.5%	1.5%	4.5%	10,600	10,600	5,342
Unspecified FMEP improvements	3.7%	2.3%	1.4%	-	-	-
Variable oil pump	2.0%	1.5%	1.0%	96	96	96
Variable coolant pump	1.2%	0.8%	0.5%	96	96	96
Bypass oil cooler	0.8%	0.5%	0.2%	27	27	27
Low viscosity oil	2.0%	2.0%	1.0%	438	1,656	3,540
Engine encapsulation	1.5%	-	-	27	-	-

Hybridisation technologies

Enhanced stop/start (R-AEA, 2017) is deployed only in LHGVs and MHGVs as long-haul driving is more continuous. For long haul the dual model hybrid electric system is deployed as an alternative.

Table 3.7: Hybridisation technologies

	Energy saving			Cost (€, 2020)		
	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
Dual-mode hybrid electric	25.0%	30.0%	6.5%	25,313	20,295	9,118
Enhanced stop/start system	4.5%	4.5%	-	1,239	1,239	-

Management technologies

Vehicle improvements using driver aids from the TIAX (2012) only came with fuel saving - no costs were included. The cost was estimated by summing similar technologies, *route management* and *training and feedback* from R-AEA (2012).

Table 3.8: Management technologies

	Energy saving			Cost (€, 2020)		
	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
Predictive cruise control	-	-	2.0%	-	-	684
Smart Alternator, Battery Sensor & AGM Battery	1.5%	1.5%	1.5%	585	585	1,053
Vehicle improvements using driver aids	-	-	10.0%	-	-	1,222

Reduction of auxiliary (parasitic) loads

Auxiliary components in the vehicle also have room for improvement. Electric cooling fans offer a greater amount of energy saving for a slightly smaller cost.

Table 3.9: Reduction of auxiliary (parasitic) loads

	Energy saving			Cost (€, 2020)		
	LHGV	MHGV	HHGV	LHGV	MHGV	HHGV
Electric cooling fans	0.5%	0.5%	0.5%	53	96	192
Electric hydraulic power steering	1.3%	0.8%	0.3%	101	192	385
High efficiency air conditioning	0.5%	0.3%	0.1%	59	112	224

ERS compatible technologies

To make a standard electric HHGV compatible with ERS (defined as BEV-ERS vehicles), technologies need to be added to the vehicle. For a catenary wire system, a pantograph attached to the hood of the cab is needed. Siemens have developed an ‘active pantograph’ which can connect to the ERS-highway at speeds of 90km/h. Built in sensor technology adjusts the pantograph to maintain contact with the catenary wires which would otherwise be displaced from the truck’s lateral movements in the lane. This technology is assumed to cost € 18,389 per vehicle and remains constant throughout the projection period.

The cost of the pantograph is added to baseline cost of BEV-ERS as it is a standard requirement of the vehicle to be compatible with the ERS. The cost does not feature in the technology packages below.

Deployment rates

The deployment of technologies is broken down into four different Technology Packages. Technologies are grouped based on the payback period of technologies, with specific deployments drawn from R-AEA (2012). The payback period measures how long it would take to pay off the technology in terms of fuel expenditure saved. A technology is said to have a payback period of one year if the fuel saving in the first year amounts to the up-front cost of the technology. The deployment rates have been drawn from the 2012 Ricardo-AEA study, and adjusted to correspond broadly to the following aims:

- Technology Package 1 assumes that by 2025 there will be deployment of new technologies into vehicles where they have a payback period of 2 years or less. This will not correspond to 100% coverage of sales, due to the different use cases within each category (i.e. actual cost saving depends upon total distance driven).
- Technology Package 2 assumes that over 2025-33 there will be deployment in new vehicles of technologies in use cases where they have a payback period of 3.5 years or less.
- Technology Package 3 assumes deployment in new vehicles over 2033-42 of technologies in cases where they have a payback period of 5 years or less.
- Technology Package 4 assumes that by 2050 there will be full deployment in new vehicles of all technologies where they have a positive impact on the TCO.

For technologies with no available payback period, deployment rates in previous studies were used instead.

Table 3.10: Deployment rates of technologies for LHGVs

Technology	Technology Packages, LHGVs			
	1 (2025)	2 (2033)	3 (2042)	4 (2050)
10% reduction in aerodynamic drag	0%	0%	50%	100%
Light-weighting 2	100%	100%	100%	100%
Light-weighting 3	30%	60%	100%	100%
Light-weighting 4	15%	30%	60%	100%
Low rolling resistance tires	50%	75%	50%	0%
Single wide tires	0%	25%	50%	100%
Tire Pressure Monitoring System (TPMS)	0%	0%	30%	100%
Transmission friction reduction	0%	100%	100%	100%
Improved controls, with aggressive shift logic and early lockup	0%	100%	100%	100%
Mechanical turbocompound	0%	10%	30%	40%
Electrical turbocompound	0%	1%	15%	30%
Turbocharging	0%	0%	30%	100%
Heat recovery	0%	0%	5%	20%
Unspecified FMEP improvements	100%	100%	100%	100%
Variable oil pump	100%	100%	100%	100%
Variable coolant pump	100%	100%	100%	100%
Bypass oil cooler	100%	100%	100%	100%
Low viscosity oil	100%	100%	100%	100%
Engine encapsulation	100%	100%	100%	100%
Enhanced stop/start system	35%	25%	15%	0%

Full hybrid	20%	30%	50%	100%
Smart Alternator, Battery Sensor & AGM Battery	20%	60%	100%	100%
Electric cooling fans	50%	100%	100%	100%
Electric hydraulic power steering	100%	100%	100%	100%
High efficiency air conditioning	20%	100%	100%	100%

Low rolling resistance tires and *single wide tires* cannot both be deployed on the same vehicle – the total deployment of these two technologies cannot exceed 100%. *Low rolling resistance tires* feature in 50% of all sales in Technology package 1 because the costs and energy saving are both lower. Purchasers invest a small amount (€644) and are compensated by small energy savings (2.5%). The deployment increases to 75% by 2033, with the remaining use cases including *single wide tires*, across 25% of new sales. By 2050 *single wide tires* make up all tire sales because of the large energy saving potential.

The same is true of *enhanced stop/start systems* and *full hybrid* technologies. Both cannot feature on a single vehicle. The cost of *enhanced stop/start* is smaller, so it is implemented in a few business cases, covering 35% of new sales. Full hybrid technology is more expensive but in the long-run the energy savings are much higher (so it suits use cases which cover a larger mileage). It only makes economic sense for 20% of sales in Technology package 1. By 2033, *full hybrids* begin to dominate as the potential TCO saving covers more use cases, at the expense of *enhanced stop/start*. Moreover, the implementation of a *stop/start system* is complex, requiring high torque and durability requirements which may mean it is more likely hauliers invest in a *full hybrid* system instead (R-AEA, 2017).

Table 3.11: Deployment rate of technologies for MHGVs

Technology	Technology Packages, MHGVs			
	1 (2025)	2 (2033)	3 (2042)	4 (2050)
15% reduction in aerodynamic drag	100%	100%	100%	100%
Lightweighting 1	100%	100%	100%	100%
Lightweighting 3	20%	50%	100%	100%
Lightweighting 4	0%	50%	100%	100%
Low rolling resistance tires	100%	100%	100%	100%
Tire Pressure Monitoring System (TPMS)	0%	50%	100%	100%
Transmission friction reduction	0%	0%	100%	100%
Mechanical turbocompound	0%	10%	30%	40%
Electrical turbocompound	0%	1%	15%	30%
Turbocharging	0%	0%	0%	100%
Heat recovery	0%	0%	5%	20%
Unspecified FMEP improvements	100%	100%	100%	100%
Variable oil pump	100%	100%	100%	100%
Variable coolant pump	100%	100%	100%	100%
Bypass oil cooler	100%	100%	100%	100%
Low viscosity oil	100%	100%	100%	100%
Enhanced stop/start system	100%	75%	50%	0%

Full hybrid	0%	25%	50%	100%
Smart Alternator, Battery Sensor & AGM Battery	20%	60%	100%	100%
Electric cooling fans	100%	100%	100%	100%
Electric hydraulic power steering	100%	100%	100%	100%
High efficiency air conditioning	20%	60%	100%	100%

Table 3.12: Deployment rate of technologies for HHGVs

Technology	Technology Packages, HHGVs			
	1 (2025)	2 (2033)	3 (2042)	4 (2050)
25% reduction in aerodynamic drag	50%	100%	100%	100%
Lightweighting 1	50%	100%	100%	100%
Lightweighting 2	50%	100%	100%	100%
Lightweighting 3	50%	100%	100%	100%
Lightweighting 4	15%	30%	60%	100%
Single wide tires	50%	75%	100%	100%
Tire Pressure Monitoring System (TPMS)	50%	100%	100%	100%
Transmission friction reduction	100%	100%	100%	100%
Controllable air compressor	20%	50%	100%	100%
Mechanical turbocompound	50%	100%	100%	100%
Turbocharging	50%	100%	100%	100%
Heat recovery	0%	100%	100%	100%
Unspecified FMEP improvements	50%	100%	100%	100%
Variable oil pump	50%	100%	100%	100%
Variable coolant pump	50%	100%	100%	100%
Bypass oil cooler	50%	100%	100%	100%
Low viscosity oil	50%	100%	100%	100%
Dual-mode hybrid electric	0%	30%	50%	100%
Predictive cruise control	100%	100%	100%	100%
Smart Alternator, Battery Sensor & AGM Battery	45%	50%	70%	100%
Vehicle improvements using driver aids	50%	75%	100%	100%
Electric cooling fans	100%	100%	100%	100%
Electric hydraulic power steering	25%	75%	100%	100%

Total impact of technology packages

Table 3.13 shows the total energy saving and cost of each technology package to be deployed for ICE HGVs. The technology packages vary by powertrain because not all technologies are applicable to all advanced powertrains. For example, there will be no deployment of *heat recovery* in BEVs or FCEVs as there is no internal combustion engine to recover heat from. The implication is that the total energy saving and costs for each technology package decrease as you move through powertrains from ICE to BEV-ERS to BEV/FCEV.

Table 3.13: Technology Packages for ICEs

LHGV	Energy saving	Cost (€, 2020)	Incremental energy saving	Incremental Cost (€, 2020)
Technology package 1	19.9%	4,545	19.9%	4,545
Technology package 2	26.3%	7,158	6.4%	2,613
Technology package 3	32.4%	12,668	6.1%	5,510
Technology package 4	45.0%	23,619	12.5%	10,950
MHGV	Energy saving	Cost (€, 2020)	Incremental energy saving	Incremental Cost (€, 2020)
Technology package 1	22.3%	5,952	22.3%	5,952
Technology package 2	26.4%	10,100	4.1%	4,148
Technology package 3	31.6%	16,150	5.2%	6,050
Technology package 4	39.3%	26,403	7.7%	10,254
HHGV	Energy saving	Cost (€, 2020)	Incremental energy saving	Incremental Cost (€, 2020)
Technology package 1	20.4%	6,401	20.4%	6,401
Technology package 2	35.9%	18,773	15.6%	12,371
Technology package 3	39.8%	21,454	3.9%	2,681
Technology package 4	42.2%	26,437	2.3%	4,982

A pattern seen across all powertrains in the HGV segment is the potential energy savings in Technology package 1, which are considerably lower in the other packages.

