European Climate Foundation

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

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clarity from complexity

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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	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. BEV and BEV-ERS vehicles).
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 together.
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. It is clear that 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 Italy, 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 Italy.

The aim of this study was to assess the techno-economic potential of different pathways to decarbonise road freight, taking into account the specific characteristics of the Italian 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 advanced powertrains. The analytical team was composed of Cambridge Econometrics and the Politecnico di Milano. The analytical team worked in coordination with the European Climate Foundation (ECF), Transport & Environment (T&E), Motus-e and Kyoto Club to understand, in the specific Italian 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 tailpipe powertrains can substantially reduce the CO_2 emissions associated with the road freight fleet. As the power sector will also decarbonise, both tank-to-wheel and well-to-wheel CO_2 emissions will substantially decrease in such a scenario.

Furthermore, the deployment of zero-emission 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 zero carbon vehicles. Scenarios dominated by ERS-enabled or hydrogen fuel cell vehicles require greater total investment in infrastructure than 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 carbon trucks are likely to become cheaper than ICEs in the coming years; during this decade (the 2020s) for BEV and BEV-ERS, and by 2030 for FCEVs. 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 carbon 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 a zero carbon 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 be needed to achieve zero carbon across the sector. It is however important to highlight that conventional ICE vehicles will become more and more expensive 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 this study shows.

1 Introduction

1.1 Background

Low-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 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 may 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 across the economy) by that date. There are a wide range of potential measures which can reduce emissions, and ultimately a combination of many measures 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 report is to explore the potential options and technology pathways for delivering zero-carbon freight in Italy. This work is focused only on the improvement of the powertrain solutions used in the fleet, not taking into account the effects of the other two pillars among the European sustainable mobility strategy (Shift and Avoid). Thus, the work explores the techno-economic potential of different pathways to decarbonise road freight, taking into account the specific characteristics of the Italian 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 national level (e.g. the required electric charging and hydrogen refuelling infrastructure requirements).

The aim of the work is therefore to understand, in the specific Italian 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 emissions).

1.2 Methodology

For this report, a set of scenarios were defined in which it was assumed that a certain low-carbon vehicle technology mix would be taken up. The particular factors affecting hauliers' decisions to purchase zero carbon 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)s 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 lifetimes.

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 Italian 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:

- Chapter 2 sets out the scenarios that were developed to inform the analysis and are required to answer the questions raised by the Consultation Group.
- Chapter 3 presents the main modelling assumptions and technology cost data.
- Chapter 4 presents the results of the vehicle stock modelling exercise.
- Chapter 5 focuses on the new recharging and refuelling infrastructure that is required to support the deployment of zero carbon vehicles.
- Chapter 6 shows the environmental impacts of each scenario.
- Chapter 7 is devoted to an in-depth comparison of the costs of technologies through the TCO analysis.
- Chapter 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 Consultation Group[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 low carbon powertrains; they do not necessarily reflect current predictions of the future makeup of the Italian 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 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. • This is a 'no-policy' scenario, where it is assumed that all current decarbonisation policies are revoked.
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 Italy. On the other hand, these scenarios assess the impacts arising from the introduction of an additional policy at the European or Italian 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. BEV become the dominant powertrain in all scenarios).

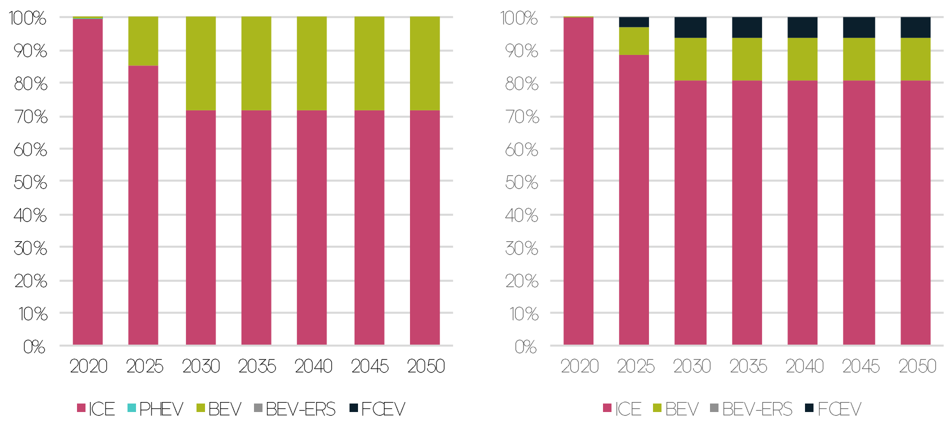
Reference scenario

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 most of the stock up to 2050, with only 0.4% of new vans and 0.1% of new HGV sales being electrified (BEVs) as shown in Figure 2.1.

CPI scenario

The CPI scenario reflects the achievement, by 2025 and 2030, of the currently agreed 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 28.5% of 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 13.0% and 6.1% 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.

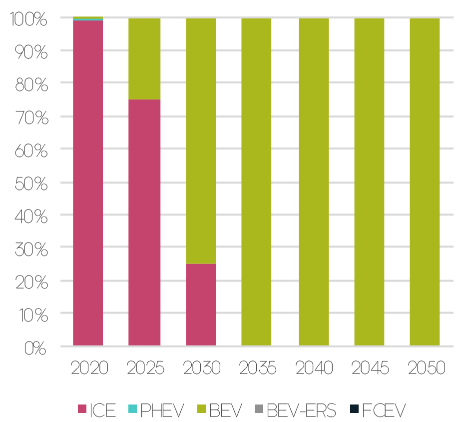
Figure 2.1: Sales mix of vans (left) and HGVs (right) in the CPI scenario (% of annual new vehicle sales)



Van powertrain deployment in the TECH scenarios

Van sales in the TECH scenarios are shown 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 primarily for short range urban transport where the limited range of BEVs is not a major factor.