3.3 Vehicle costs

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

The cost of technologies which reduce CO_2 emissions from road freight will reduce over time as scale economies are achieved, but the cost faced by hauliers will increase as more technologies are added to reach tighter CO_2 limits. In 2030, battery-electric and fuel-cell electric vehicles are projected to be more expensive than diesel and gasoline vehicles. By 2050, the difference in price will be narrowed and BEVs will become even cheaper than ICE vehicles as the cost of diesel vehicles is increasing and zero carbon vehicles become cheaper as they start being manufactured at scale.

Baseline vehicle

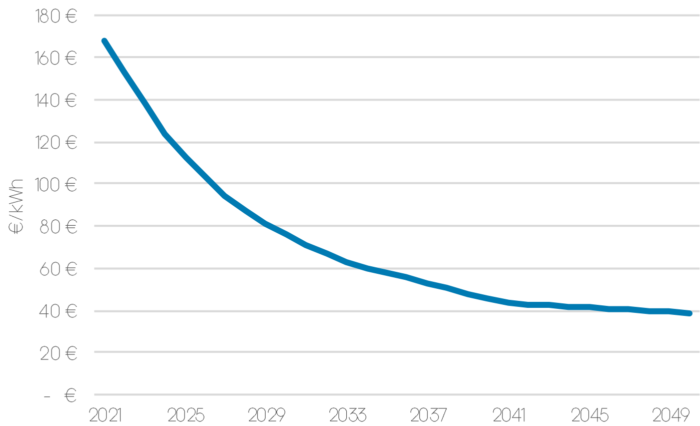
The baseline ICE vehicle costs are taken from recent market trends and the literature: we assume a baseline cost for vans in line with the cost (excluding taxes and margins) of a medium-sized diesel van (e.g. the Opel Movano), while the cost of LHGVs and MHGVs are taken from the study of AEA Technology (2012), and the cost of HHGVs is taken from the analysis of NREL (2021).

Battery costs

For the battery pack price projections, we rely on historical prices and forecasts published by BloombergNEF (2020) for battery prices up to 2030.

For the remaining period, we apply a smoothed curve to project the prices until 2050. Based on the estimations, battery pack prices continue to decrease, but at a more moderate rate than earlier, to reach approximately €30/kWh by 2050. The projected battery pack prices are shown in Figure 3.1. These prices also include a 40% premium which was added to reflect other additional costs (e.g. battery management system, housing) (FCH and Roland Berger, 2020) and to estimate the battery pack's retail cost (T&E, 2020).

Figure 3.1: Battery pack retail price projections (€/KWh, 2020)



Fuel cell and hydrogen storage costs

Fuel cell and hydrogen storage costs are taken from a recent study of the University of California (2020). Both fuel cell and hydrogen storage costs are expected to more than halve between 2020 and 2040, but no further decrease is projected beyond 2040. The evolution of fuel cell costs is visualized in Figure 3.2 and hydrogen storage costs are shown in Table 3.14.

Figure 3.2: Fuel cell price projections (€/kW, 2020)

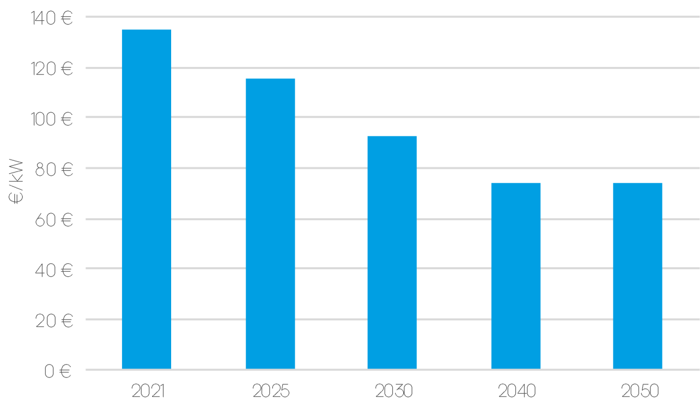


Table 3.14: Compressed gaseous H2 gas tank costs (€/kg, 2020)

Additional components, FCEV	2021	2025	2030	2040	2050
Compressed gaseous H_2 gas tank costs (€/kg, 2020)	440	347	232	185	185

Additional system requirements costs

We base our costs of additional system requirements estimates on the extensive overview of the costs of new technologies to reduce truck emissions published by CE Delft (2013). The additional system requirements are the electric systems (power electronics, battery management systems, etc.) necessary to control the power transfer of vehicles with advanced powertrain.

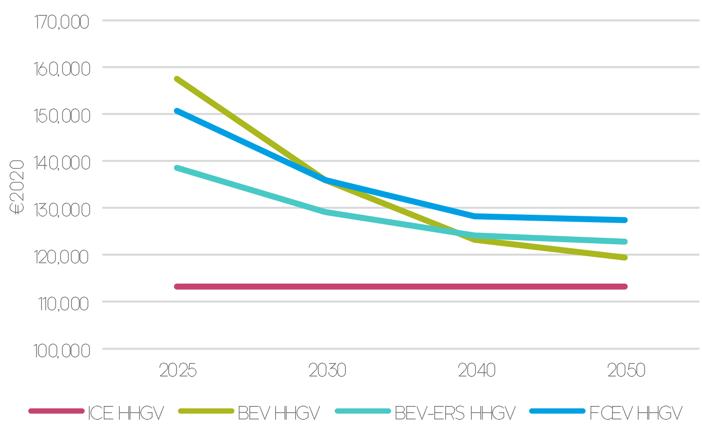
Powertrain costs

In our model, the powertrain costs for ICEs are expected to increase slightly due to the future introduction of the Euro VII standards which, according to the ICCT (2021), will likely lead to a cost increase between 2% and 5% relative to the current price of a new Euro VI truck. In contrast, the powertrain costs of BEVs, BEV-ERS and FCEVs are projected to decrease due to future mass-production. The projected powertrain costs (excluding the costs of additional energy efficiency technologies, margins, and taxes) for each vehicle type are summarised in Table 3.15. FCEVs costs also include the compressed gaseous hydrogen tank and BEV-ERS costs include the pantograph and on-board connection system in addition to the previously mentioned components.

Table 3.15: Powertrain costs (excluding the costs of additional energy efficiency technologies, margins, and taxes) by vehicle powertrain and size (€, 2020)

Powertrain	Size	2025	2030	2040	2050
ICE - Diesel	Vans	19,902	19,902	19,902	19,902
	LHGVs	53,410	53,410	53,410	53,410
	MHGVs	87,171	87,171	87,171	87,171
	HHGVs	113,265	113,265	113,265	113,265
BEV-ERS	Vans	-	-	-	-
	LHGVs	50,934	47,837	46,446	46,057
	MHGVs	93,180	86,348	83,148	82,262
	HHGVs	138,578	128,990	124,175	122,829
BEV	Vans	25,773	22,917	21,419	21,000
	LHGVs	63,803	56,681	52,615	51,479
	MHGVs	111,607	98,330	90,840	88,746
	HHGVs	157,540	135,879	123,039	119,449
FCEV	Vans	27,374	24,179	22,254	21,985
	LHGVs	70,206	63,466	59,732	59,433
	MHGVs	122,977	110,921	104,363	104,004
	HHGVs	150,719	135,898	128,026	127,428

Figure 3.3: Powertrain costs (excluding the costs of additional energy efficiency technologies, margins, and taxes) for HHGVs (€, 2020)

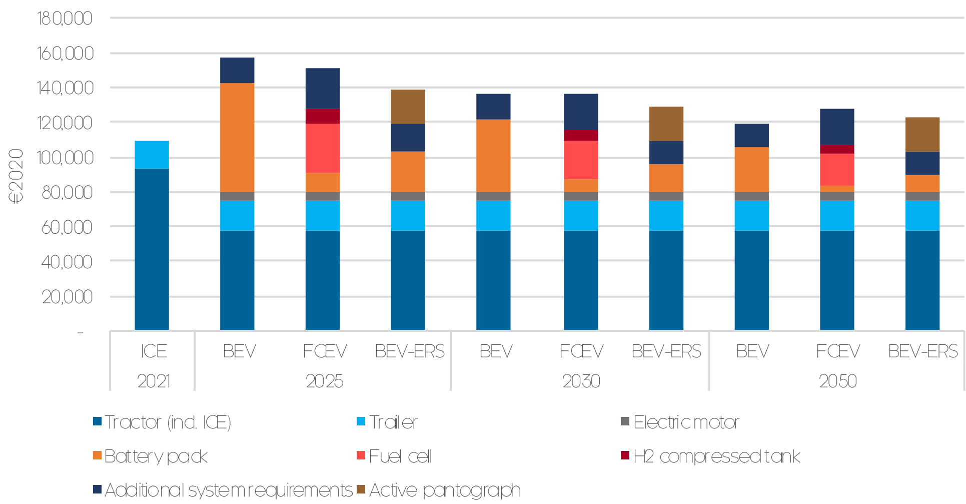


To further analyse the resulting vehicle costs we present the evolution of HHGVs costs in Figure 3.3. As can be seen, BEV costs are expected to decrease the most, falling below FCEV costs by 2030 and BEV-ERS costs by 2040.

Total cost of vehicles

The total cost can be broken down into 8 cost components: tractor, trailer, electric motor, battery pack, fuel cell, hydrogen compressed tank, additional system requirements and active pantograph. The estimated contributions of the components to the cost of HHGVs can be seen in Figure 3.4.

Figure 3.4: Breakdown of HHGVs powertrain costs (€, 2020)



However, early indications from looking at illustrative prices of trucks on the market in 2021 suggest that FCEVs may in fact be more expensive to purchase even now than BEV trucks. There is a lack of clarity on precisely which component(s) are higher cost than our estimates, however, so for the purposes of this analysis we have FCEV total costs which are initially lower than those of a BEV.

3.4 Fuel costs

Diesel and Petrol

The future oil price is a key uncertainty in the zero-carbon transport scenarios and variations in the oil price are likely to greatly affect the economic outcomes of the scenarios.

For historical data on diesel and petrol prices, we relied on the Weekly Oil Bulletin of the European Commission. In this dataset, oil prices are presented on a weekly basis, so annual average prices were estimated.

In the model we then project forward the price of petrol and diesel by assuming the same increase in prices as in the oil price projections of the IEA World Energy Outlook 2020 (Stated policies scenario).

Electricity

The historical data for electric prices (All taxes and levies included) for non-households from Eurostat[4] is used in the model. These prices reflect the electricity tariffs paid by the consumers; costs of the infrastructure used to deliver the electricity (charging points or ERS catenary) are covered through a separate infrastructure cost component. The price varies by consumption type;

[4] Data series: *nrg_pc_205*

for this modelling the consumption Band IC: 500 MWh < Consumption < 2 000 MWh is used as the central case.

Table 3.16: Real electricity prices for non-households from Eurostat (Band IC)

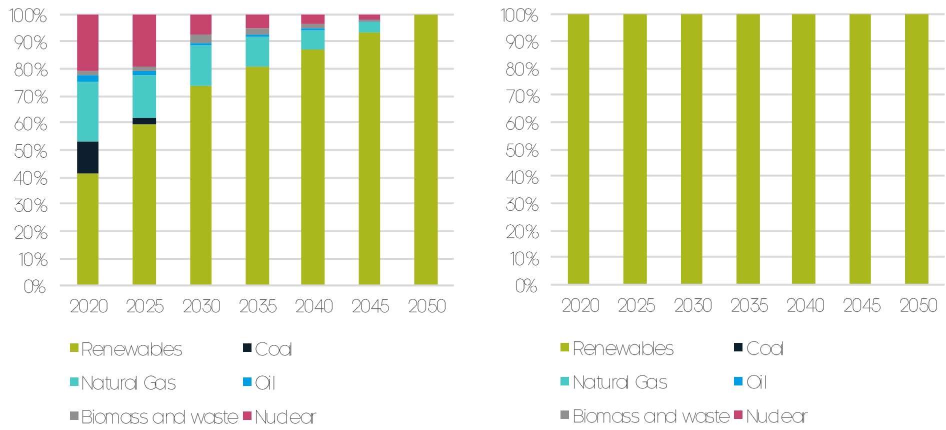
	2015	2016	2017	2018	2019	2020
Total (€/MWh, real 2020)	140	129	127	131	136	136

Projected electricity prices are based on the growth rate of electricity prices for final demand sectors from PRIMES reference scenario (2020)[5].

Electricity generation mix

In our analysis we take two electricity generation mix scenarios into account. The 'Conservative' generation mix of electricity is in line with the Integrated National Energy and Climate Plan of Spain until 2030. After that we assume increasing shares of renewables to reach a carbon neutral generation mix by 2050 (Figure 3.5). In the 'Green' electricity generation scenario electricity is sourced from renewables by generating it locally at the charger or via power purchase agreements. Thus, it is electricity generation in the 'Green' scenario is completely zero carbon in all years.

Figure 3.5 Evolution of electricity generation mix in 'Conservative' (left) and 'Green' (right) scenario (%)



Hydrogen

The production of hydrogen in Europe is expected to increase substantially, driving down the price. Currently there are two major technologies to produce hydrogen: Steam Methane Reforming (SMR) and electrolysis. While SMR has significantly lower costs, the related carbon dioxide emissions are substantial. Hydrogen production through electrolysis using renewable electricity on the other hand has no CO_2 emissions.

We take our hydrogen prices from the Hydrogen Council (2020) forecasts up to 2030. We then assume that the price remains constant after 2030, as strong uncertainty over the evolution of hydrogen prices in this timeframe persists. These values cover the costs of production, preparation, distribution and of the fuelling station.

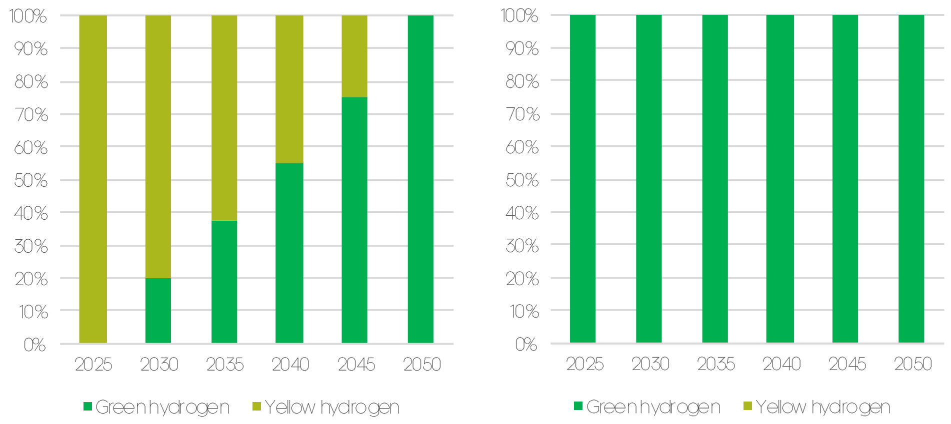
Hydrogen production mix

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. Similar to electricity generation, two hydrogen production mix

[5] European commission 2020: EU Reference Scenario 2020, Energy, transport and GHG emissions Trends to 2050. Accessed here 27/07/2021

scenarios are considered. In both scenarios it is assumed assume that hydrogen is produced through electrolysis. Hydrogen production is initially produced from grid electricity in the 'Conservative' scenario,(i.e. yellow hydrogen), then production gradually shifts towards 100% green hydrogen. In the 'Green' hydrogen mix scenario hydrogen is all produced using renewable electricity at hydrogen fuelling stations. The production mixes, used to calculate the CO_2 footprint of hydrogen, are shown in Figure 3.6.

Figure 3.6: Hydrogen production mix scenarios for road transport (% of annual hydrogen production)



3.5 Maintenance costs

In our TCO analysis, we assume different annual maintenance costs for vehicles based on their size and type of powertrain. In general, EVs have fewer components than conventional powertrains and have therefore lower maintenance costs. Annual maintenance costs for vans by powertrain were taken from Lebeau et al. (2019)[6] and costs for HHGVs were taken from a study by PwC (2020). We then project the maintenance costs of LHGVs and MHGVs by assuming a decrease in the portion of costs made up by the maintenance costs presented in the Vehicle Trends & Maintenance Costs Survey (2012).

The cost of battery replacement is included in an additional sensitivity analysis, where we assume battery replacement costs of 100$/kWh as sourced from Holland (2018).

Maintenance costs are shown in Table 3.17. These are kept constant over time.

Table 3.17: Assumed annual maintenance costs by powertrain type (€, 2020)

Powertrain	Size	Maintenance costs (€, 2020)
ICE - Petrol	Vans	403
	LHGVs	4,800
	MHGVs	4,800
	HHGVs	8,000
ICE - Diesel	Vans	845
	LHGVs	4,800

[6] Lebeau, P., Macharis, C., & Van Mierlo, J. (2019). How to improve the total cost of ownership of electric vehicles: An analysis of the light commercial vehicle segment. *World Electric Vehicle Journal*, *10*(4), 90.

	MHGVs	4,800
	HHGVs	8,000
BEV-ERS	Vans	N/A
	LHGVs	3,150
	MHGVs	3,150
	HHGVs	5,250
BEV	Vans	311
	LHGVs	3,000
	MHGVs	3,000
	HHGVs	5,000
FCEV	Vans	406
	LHGVs	3,600
	MHGVs	3,600
	HHGVs	6,000

3.6 Financial costs

For the financial costs, we assume that new vehicles are entirely financed via loan with a 6.5% average interest rate in our central scenario to repay the costs of capital over the lifetime of the vehicle. Payments are made monthly and financial costs are the difference between the amount of the total payments and the purchase price of the vehicle.

4 Vehicle stock modelling

The evolution of Spanish stock of road freight vehicles, including vans and HGVs, and the estimation of the related fuel demand and CO_2 emissions in each scenario was modelled using CE's vehicle stock model. In this section we show the impact of the assumed sales mixes and policies on the resulting stock in each case.

4.1 Projected vehicle stocks

CPI scenario

In the CPI scenario in terms of impact on the overall stock of the sales mix, less than 12% of the HGV stock in 2040 has an advanced powertrain, with BEVs contributing 8%. By 2050, BEVs make up 11% of the total HGV stock and FCEVs represent 5% (Figure 4.2).

The take up of BEVs is faster in the stock of vans. By 2040 the BEV share in the total stock is already 18% and it reaches 24% by 2050 (Figure 4.1).

The stock of road freight vehicles is expected to increase in the next decades to satisfy the increasing demand for road transport of goods, in line with the latest projections of the PRIMES reference scenario (2020) for Spain.

Figure 4.1: Stock composition for vans in the CPI scenario

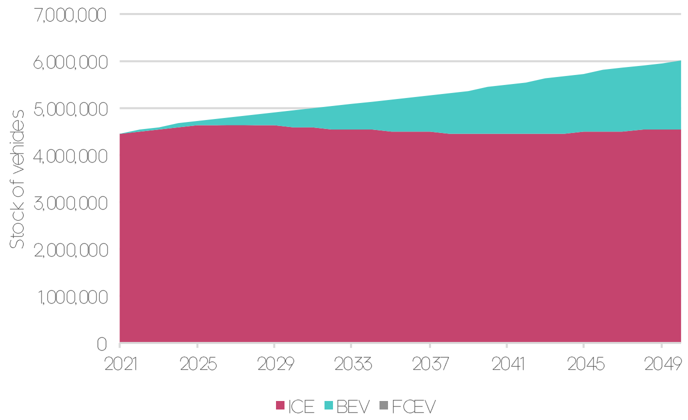
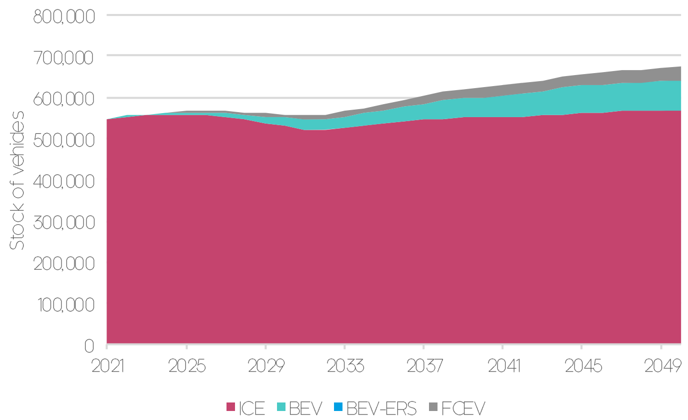


Figure 4.2: Stock composition for HGVs in the CPI scenario

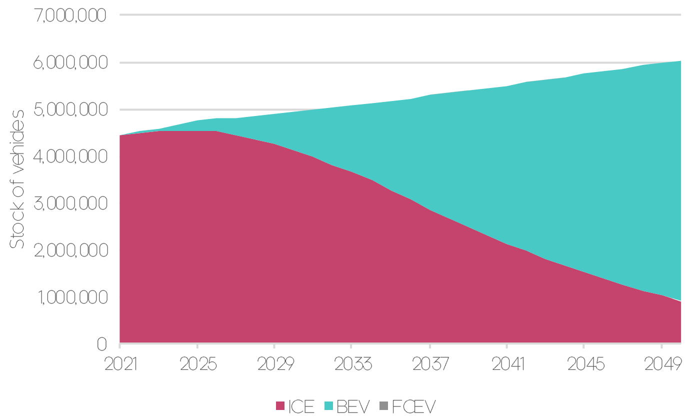


Van powertrain deployment in the TECH scenarios

Assuming the phase out of the sale of new ICE vans by 2035, the deployment of BEV van powertrains in the TECH scenarios is rapid. The share of BEVs in the total van stock continues to increase after the phase out, reaching 85% by

2050 (up from 58% in 2040), enabled by improved battery technology and the deployment of adequate depot recharging infrastructure (see Figure 4.3). Nevertheless, in 2050 carbon neutrality is still not achieved as the rest of the stock are still ICE vehicles.