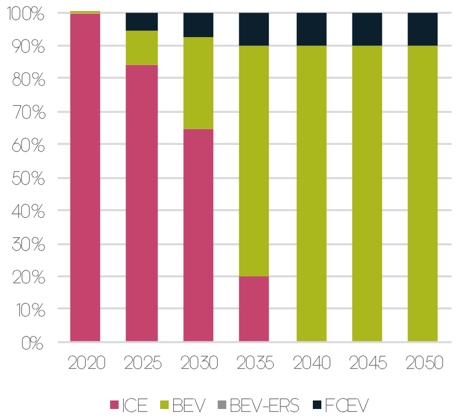
Figure 2.2: Sales mix of vans in the TECH scenarios (% of annual new vehicle sales)



HGV powertrain deployment in the TECH BEV scenario

In the TECH BEV scenario, 10% 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). In the same year there is a smaller percentage of FCEVs sold, 5.5%, to fleet operators who require the ability to travel longer distances. As shown in Figure 2.4, BEVs reach 90% of new sales by 2050 (up from 12% in 2030) due to continuous improvements in the technology and reductions in the cost of battery packs.

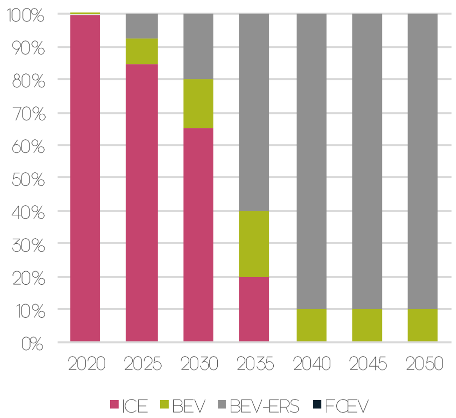
Figure 2.3: Sales mix of HGVs in the TECH BEV scenario (% of annual new vehicle sales)



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 advanced powertrains), because the ERS variants do not need large batteries.

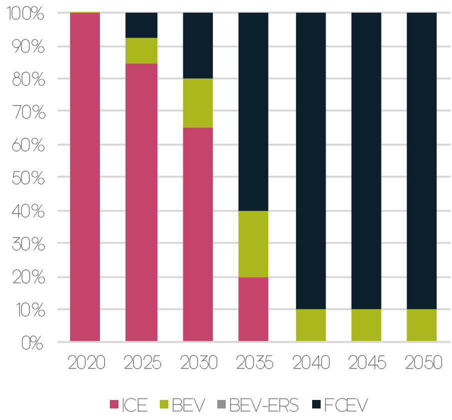
Figure 2.4: Sales mix of HGVs in the TECH ERS scenario (% of annual new vehicle sales)



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. Due to the relatively high starting capital costs, FCEVs deployment does not start in earnest until 2025, when they represent 7.5% of new sales. Under this scenario, the market share of BEVs does not expand beyond 20% in 2035, and instead FCEVs achieve rapid deployment from 2030 onwards thanks to cost reductions.

Figure 2.5: 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 Automobile Club d'Italia (ACI). • 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 sourced from the Annuario Statistico ACI, and ACEA Motor Vehicle Registrations (1990 – 2020). • The annual number of second-hand vehicles imported (and for the first time registered in Italy) is taken from the Import and Export of Vehicles statistics of Associazione Nazionale Filiera Industria Automobilistica (ANFIA). • Information on the average age of imported second-hand vehicles is taken from an article of h24 Notizie. • Total new registrations beyond 2021 are calculated to ensure the stock meets the 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).
Road freight activity	• Projections for road freight transport activity (expressed in Gtkm) for heavy goods and light commercial vehicles are taken from the PRIMES 2020 Reference Scenario.

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

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 (LHGVs, MHGVs, HHGVs) are derived from the analysis of the age distribution of the total Italian HGVs stock between 2005-2010. • For vans, the survival rate curve is created using data (current stock by year of registration of the vehicles) from the Parco Circolante dei Veicoli database provided by the Ministero delle Infrastrutture e dei Trasporti and Motorizzazione Civile (Italian stock of vehicles as of 31 December 2019).
Sales mix	• Sales mix of recent years of history by powertrain type (2019 and 2020) is taken from Annuario Statistico ACI, 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 Consultation Group.
Load	• Specific payloads (% of max payload) by vehicle type (vans, LHGVs, MHGVs) are taken from the Trucking into a Greener Future (2018) study of Cambridge Econometrics. For HHGVs, the assumed share of max payload is 50%. • 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 for Italy; Gross vehicle weight of MHGVs is based on the study of ICCT and weight profiles for LHGVs and HHGVs are based on archetypes derived from the 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 natural gas) 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	• For the central case of the TCO analysis, we use data on electricity prices paid by non-household consumers (Band IC : 500 MWh < Consumption < 2 000 MWh) from Eurostat to represent the expected demand of a small haulage company.

	• Through the projection period we assume electricity prices to grow in line with the electricity price projections for Italy from the PRIMES 2020 Reference Scenario.
Hydrogen price	• Hydrogen price projections are taken from the Hydrogen Council (2020) forecasts up to the year 2030, and thereafter we assume that the price remains constant, due to extensive uncertainty over the evolution of the hydrogen prices in this timeframe.
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	-
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 in 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-emissions vehicles become cheaper as they start being manufactured at scale.

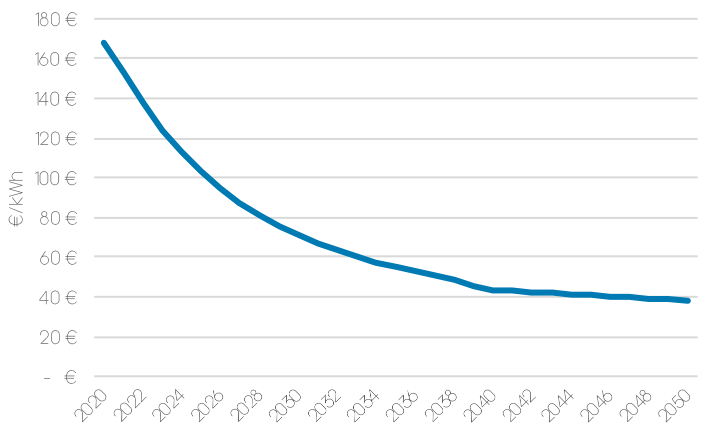
Baseline vehicle

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 Fiat Ducato), 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 forecasted 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 (€, 2020)



Fuel cell and hydrogen storage costs

Fuel cell and hydrogen storage costs are taken from a recent study from 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 (€2020)

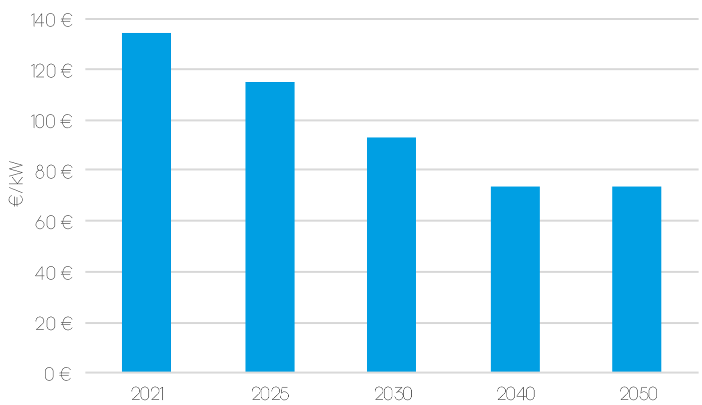


Table 3.14: Compressed gaseous H2 gas costs (€/kg, 2020)

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

Additional system requirement 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.

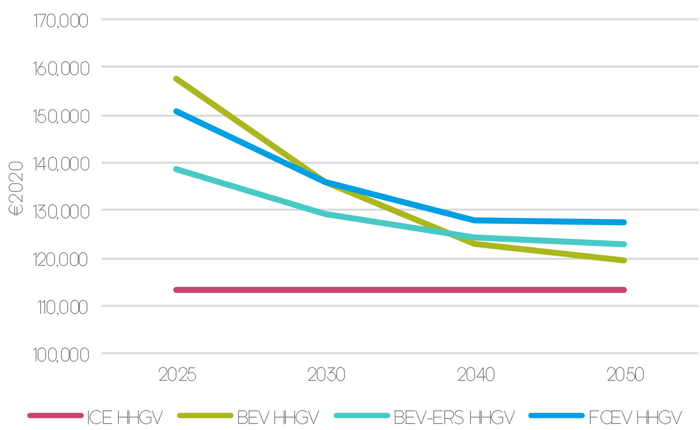
Powertrain costs

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 powertrains 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)

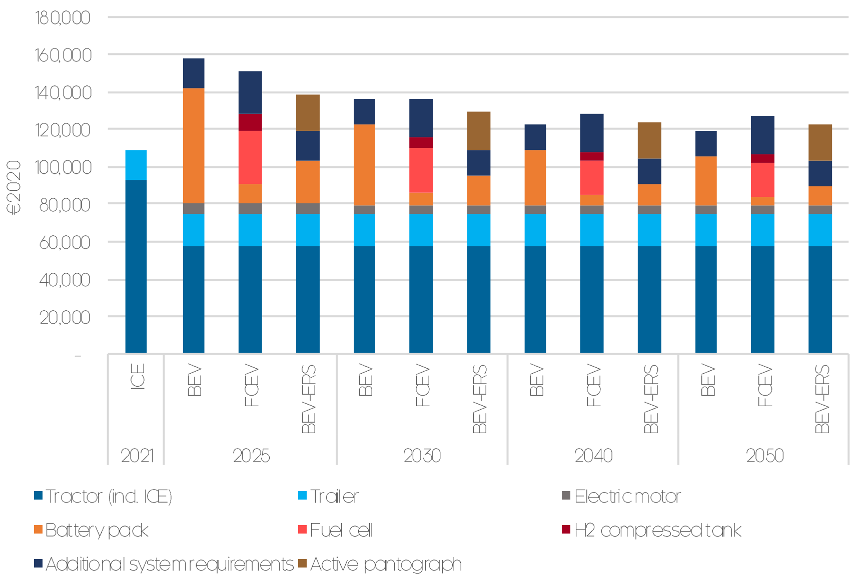


To further analyse the resulting vehicle costs we present the evolution of HHGVs costs in Figure 3.3. As can be seen, BEV costs are expected to decrease the most, falling below the FCEV costs by 2030 and the BEV-ERS costs by 2040.

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. Costs rapidly decrease between 2025 and 2030 due to economies of scale while after 2030 cost reductions are mostly a result of cheaper batteries.