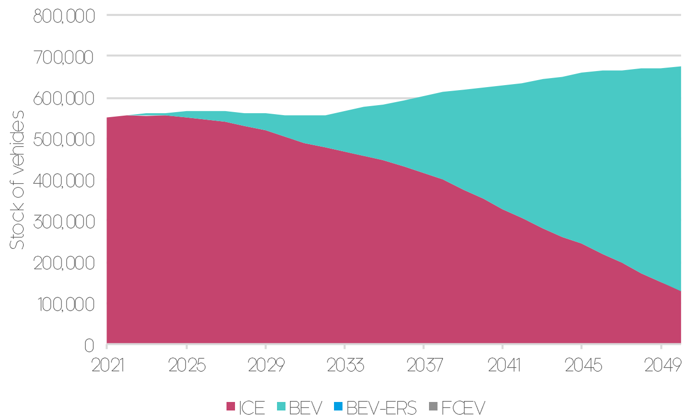
Figure 4.3: Stock composition for vans in the TECH scenarios



HGV powertrain deployment in the TECH BEV scenario

In the TECH BEV scenario, BEVs reach 100% of new sales by 2050 (up from 35% in 2030), which translates into 81% of the stock in 2050 (up from almost 10% of the stock in 2030) (Figure 4.4).

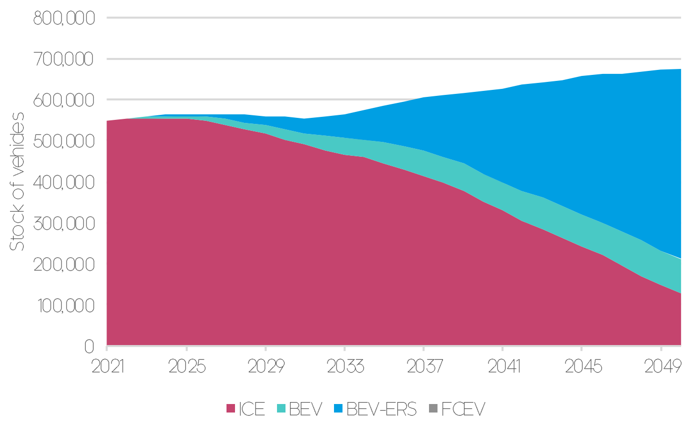
Figure 4.4: Stock composition for HGVs in the TECH BEV scenario



HGV powertrain deployment in the TECH ERS scenario

In this scenario the slow build-up of the dominant BEV-ERS technology due to infrastructure requirements means that only 32% of the vehicle stock in 2040 is ERS-enabled, and the stock remains dominated by ICEs at this point. However, by 2050 ERS-enabled vehicles are more than 68% of the stock, and ICEs have shrunk to 19%.

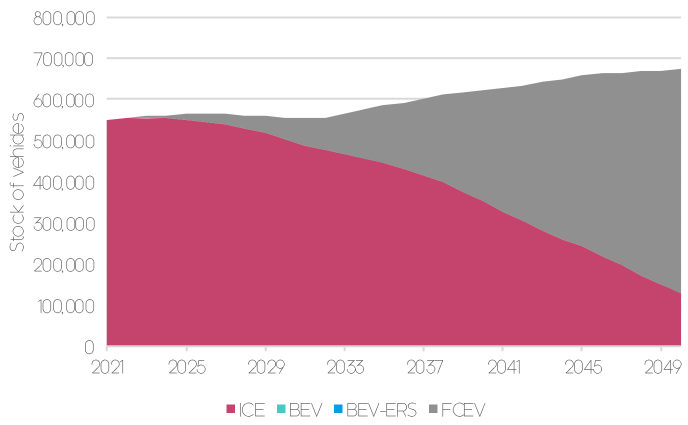
Figure 4.5: Stock composition for HGVs in the TECH ERS scenario



HGV powertrain deployment in the TECH FCEV scenario

Under this scenario, the build-up of FCEVs is identical to the deployment of BEV-ERS powertrains in the TECH ERS scenario. Due to the relatively high starting costs for the technology, FCEVs achieve rapid deployment from 2035 onwards, reaching 43% of the stock in 2040 and 81% in 2050.

Figure 4.6: Stock composition for HGVs in the TECH FCEV scenario

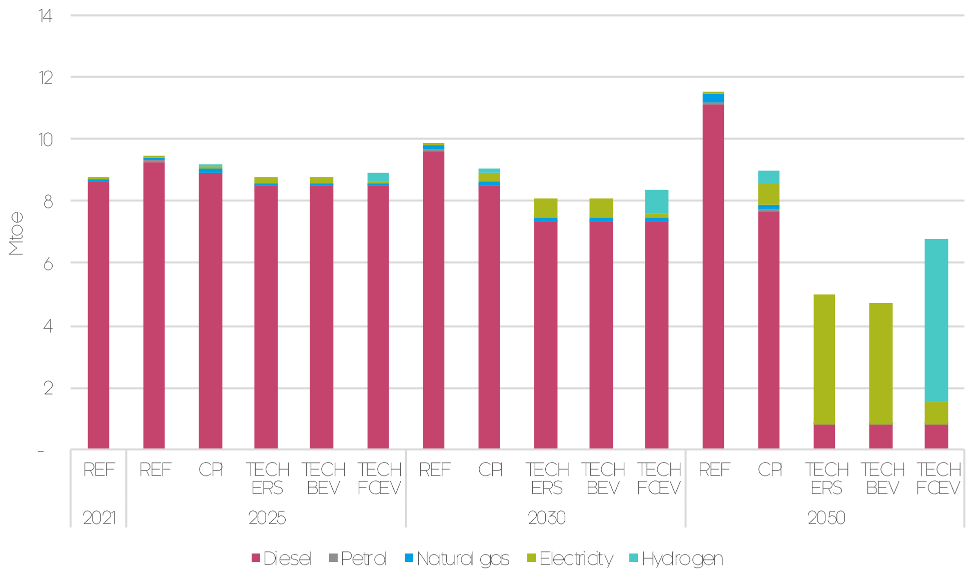


As in the case of vans, the stock of HGVs in the TECH scenarios is not fully decarbonised by the year 2050, and the zero-carbon target for the sector is not achieved.

4.2 Final energy consumption

The deployment of advanced powertrains and the combined uptake of fuel-efficient technologies substantially increase the efficiency of the vehicle stock and consequently reduces the associated energy consumption. As Figure 4.7 shows, the vehicle stock's fuel consumption reduces modestly by 2030 in the TECH scenarios compared to the CPI scenario. However, by 2050 as the share of advanced powertrain vehicles increases, annual fuel demand falls by more than 56% in TECH BEV and TECH ERS scenarios and by 41% in the TECH FCEV scenario compared to the Reference scenario. Fuel demand reduction in the TECH FCEV scenario is more moderate due to the lower efficiency of fuel cell technology compared to battery-electric powertrains. Electricity and hydrogen demand grow in line with the rollout of the stock of the advanced powertrains. By 2050, due to their higher efficiencies, their share of total energy demand is lower than their share of the vehicle stock.

Figure 4.7: Stock fuel consumption of fossil fuels, hydrogen and electricity (Mtoe)



5 Infrastructure requirements

This section describes the definition, costs, and rate of deployment of:

- Electric road systems;
- Electric charging posts;
- Hydrogen refuelling stations.

It also provides a breakdown of our calculation for total infrastructure requirements.

The primary infrastructure to serve BEVs will be rapid chargers on highways, with an output of 700 kW. Alongside these there will also be BEV depot chargers (90kW) for slow charging overnight.

The main source of electricity for ERS-enabled vehicles will be via an electric road system (ERS). There will also be a roll out of slow depot chargers (22kW) for each vehicle, to facilitate overnight charging of vehicles. As the deployment of ERS increases the time spent in electric mode will increase, reflecting an increased use of the ERS infrastructure. To incentivise the take up of ERS vehicles the ERS infrastructure deployment has been front-loaded.

The main infrastructure required to serve FCEVs will be hydrogen refuelling stations (HRS). For this technology to take off, sufficient front loading is needed to incentivise hauliers to invest in FCEV HGVs. After an initial spike in deployment the roll out of hydrogen refuelling is determined by a refuelling density assumption.

5.1 Electric road systems

Costs

We base the cost assumptions for installation, operation and maintenance of ERS in the HGV stock model on BMVI (2017). Installation costs decrease in time, as the installation costs in 2020 (€m/km) represent the costs in the earlier stages of deployment, and then installation costs in 2050 (€m/km) are the costs estimate of a mature deployment, after substantial learning and associated cost reductions have taken place. Linear interpolation is used to derive the cost in each year between 2020 and 2050.

Table 5.1: Cost assumption for ERS (€m/km)

	Installation cost in 2020 (€m/km)	Installation cost in 2050 (€m/km)	O&M cost (€m/km)
Assumption	2.41	2.14	0.05

Deployment

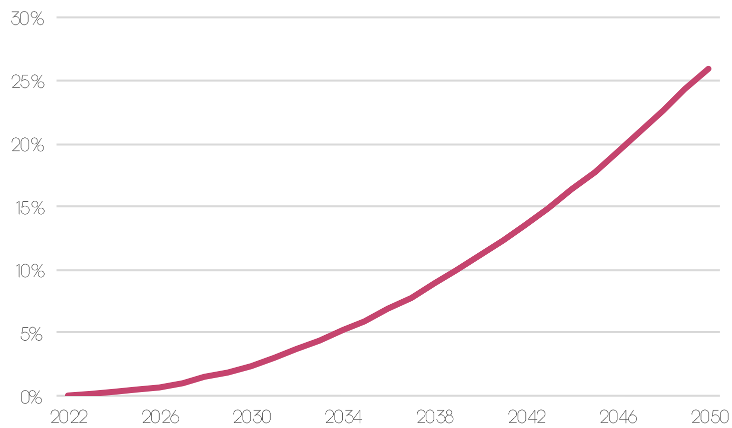
The ERS catenary infrastructure is deployed along the highways network in Spain and most important motorways in the country. Based on Mapa de Tráfico de la DGC. Año 2019, the traffic flow maps for heavy duty vehicles, we identified the portion of the Spanish highways network with the highest levels of traffic for HGVs, that is the highways that most require to be equipped with ERS catenary infrastructure in the TECH ERS scenario to allow the dynamic charging of the progressively growing fleet of BEV ERS vehicles.