Figure 3.4: Breakdown of HHGVs total vehicle costs (€2020)



3.4 Fuel costs

Diesel and Petrol

The future oil price is a key uncertainty in the low-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 (including all taxes and levies) for non-households from Eurostat[3] is used in the model to estimate the fuelling cost of BEVs and ERS enabled BEVs. These prices reflect include 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 components. The prices vary by consumption type; for this modelling the consumption Band IC: 500 MWh < Consumption < 2 000 MWh is used as the central case.

[3] Data series: *nrg_pc_205*

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

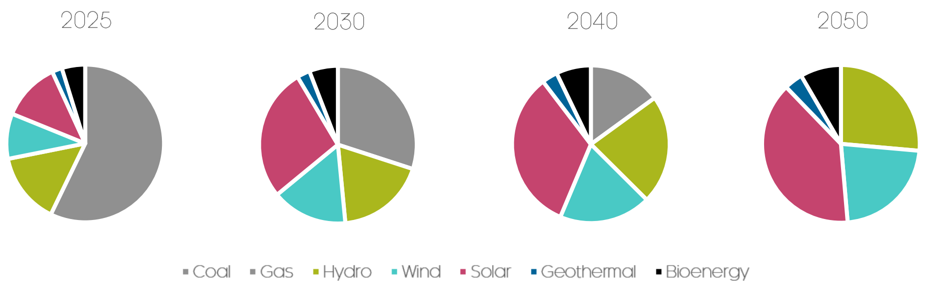
	2015	2016	2017	2018	2019	2020
Total (€/MWh, real 2020)	199	189	177	171	191	175

Projections for electricity prices are based on the growth rate of electricity prices for final demand sectors from the PRIMES reference scenario (2020)[4].

Electricity generation mix

The generation mix of electricity is in line with the current discussions on the coming update of the Piano Nazionale Integrato per l'Energia e il Clima (PNIEC, 2019). This scenario reflects the planned evolution of the power generation sector up to the year 2040 as according to the National Energy and Climate Plan of Italy. The current discussions, in particular, focus on a target of 70% of the electricity to be generated from renewable sources by the year 2030. After that, we assume increasing shares of renewables to reach a zero carbon generation mix by 2050 (Figure 3.5).

Figure 3.5 Assumed evolution of the electricity generation mix in Italy



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. However, emissions can be reduced by around 90% through carbon capture and storage (CCS) technologies. Hydrogen generated by steam methane reforming with CCS is labelled as blue hydrogen. 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.

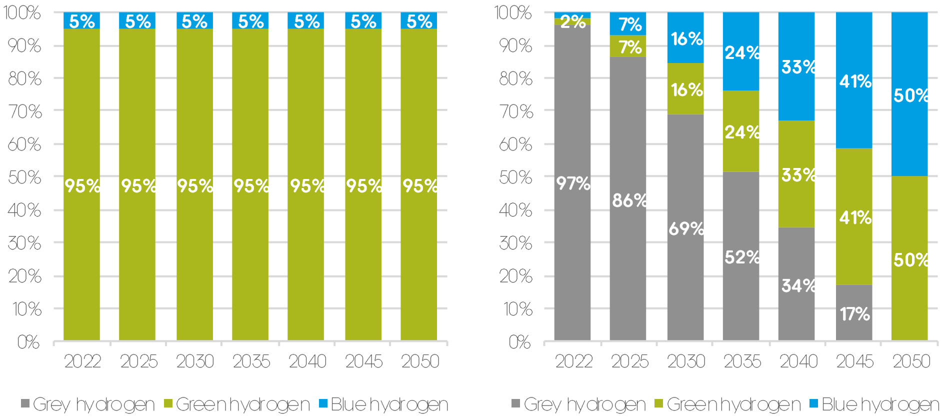
Hydrogen production mix

The hydrogen production mix in any given hydrogen market will be influenced by the relative costs of each production source, customer demand (in terms of the carbon footprint of hydrogen) and policies such as incentives for green hydrogen. As great uncertainty remains around how the hydrogen production mix will look like for Italy in the future, in our analysis we consider two hydrogen mix scenarios: a green and a blue scenario. In the green production mix scenario, we assume that most of the hydrogen used as a road transport fuel is produced through electrolysis using renewable electricity produced locally at hydrogen fuelling stations. In the blue production mix scenario, the

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

hydrogen produced by SMR with a carbon capture and storage (CSS) system has equal role as green hydrogen by the year 2050. The production mixes used to calculate the CO_2 footprint of hydrogen, are shown in Figure 3.6.

Figure 3.6: Green (left) and blue (right) 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)[5] 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).

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
	MHGVs	4,800
	HHGVs	8,000
BEV-ERS	vans	N/A
	LHGVs	3,060
	MHGVs	3,060
	HHGVs	5,100
BEV	vans	317

[5] 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.

	LHGVs	3,060
	MHGVs	3,060
	HHGVs	5,100
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.

If the new vehicle were fully purchased up front by haulage companies, such a cost would be not part of their TCO calculations.

4 Vehicle stock modelling

The evolution of Italian 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 13% of the HGV stock in 2040 is advanced powertrains, with BEVs contributing 9%. By 2050, BEVs make up 11% of the total HGV stock and FCEVs represent 5% (see Figure 4.1).

The take up of BEVs is faster in the stock of vans. By 2040 the BEV share in the total stock is already above 20% and it reaches almost 27% by 2050 (Figure 4.2).