Based on this, we selected the highways reported in Table 5.2 and projected the deployment of the ERS catenary infrastructure as showed in Figure 5.1.

Table 5.2: Network of roads covered with ERS catenary infrastructure by 2050 in the TECH ERS scenario

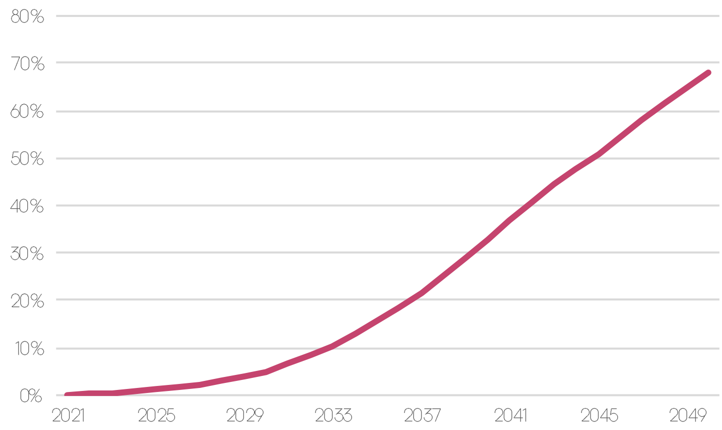
Reference	Name	Length (km)
A-2	Madrid – Barcelona	537
A-3	Madrid – Valencia	348
A-35	Almansa – Xàtiva	45
A-4	Madrid – Cádiz	577
A-6	Madrid – Arteixo	518
A-7	La Jonquera – Algeciras	418
AP-7	La Jonquera – Vera	849
N-340	Barcelona – Cádiz	546
SE-30	Alcalá de Guadaíra – Santiponce	22
V-30	Valencia	17
V-31	Valencia – Silla	14

Figure 5.1: Projected share of Spanish highways network covered by ERS in the TECH ERS scenario (%)



We assume an increasingly rapid deployment of infrastructure as learning takes place and costs decrease. Despite the slow initial take up, about 26% of the considered network is covered by ERS in 2050 (up from 2.4% in 2030 and 11.1% in 2040). The projected share of ERS enabled HGVs is also presented in Figure 5.2.

Figure 5.2: Share of HGV fleet that is ERS enabled (%)



As described in the TECH ERS scenario, due to the necessary infrastructure requirements BEV ERS vehicles are only 5% of the HVGs fleet in 2030; however, their share rapidly expands thereafter, reaching 68% in 2050.

5.2 Rapid charging

A few firms have recently announced battery electric HGVs which will rely upon rapid charging technology for on-route recharging. Such vehicles will require dedicated high-power charging infrastructure installed along key transport routes (e.g. the core TEN-T network) and lower-powered chargers installed at haulage depots to enable overnight charging.

Costs

The production and installation costs for depot and rapid charging have been based on the cost analysis for chargers from Trucking into a Greener Future (2018) and from the feedback received by the Polytechnic University of Milan.

Depot chargers have been included at different sizes to support different size batteries in the fleet. The function of these chargers is to enable overnight slow charging of vehicles, and it is assumed that depot owners would buy the cheapest charger that fulfils their need.

Table 5.3: Rapid charging infrastructure based on Cambridge Econometrics (2018)

Main application	Charging point features	Power (kW)	Cost (€, 2020)	
			Production	Installation
Depot – vans	Van wall box Brownfield	7 kW	855	427
Depot – ERS HHGVs	Overnight charging Brownfield	22kW	10,683	4,074
Depot – BEV HHGVs	Overnight charging Brownfield	90kW	34,186	10,683
Rapid charging	Greenfield	700kW	512,797	398,619

The installation 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. These costs are based on linear scale up of the additional costs of 350kW charging posts from Fuelling Europe's Future (2018). We have assumed that all depot chargers are brownfield sites, and rapid charging sites will be greenfield, reflecting the substantial additional space requirements of new rapid charging stations and the tight limits to existing HGV stopping and refuelling space in much of Spain.

Table 5.4: Additional costs for preparing sites for rapid charging

	Item	Initial stage (2 chargers) (€, 2020)	Mature Stage (8 or more chargers) (€, 2020)
Brownfield site	Grid connection	10,683	368,573
	Civils	68,373	87,603
	TOTAL	79,056	456,175
Greenfield site	Access roads	53,416	53,416
	Site works	106,833	106,833
	Professional fees	35,255	35,255
	Grid connection	5,342	363,231
	Civils	68,373	87,603
	TOTAL	269,218	646,337

Source: SDG for the EC, Clean Power for Transport Infrastructure Deployment, 2017.

To determine the roll out of rapid charging infrastructure to meet the demand of HGVs we have derived an infrastructure density assumption summarised in Table 5.5.

Table 5.5: Infrastructure density (EVs per charging point) based on Cambridge Econometrics (2018) and Nikola (2016)

	2020	2030	2040	2050
Depot - BEVs	1.0	1.0	1.0	1.0
Depot – ERS HHGVs	1.0	1.0	1.0	1.0
Depot - vans	1.0	1.0	1.0	1.0
Rapid charging - High	28.7	28.7	28.7	28.7

5.3 Hydrogen refuelling stations

The main components of a hydrogen refuelling station (HRS) are a compressor, refrigeration equipment and a dispenser. An HRS will dispense 700 bar hydrogen in conjunction with the performance specification set out in the SAE J2601 international standard. The current technology level and manufacturing volumes means that the costs of a hydrogen refuelling tank are relatively high.

We have selected two different HRS sizes for the stock model; 10,000kg/day and 25,000kg/day. Our cost estimates of HRS are linearly scaled using the 0.6 power rule from the cost of a 3,000kg/day station initial conceived for hydrogen buses[7]. The cost of a dispenser (including installation & civil etc.) is in the range of €100,000 – €300,000. A 3,000kg/day charger requires 5 dispensers, this ratio is used to determine the number of dispensers needed for a 10,000kg and 25,000kg HRS. The investment cost of a storage and compression unit combined is within the range of 2,500 – 5,000 €/(kg H2 /day). Larger HRS can achieve costs at the lower end of the range, and since the modelled chargers are large, we assume costs at the bottom end of these ranges.

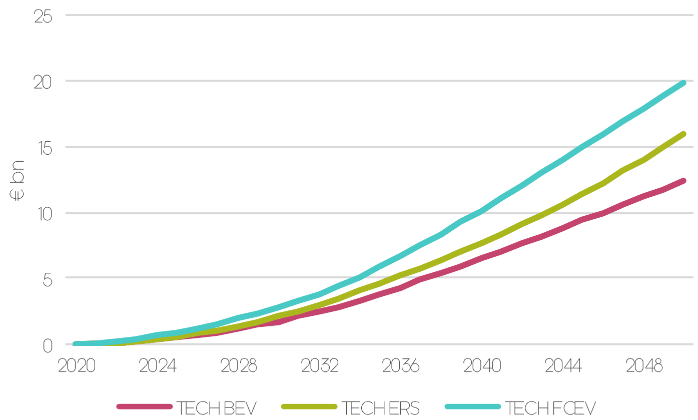
Table 5.6: Installation costs for hydrogen refuelling stations (€, 2020)

Size of charger	Number of dispensers per station	Installation cost of dispensers (€m)	Installation cost of storage and compression unit (€m)	Total installation cost (€m)
10,000 kg	17	2	26	28
25,000 kg	42	4	46	48

5.4 Total cumulative investment in infrastructure

Figure 5.3 below shows the cumulative infrastructure investment requirements by scenario from 2021 to 2050. In the TECH scenarios the rapid deployment of the required infrastructure is essential to enable the penetration of EVs to the fleet. The deployment of hydrogen refuelling stations is more capital intensive than the installation of charges or ERS catenaries. The cumulative infrastructure investment in the TECH FCEV scenario reaches almost €20 billion by 2050, while in in the TECH ERS scenario it is €16 billion and in TECH BEV, where infrastructure costs are lowest, it is €12 billion.

Figure 5.3: Total cumulative investment in infrastructure by scenario (€ bn, 2020)



[7] NewBusFuel. Accessed here on 09/06/2021

6 Environmental impacts

6.1 Impact on CO_2 emissions

Average emissions

The evolution of average CO_2 emissions for new vehicles and for the stock in each scenario are shown in Figure 6.1 for vans and in Figure 6.2 for HHGVs. Apart from the REF scenario, all scenarios meet or exceed the European Commission's proposed reductions of 15% by 2025 and 30% (31% for vans) by 2030 (in terms of gCO_2/km compared to the baseline). In the case of vans, tailpipe emissions from new vehicles drop to zero after the phase out of sales of ICEs in 2035, and the same happens from 2040 for HGVs.

Tailpipe emissions of new vehicles are zero after 2040, however, the tailpipe emissions of the total vehicle stock do not reach zero by 2050, as ICE vehicles sold in earlier years (before the phase-out) are still on the road.

Figure 6.1: Average new vehicle (left) and average stock (right) tailpipe CO_2 emissions of vans (gCO_2 / km)

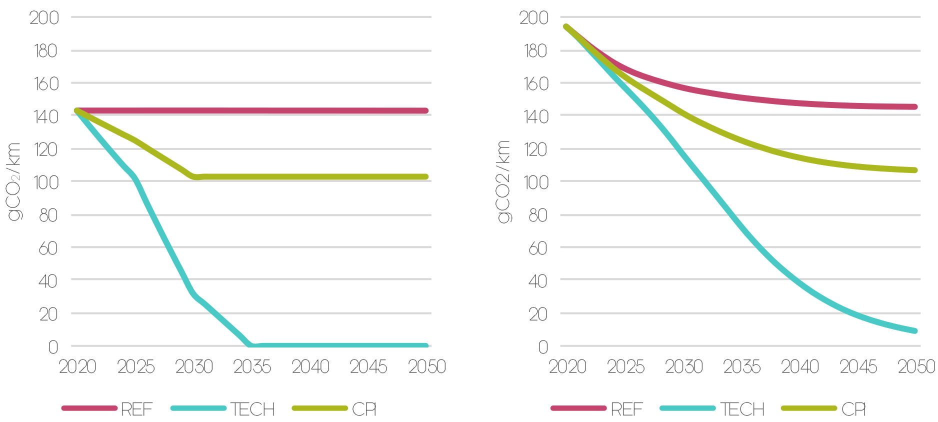
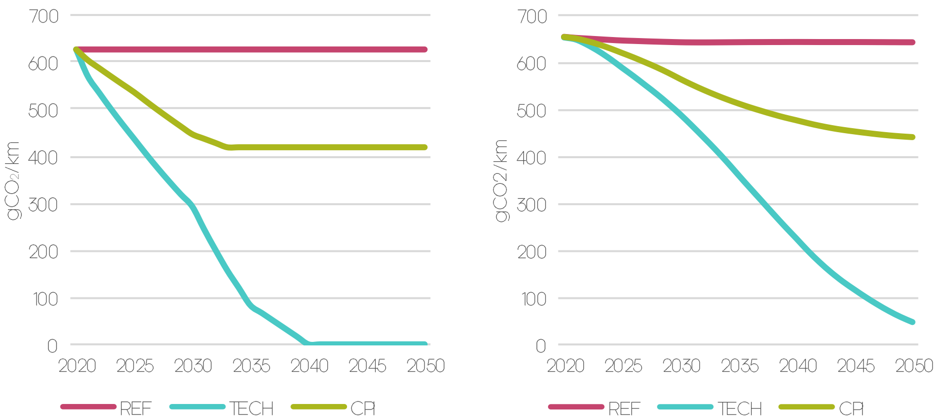
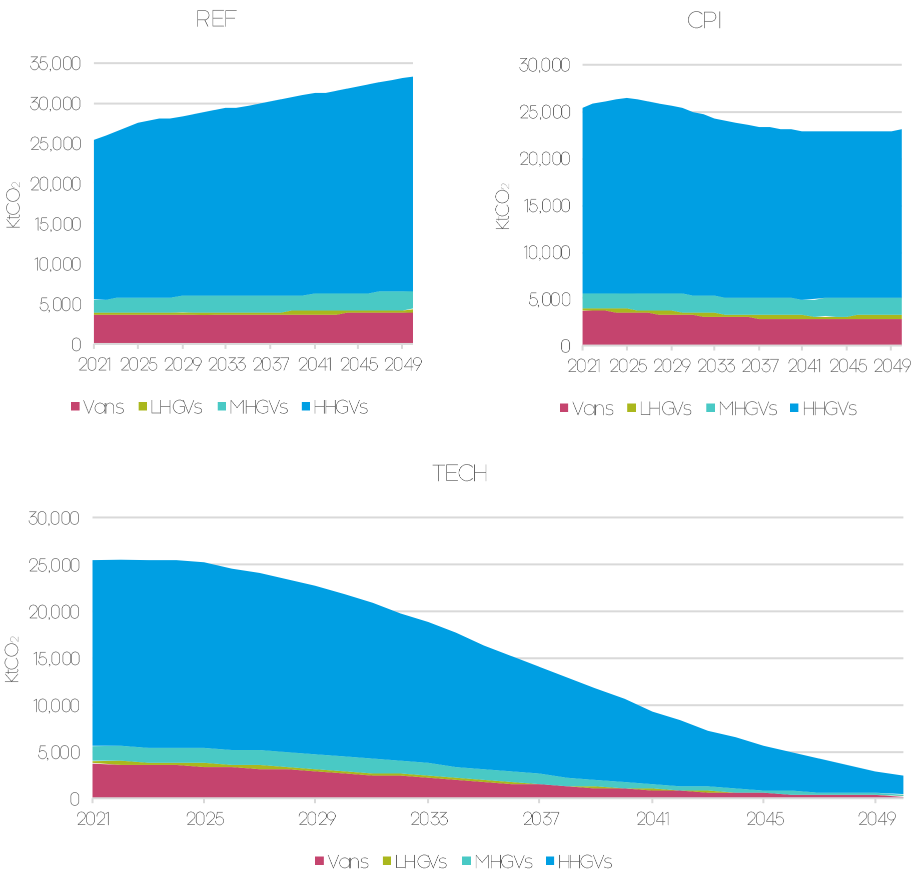


Figure 6.2: Average new vehicle (left) and average stock (right) tailpipe CO_2 emissions of HHGVs (gCO_2 / km)



Despite this, the penetration of zero emission technologies leads to a considerable drop in tailpipe emissions between 2030 and 2050, as outlined in Figure 6.3. Annual tailpipe CO_2 emissions are almost 93% lower by 2050 in the TECH scenarios than in the Reference scenario, whereas in the CPI scenario the reduction is only 31%.

Figure 6.3: Tailpipe CO_2 emissions of the stock ($ktCO_2$)

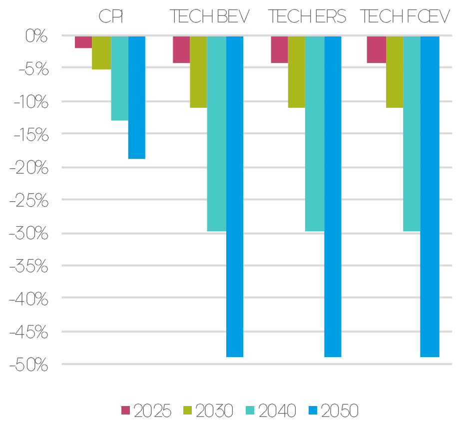


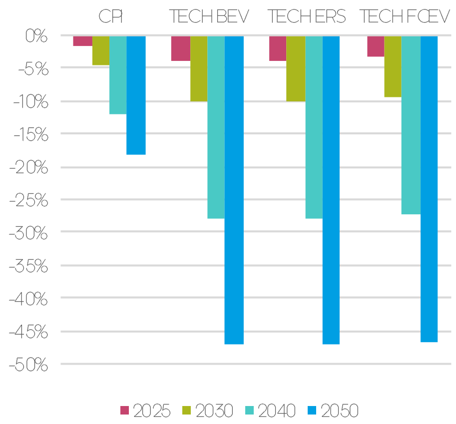
Well-to-wheel emissions

Figure 6.4 shows the cumulative well-to-wheel CO_2 emissions reductions of the vehicle stock under each scenario compared to the baseline (REF). Well-to-wheel emissions take into account the emissions associated with the generation of electricity and hydrogen used as fuel by zero carbon vans and HGVs.

All TECH scenarios achieve reduction greater than 47% via a combination of increased fuel efficiency and switching the energy source from diesel to zero-carbon electricity. Savings are highest in case of the TECH scenarios with ‘Green’ electricity and hydrogen mix scenario, achieving more than 49% reduction compared to the baseline. In the ‘Conservative’ production scenario the TECH BEV and TECH ERS scenarios outperforms the TECH FCEV scenario due to the energy loss occurring during electrolysis. Using grid electricity to produce hydrogen and fuel FCEVs leads to higher implied emissions.

Figure 6.4: Cumulative CO_2 well-to-wheel emission reductions in the 'Green' electricity and hydrogen mix scenario (left) and in the 'Conservative' electricity and hydrogen mix scenario (right) (%)



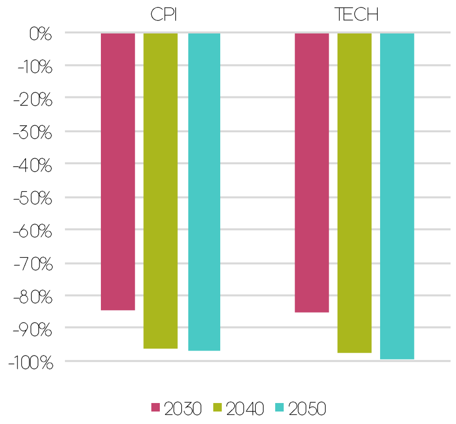


Impacts on emissions of particulate matter and nitrogen oxides

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 road freight transport.

In the CPI scenario, annual particulate matter emissions (PM_{10}) from vehicle exhausts are cut by 97% in 2050 and NO_x emissions from vehicle exhausts are cut 96% in 2050 compared to 2020 levels (see Figure 6.5). In the TECH scenarios impacts are even higher for both particulate matter (almost 100% by 2050) and NO_x (99% by 2050).

Figure 6.5: Tailpipe emissions of NO_x (left) and PM_{10} (right) of the vehicle stock (% difference from baseline in 2020)



In the short to medium term, much of the reductions seen across all of the scenarios are related to the impact of the Euro 5, Euro 6, and Euro 7 emissions standards. This is due to the fact that the progressive replacement of old ICE vehicles with newer and more efficient diesel vehicles allows substantial decreases in PM10 and NO_x annual emissions. However, beyond 2030, tailpipe emissions in the CPI scenario decrease at a slower rate compared to the TECH scenarios. This is mainly achieved by the transition away from petrol and diesel vehicles towards electricity and hydrogen.

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

7 Analysis of the Total Cost of Ownership

In the earlier analysis, we took as given the deployment scenarios, where hauliers took up available zero carbon technologies to reduce the environmental impact of road freight. However, the realised take-up of the advanced technologies will be determined by the owners of these vehicles, the hauliers. Thus, it is also important to look at the total cost of owning different kinds of vehicle.

To calculate the Total Cost of Ownership (TCO) of vans and HHGVs, we add up the different costs associated with owning a vehicle over its lifetime. The cost components considered in the central case are the following:

- **Depreciation**: the purchase price of a vehicle (including VAT) minus the resale price at the end of the TCO period, i.e. the value lost at the point between purchase and sale of the vehicle.
- **Fuel costs**: the cost of the fuel/energy to cover the mileage driven over the TCO period.
- **Maintenance costs**: the cost of maintaining and fixing the vehicle.
- **Infrastructure costs**: for electric vehicles, the CAPEX and OPEX of a depot charger over the TCO period, and a per vehicle contribution to the total costs of the rapid charging infrastructure network; for hydrogen vehicles, a per vehicle contribution to the total costs of the network of hydrogen refuelling stations; for ERS-enabled vehicles, a per vehicle contribution to the total costs of the catenary infrastructure network.
- **Financial costs**: the cost of financing the purchase cost of the vehicle[8].

Furthermore, we consider additional sensitivities and use-cases to explore the effect of changes in the assumptions regarding fuel prices, mileage, and the holding period, as well as the impact of potential future policies that are now under discussion.

7.1 Archetypes

We base our calculations on vans and HHGVs archetypes partially taken from recent literature, for example Lebeau at al. (2019) and Roland Berger (2017), and further informed and updated using the feedback received from the Steering Committee. This allows us to take into account the latest developments and trends in the Spanish (and European) market of road freight vehicles. Archetypes represent an average vehicle of a certain size class and facilitate the calculation of the cost components in the TCO analysis. The characteristics of the archetypes for vans are shown in Table 7.1.