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

Figure 4.2 Stock composition for vans in the CPI scenario

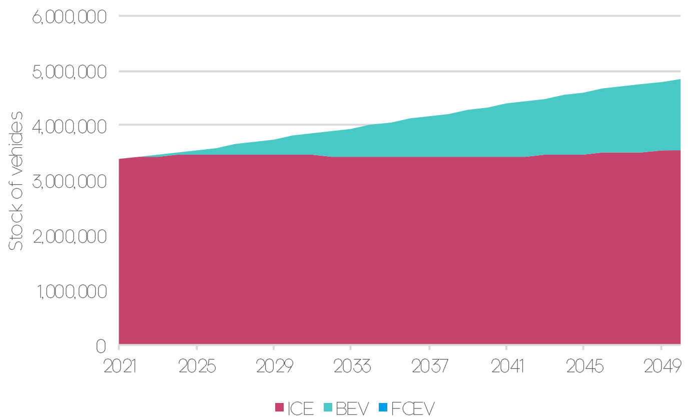
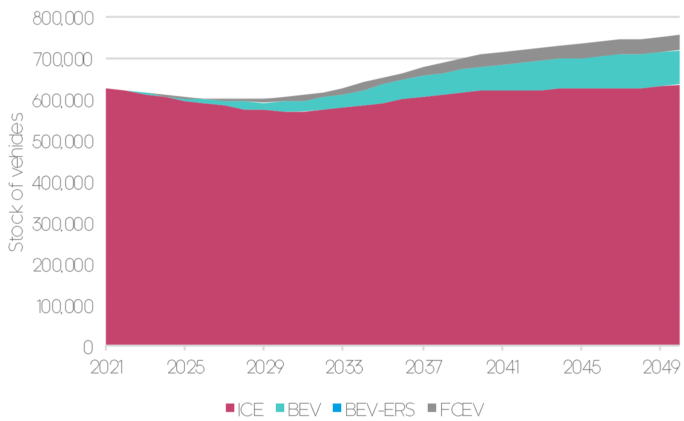


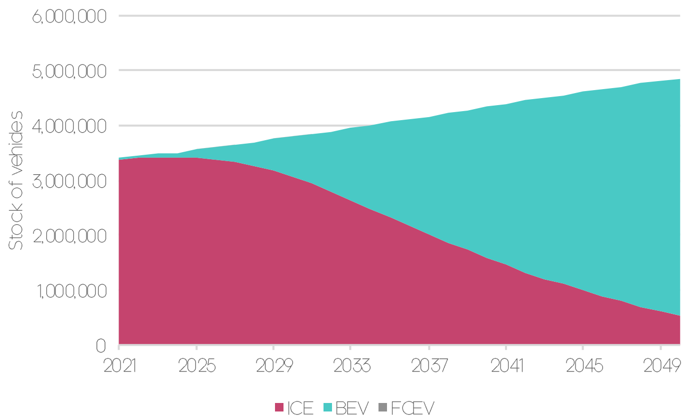
Figure 4.1 Stock composition for HHGVs in the CPI scenario



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 89% by 2050 (up from 63% in 2040), enabled by improved battery technology and the deployment of adequate depot recharging infrastructure (Figure 4.3). Nevertheless, in 2050 a zero carbon fleet is still not achieved; although sales of ICE vans were phased out in 2035, in 2050 still around 11% of the fleet consists of ICEs that are more than 15 years old and were sold prior to the ban.

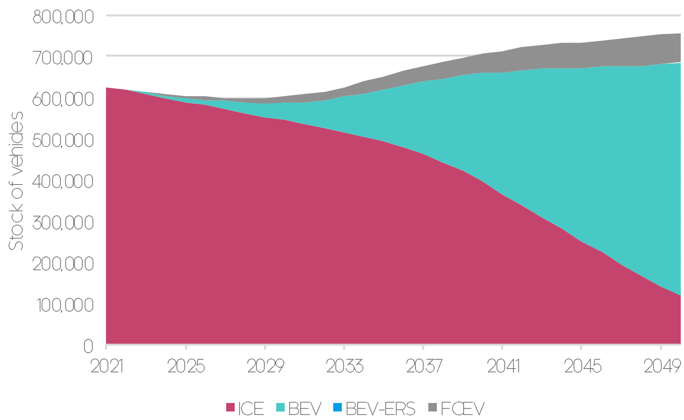
Figure 4.3: Stock composition for vans in the TECH scenarios



HGV powertrain deployment in the TECH BEV scenario

In the TECH BEV scenario, BEVs reach 90% of new sales by 2050 (up from 28% in 2030), which translates into 75% of the stock in 2050 (up from 7% of the stock in 2030). FCEVs that are used for longer distances represent 10% of the total HGV stock in 2050 (Figure 4.4).

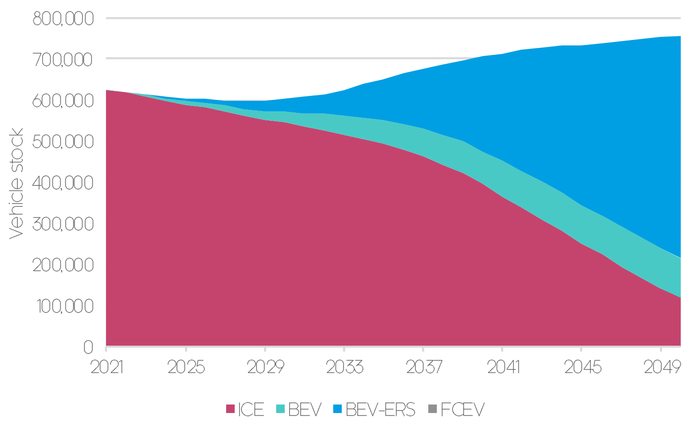
Figure 4.4: Stock composition for HGVs in the TECH BEV scenario



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 33% 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 almost 72% of the stock, and ICEs have shrunk below 16%.

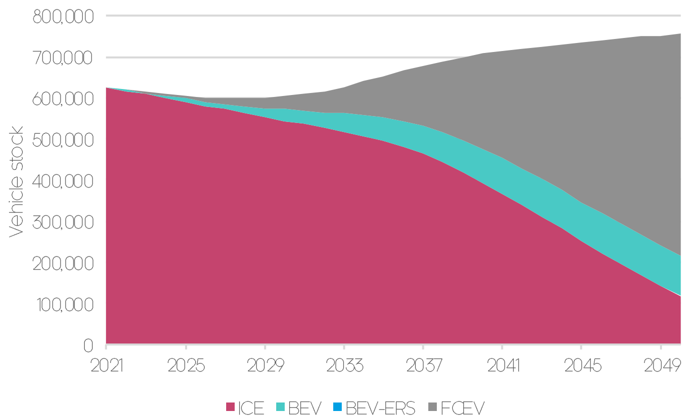
Figure 4.5: Stock composition for HGVs in the TECH ERS scenario



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 33% of the stock in 2040 and almost 72% in 2050.

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

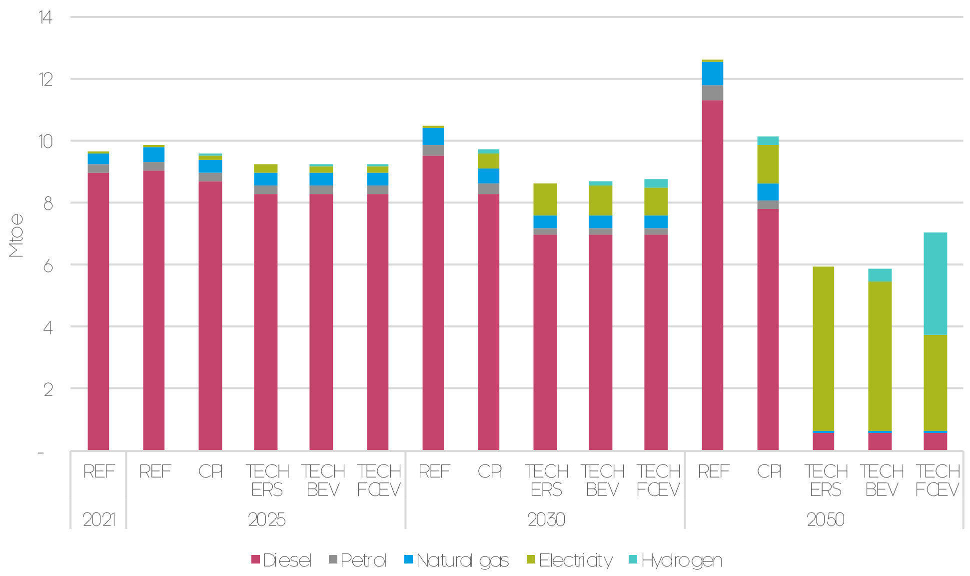


As in the case of vans, the stock of HGVs in the TECH scenarios is not fully decarbonised by the year 2050, and the zero-carbon target for the sector is not achieved.

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 energy demand falls by more than 52% in the TECH BEV and TECH ERS scenarios, and by 44% 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 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: Annual stock fuel consumption of fossil fuels, hydrogen and electricity



5 Infrastructure requirements

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

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

It also provides a breakdown of the calculations of total infrastructure requirements in the scenarios.

The primary infrastructure to serve BEVs will be ultra-fast chargers on highways, with a power output of 700 kW used in the modelling. Alongside these there will also be BEV depot chargers (90kW) for slower charging overnight.

In the TECH ERS scenario, the main source of electricity for ERS-enabled vehicles will be via an electric road system (ERS). The electric road system will be deployed on the main highways of Italy, in a way that is, according to our analysis sufficient to allow the penetration into the fleet of a large proportion of ERS-enabled vehicles[6]. 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 achieve the modelled take-up, sufficient front loading is needed to allow hauliers to invest in FCEV HGVs. 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). The cost estimates include energy feed-in points, supply lines from the energy feed point to the substation on the line, substations, poles, overhead catenary (contact lines), passive protection systems, crossings of gantries and flyover bridges structures, project planning, tendering and project management. Installation costs decrease over 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.

[6] To address the uncertainty around the density of ERS network required, in the TCO analysis later in this report we consider a sensitivity where the 'off network' range of ERS vehicles is extended through the use of larger batteries.

Table 5.1: Cost assumptions for ERS infrastructure

	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 Italy and most important motorways in the country. Based on the traffic flow maps for heavy duty vehicles, provided by the 2021 edition of the Almanacco della Logistica (CONFETRA, 2021), we identified the portion of the Italian highways network with the highest levels of traffic for HGVs, that is the highways that mostly 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.

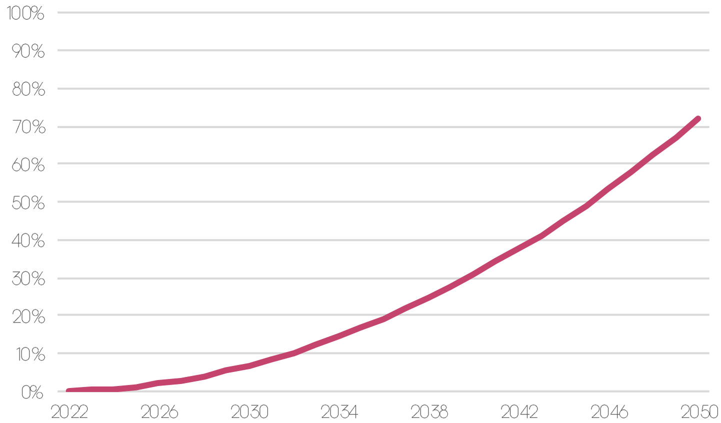
Based on this, we selected the highways reported in Table 5.2 and projected the deployment of the ERS catenary infrastructure as showed in Figure 5.1.