[8] See Section 3 for more details about the cost components.

Table 7.1: Powertrain characteristics - Archetypes for vans by type of powertrain

	ICE diesel	BEV	FCEV
Battery (kWh)	-	70	45
Electric drive (kW)	-	90	90
Fuel cell (kW)	-	-	45
H2 stored (Kg)	-	-	3
Diesel engine (kW)	90	-	-

Regarding the archetypes for HHGVs, we start from the powertrain characteristics outlined in the analysis of the University of California (2020) and in the study of the ICCT (2017), and further inform and update the archetypes using the feedback received from the Steering Committee. The characteristics of the archetypes for HHGVs are summarised in Table 7.2.

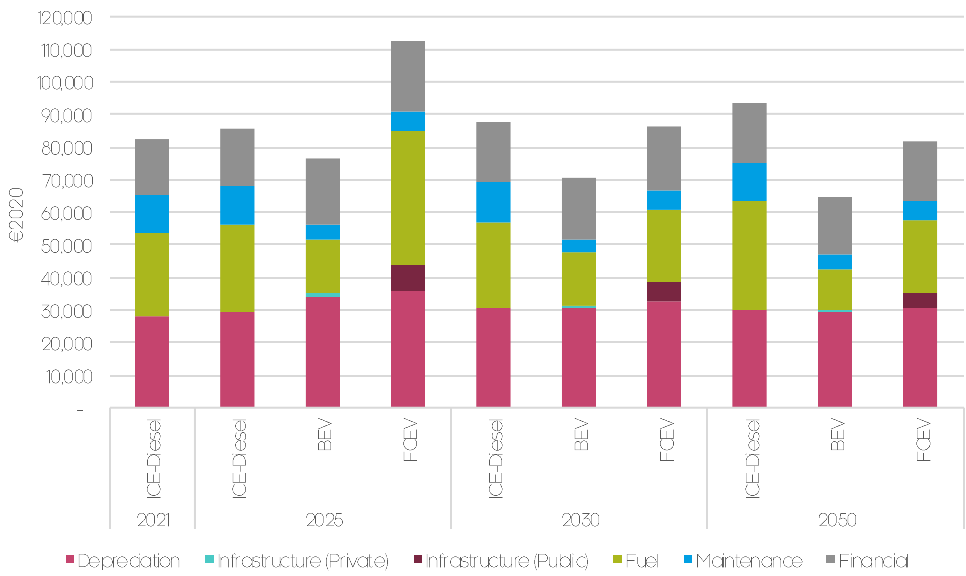
Table 7.2: Powertrain characteristics – Archetypes for HHGVs by type of powertrain

	ICE diesel	BEV	BEV-ERS	FCEV
Battery (kWh)	-	600	225	100
Electric drive (kW)	-	350	350	350
Fuel cell (kW)	-	-	-	250
H2 stored (Kg)	-	-	-	24
Diesel engine (kW)	350	-	-	-

7.2 Central case

Vans Figure 7.1 shows the estimated total cost of ownership of vans over a 14-year ownership period. In the case of vans, we consider ICE-Diesels, BEVs and FCEVs.

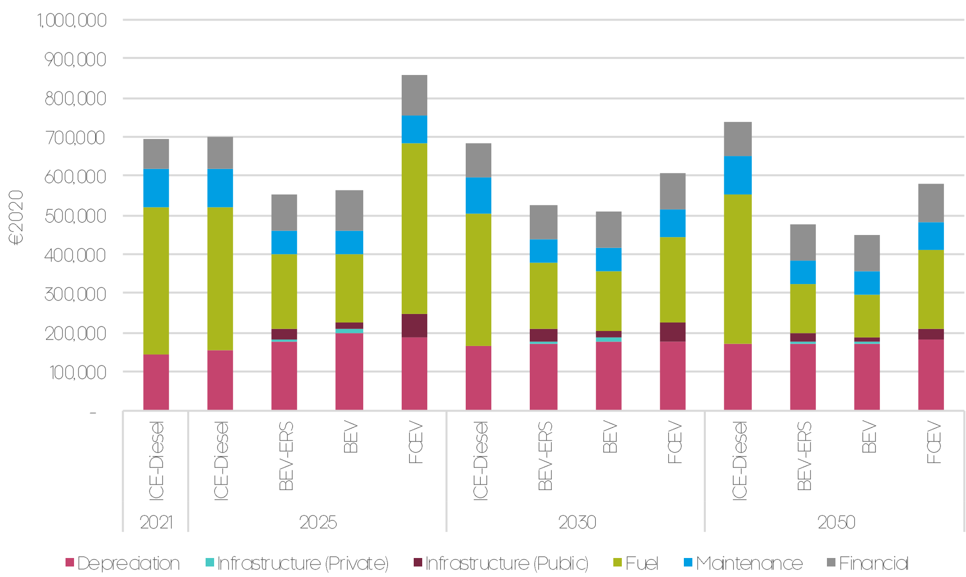
Figure 7.1: Total cost of ownership for vans over 14 years (€, 2020)



Based on the calculations, BEV vans will become the cheapest powertrain to own by 2025, although only marginally cheaper than an ICE. The main factors explaining the cost differential are the reduced fuel costs, due to the higher efficiency compared to ICE and FCEV, and the lower maintenance costs, which compensate for the higher depreciation and financial costs. FCEV vans become competitive with ICE diesel in 2030, as hydrogen prices fall due to the economies of scale associated to the mass production, while BEVs are substantially cheaper than ICEs by the same point.

HHGVs As for the HHGVs, we also consider ERS enabled BEVs in addition to the other technologies over a 12-year lifetime period (Figure 7.2).

Figure 7.2: Total cost of ownership for HHGVs over 12 years (€, 2020)



We can see similar patterns in the evolution of HHGVs' cost components as for vans. BEVs and ERS enabled BEVs are already cheaper in 2025 than ICEs. Although ERS enabled BEVs total cost of ownership is lower in 2025 than pure BEVs, as battery prices further decrease BEVs become the lowest cost by 2030. FCEV HHGVs are cost-competitive from 2030 onwards thanks to reductions in the price of hydrogen.

The main finding of the TCO analysis is that due to the low fuel costs and increased efficiency of the electric motor, the lower running costs of BEV based powertrains more than outweigh the higher capital costs. For FCEVs, the vehicles achieve cost-competitiveness with ICEs by 2030 due to the substantial decrease in hydrogen prices. FCEVs and BEVs are broadly similar in TCO terms over the period 2030-50.

Overall, the TCO comparison shows that the uptake of fuel-efficient vehicles should not raise overall costs to hauliers. However, there are other challenges to overcome to ensure uptake of more fuel-efficient vehicles:

- fuel expenses are covered by the clients as part of standard contracts, reducing the incentive of hauliers to reduce these costs
- the haulage sector has many SME operators that lack the capacity to finance investments in more fuel-efficient rolling stock

7.3 Sensitivities

There is inherent uncertainty surrounding any analysis of future costs. However, there are particularly large uncertainties around the future price trajectory of fuels and other key cost components. To explore the impact of these, we further tested the TCO results through sensitivity analyses, varying each element one-at-a-time and drawing out potential implications.

Fuel price sensitivities

Fuel costs represent the greatest cost component in the TCO analysis. Therefore, changes in the fuel prices might have a significant impact on the total cost. The impact of a +-25% change in fuel prices in 2030 is outlined in Figure 7.3.

Figure 7.3: Total cost of ownership fuel price sensitivities for vans (left) and HHGVs (right) in 2030 (€, 2020)

In general, we can see that fuel price changes do not affect the basic trends in the TCO analysis. Although there are some examples when ICEs become lower cost than FCEVs, e.g., if fossil fuels are 25% cheaper than in the central case and hydrogen prices are 25% more expensive, it seems more likely that fossil fuel prices are underestimated in the central case and therefore that the gap between EVs and ICEs is even greater.

Cost of use sensitivities

The evolution of cost components highly depend on how much the trucks are used. Therefore, we also carry out a sensitivity analysis considering +-25% mileage change.

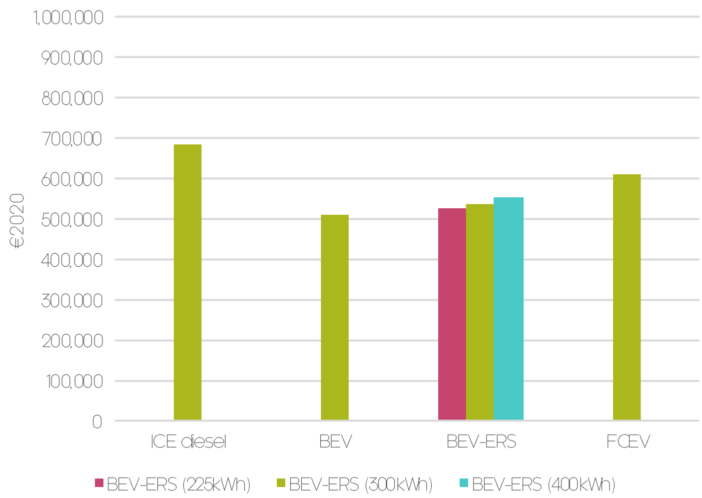
Figure 7.4: Total cost of ownership cost of use sensitivities for vans (left) and HHGVs (right) in 2030 (€, 2020)

Based on Figure 7.4 we can see that the more the trucks are used the more cost-effective zero carbon powertrain vehicles become. This reflects the fact that vehicles which travel longer total distances use more energy input, and the cost of the required energy is much lower for electric vehicles than their diesel equivalents. This effect is especially significant in case of BEVs and ERS-enabled BEVs due to the lower cost of electricity than hydrogen's.

BEV-ERS battery sensitivities

The battery size of ERS-enabled BEVs heavily depends on the use of the vehicle. Therefore, we consider three battery options for ERS enabled BEVs: 225kWh, 300 kWh and 400kWh. Battery costs are reflected in the cost of vehicles; thus, it is included in depreciation cost component in the TCO analysis. While changes in the battery pack size does not substantially impact the TCO of BEV-ERS compared to ICE, ERS-enabled vehicles would further reduce their competitiveness with BEV vehicles if larger batteries are required (see Figure 7.5).