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

Reference	Name	Length (km)
A1	Milano – Napoli	760
A14	Bologna – Taranto	743
A4	Torino – Trieste	517
A22	Brennero – Modena	315
A21	Torino – Brescia	238
A26	Genova – Gravellona	197
A10	Genova – Ventimiglia	158
A5	Torino – Aosta	143
A7	Milano – Genova	136
A23	Palmanova – Tarvisio	120
A13	Bologna – Padova	117
A15	Parma – La Spezia	110
A27	Belluno – Venezia	83
A11	Firenze – Pisa	82
A32	Torino – Bardonecchia	73
A35	Brescia Bergamo Milano	62
A8	Varese – Milano	44
A9	Como – Lainate	42
A20	Palermo – Messina	183
A18	Messina – Rosolini	117

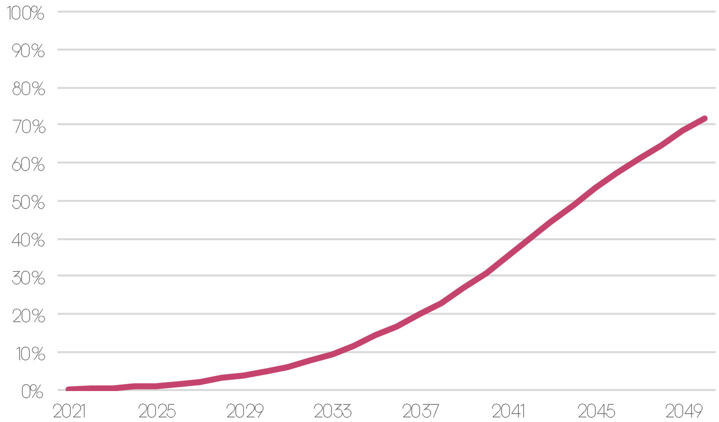
A2	Salerno – Reggio Calabria	442
A19	Palermo – Catania	199
SS 3 bis	Orte – Cesena	251
SS131	Superstrada Carlo Felice	231

Figure 5.1: Projected share of Italian highways network (plus SS3bis and SS131) 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, around 72% of the considered network (all highways plus SS3bis and SS131) is covered by ERS in 2050 (up from 7% in 2030 and 31% 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 72% in 2050.

5.2 Ultra-fast charging

A few firms have recently announced battery electric HGVs which will rely upon ultra-fast 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 ultra-fast charging are based on the cost analysis for chargers from Trucking into a Greener Future (2018) and from the feedback received from the Polytechnic University of Milan.

Depot chargers have been included at different sizes to support different size batteries of the vehicles 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: Ultra-fast charging infrastructure assumptions

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	4,273	1,603
Depot – BEV HHGVs	Overnight charging Brownfield	90kW	34,186	10,683
Ultra-fast 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 ultra-fast charging sites will be greenfield, reflecting the additional space requirements of new ultra-fast charging stations and the limits to existing HGV stopping and refuelling space.

Table 5.4: Additional costs for preparing sites for ultra-fast 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 ultra-fast charging infrastructure to meet the demand of HGVs we have derived the infrastructure density assumption summarised in Table 5.5.

Table 5.5: Infrastructure density (EVs per charging point)

	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
Ultra-fast charging - High	47.1	47.1	47.1	47.1

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, and the current technology level and manufacturing volumes imply that the costs of a hydrogen refuelling tank are relatively high.

We have nominated 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[8]. 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

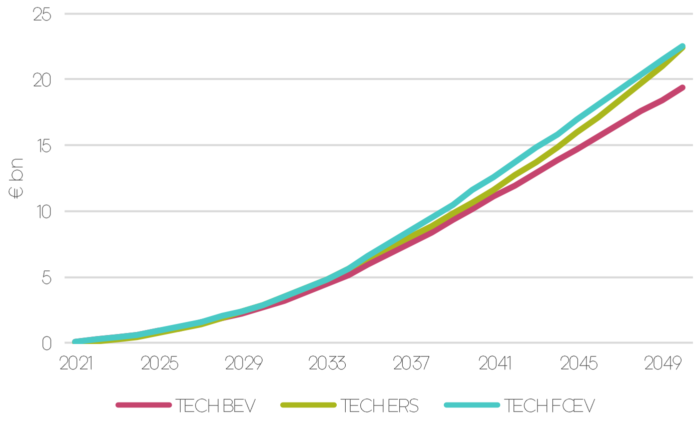
Figure 5.3 below shows the cumulative infrastructure investment requirements by scenario from 2021 to 2050. In the TECH scenarios the rapid deployment of the required infrastructure is essential to enable the penetration of EVs to the fleet. The deployment of hydrogen refuelling stations is more capital intensive than the installation of charges or ERS catenaries. The cumulative

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

[8] ibid

infrastructure investment in the TECH FCEV scenario reaches almost €23 billion by 2050 while in TECH ERS it is €22.5 billion and in TECH BEV, being the cheapest TECH scenario, it is €19 billion.

Figure 5.3: Total cumulative investment in infrastructure by scenario



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 6.2 for vans and in Figure 6.1 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 for new vehicles (in terms of gCO_2/km compared to the baseline in 2021). 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 even by 2050, as ICE vehicles sold in earlier years (before the phase-out) are still on the road.