Figure 7.5: Total cost of ownership BEV-ERS battery sensitivities for HHGVs in 2030 (€, 2020)

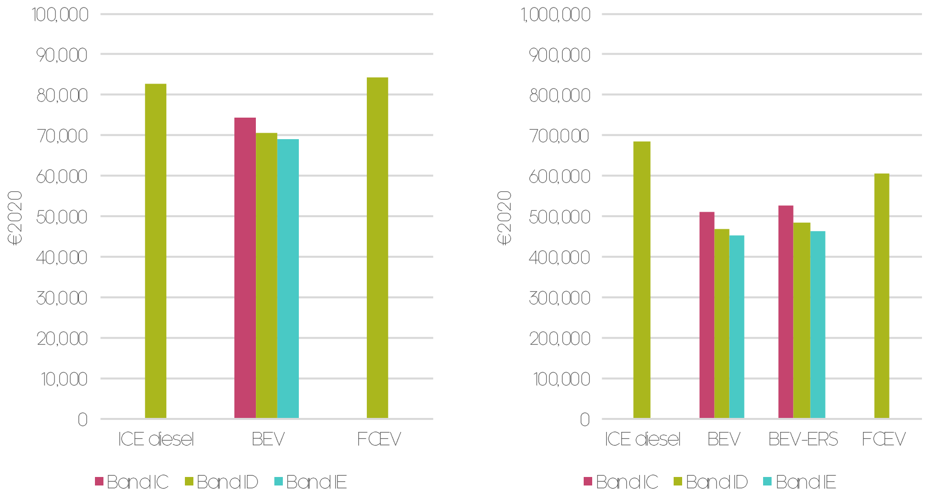


7.4 Alternative use-cases

Electricity tariffs

Although most haulier companies own only a few trucks, there are a number of larger operators as well. In the central case we used the non-household Band-IC electricity tariffs of Eurostat, however, major companies may exceed the 2 000 MWh annual consumption. Figure 7.6 shows that large consumers facing lower electricity tariffs experience substantially lower fuel costs, which further improves the price competitiveness of BEVs.

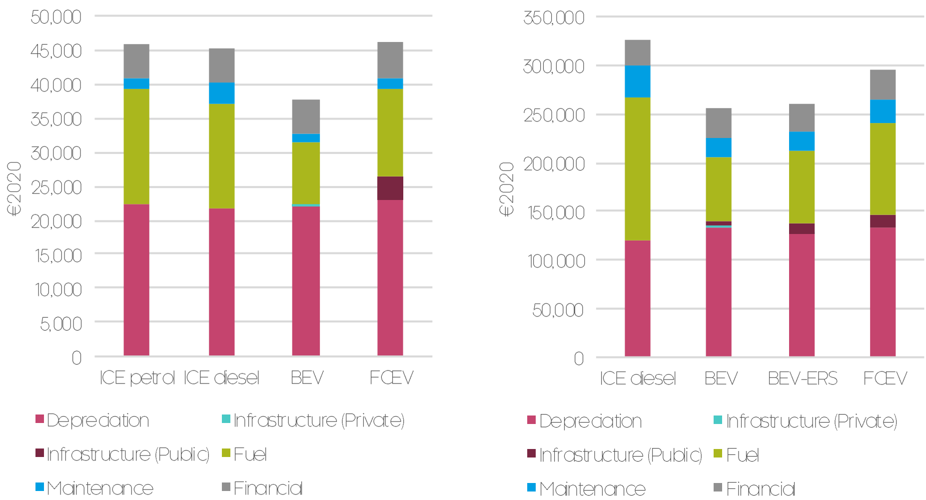
Figure 7.6: Total cost of ownership with different electricity tariffs for vans (left) and HHGVs (right) in 2030 (€, 2020)



Short holding period

To explore the effect of the considered holding period of vans and HHGVs we calculated the TCO over a 4-year holding period, which might reflect a large fleet operator who owns and runs newer vehicles for a limited number of years before re-selling them. With a short holding period, the relevance of the depreciation cost component increases compared to the fuel, maintenance, and infrastructure costs as can be seen in Figure 7.7. Although the purchasing price of vehicles with advanced powertrains is higher, even over a shorter holding period the total cost of ownership is higher for conventional ICEs, with the exception of an FCEV van in 2030.

Figure 7.7: Total cost of ownership over a short holding period for vans (left) and HHGVs (right) in 2030(€, 2020)



7.5 The role of policies

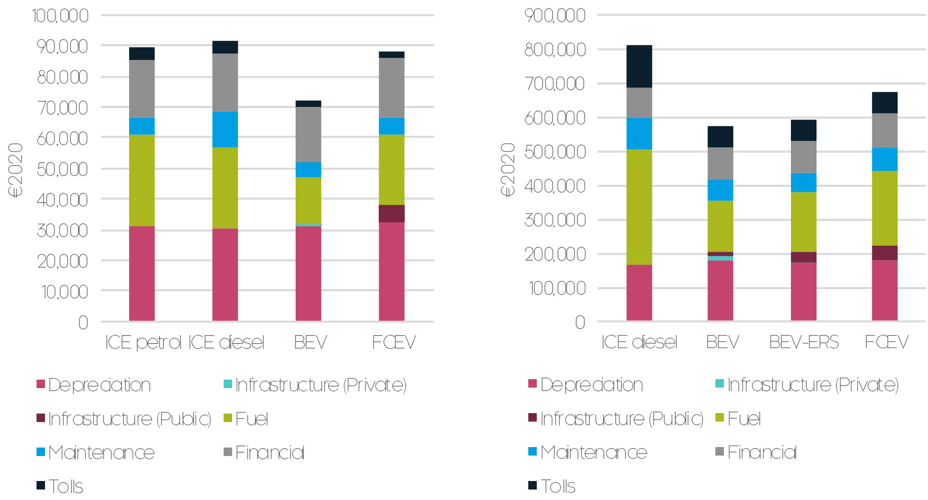
The EU has set ambitious targets to decarbonise all parts of its economy to move towards climate neutrality by 2050, and as part of this has started to set out policy proposals that may influence hauliers' costs.

Eurovignette directive

Incentivising cleaner trucking, the European Parliament guarantee a 50% discount on road charges for zero carbon trucks by 2023 as part of an overhaul of road tolls in Europe[9]. As road charges represent a substantial share of hauliers' costs zero carbon truck owners can benefit greatly from the discount. This discount could even increase to a maximum of 75%.

The driving profiles used in our analysis are taken from Krause et al. (2020)[10]. vans are mostly used for urban transport, with only 28% of distance travelled on highways. On the contrary, the share of distance covered on highways is 63% for HHGVs. Consequently, tolls largely increase cost of ownership for HHGVs and the 50% discount widens the TCO gap between BEVs and ICEs (Figure 7.8).

Figure 7.8: Total cost of ownership with tolls for vans (left) and HHGVs (right) in 2030 (€, 2020)



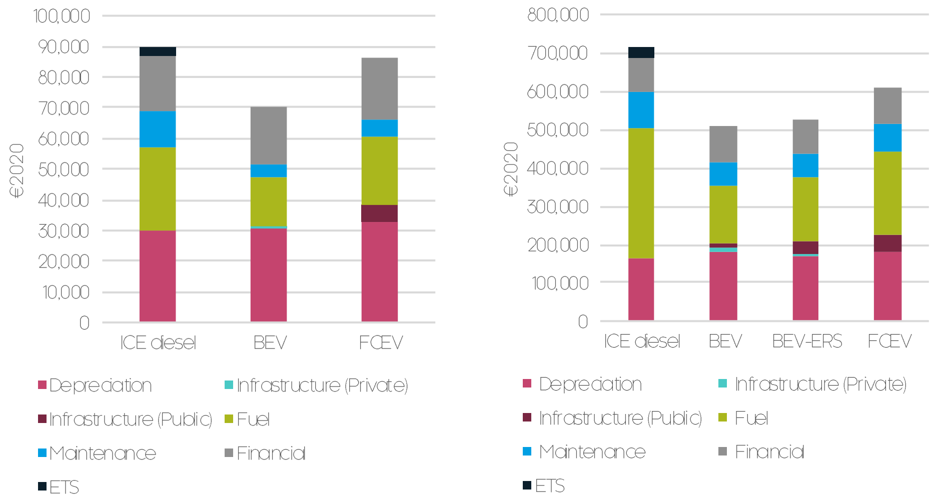
ETS extension to transport

The current energy and climate legislation package of the European Commission proposes the extension of the Emissions Trading Scheme (ETS) to the road transport sector. A carbon price applied on road freight would increase the cost of fuels such as gasoline and diesel and provide an incentive for road freight transport companies to reduce their fuel consumption. Assuming a separate ETS for transport in parallel to the existing EU ETS, we calculate an ETS cost assuming a carbon price of €50 broadly in line with the current central ETS allowance prices (Figure 7.9). This ETS cost is only relevant for ICEs as tailpipe emission of vehicles with advanced powertrains are zero. Given the increasing ambition of climate policies at the European and global levels, it is likely that the EU ETS price will continue to increase compared to the current levels, and the impacts on the TCO of ICE diesels could become even more significant. Nonetheless, even at the modelled, levels, they further increase the costs of ICE diesel vehicles compared to the zero carbon equivalents.

[9] Transport & Environment, Accessed here 27/07/2021

[10] Krause, J., Thiel, C., Tsokolis, D., Samaras, Z., Rota, C., Ward, A., ... & Verhoeve, W. (2020). EU road vehicle energy consumption and CO2 emissions by 2050–Expert-based scenarios. *Energy Policy*, 138, 111224.

Figure 7.9: Total cost of ownership with Transport ETS for vans (left) and HHGVs (right) in 2030 (€, 2020)



8 Conclusions

This study explored the potential options and technology pathways for delivering zero-carbon freight in Spain. From the analysis, a number of key messages emerge:

- A rapid transition to zero carbon powertrains can substantially reduce the CO_2 emissions associated to the road freight fleet. Both tank-to-wheel and well-to-wheel CO_2 emissions will substantially decrease in such a scenario.
- Phasing out the sale of ICE vans in 2035 and ICE HGVs in 2040 in the TECH scenarios does not lead to carbon neutrality by 2050, as a number of ICE vehicles sold before the phase out will still be part of the fleet. Additional policies might therefore be needed to achieve net zero emissions across the sector. It is however important to highlight that conventional ICE vehicles will become less and less competitive over their lifetime compared to EV trucks, with the likely result that hauliers will rely less and less on these vehicles.
- The deployment of zero carbon vans and HGVs requires the simultaneous deployment of adequate charging and refuelling infrastructure to support the growing fleet of zero carbon vehicles. The TECH ERS ad TECH FCEV scenarios require greater expenditure on such infrastructure than the scenario where BEVs dominate.
- The analysis of the TCO shows that zero carbon trucks are likely to become cheaper than ICEs over the 2020s (BEV and BEV-ERS), and by 2030 for FCEVs. The cost of technologies will reduce over time as scale economies are achieved and low electricity and hydrogen prices make vehicles with advanced powertrains more cost-efficient. Zero emission trucks can further benefit from additional policies which lower the cost of these technologies, or increase the costs of diesel vehicles.

Appendices

Appendix A This is the title of the first appendix