Figure 6.2: Average new vehicle (left) and average stock (right) tailpipe CO_2 emissions of vans

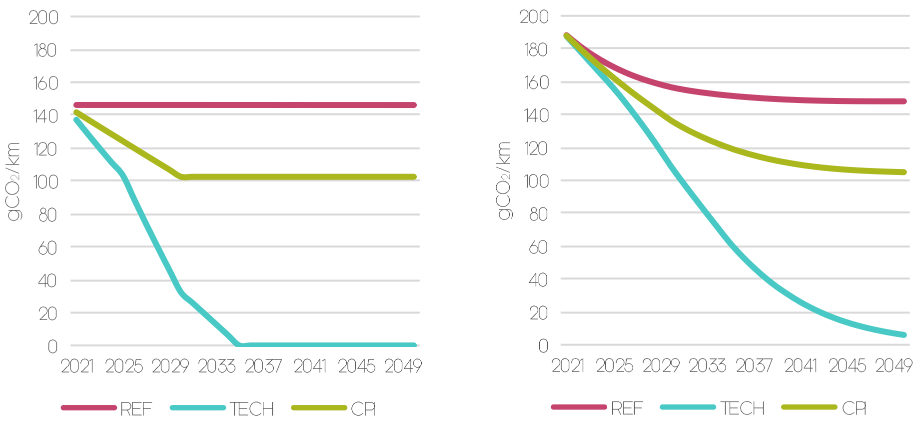
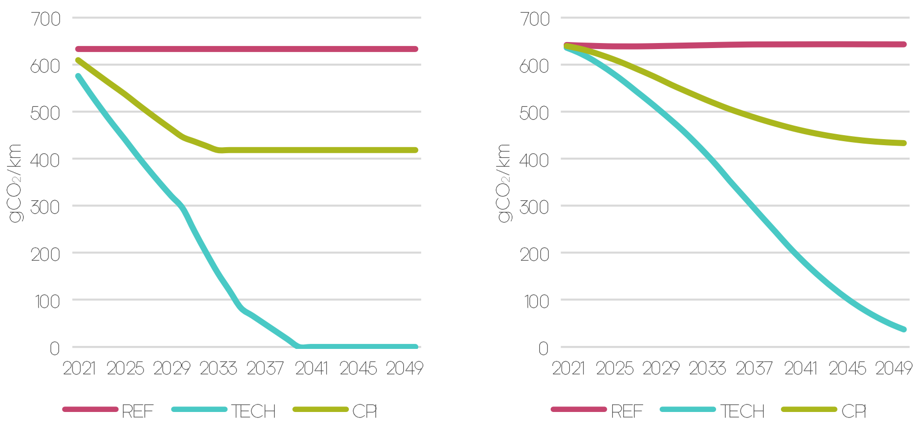
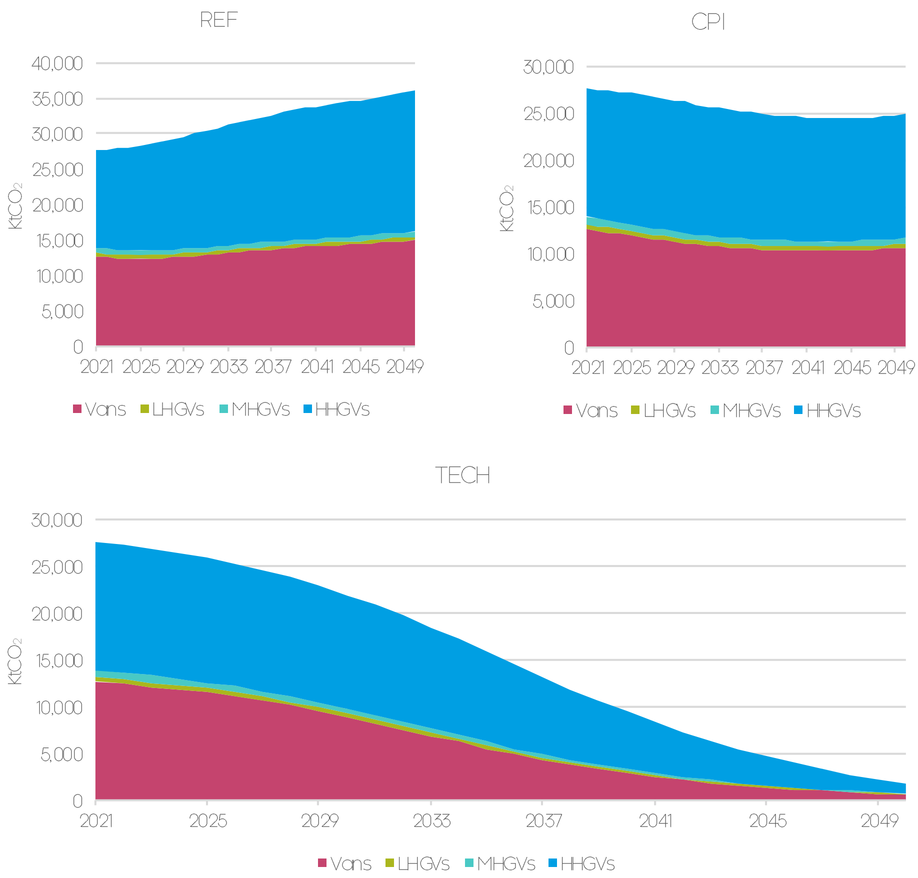


Figure 6.1: Average new vehicle (left) and average stock (right) tailpipe CO_2 emissions of HHGVs



Despite this, the penetration of low-carbon 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 95% 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: Annual tailpipe CO_2 emissions of the stock



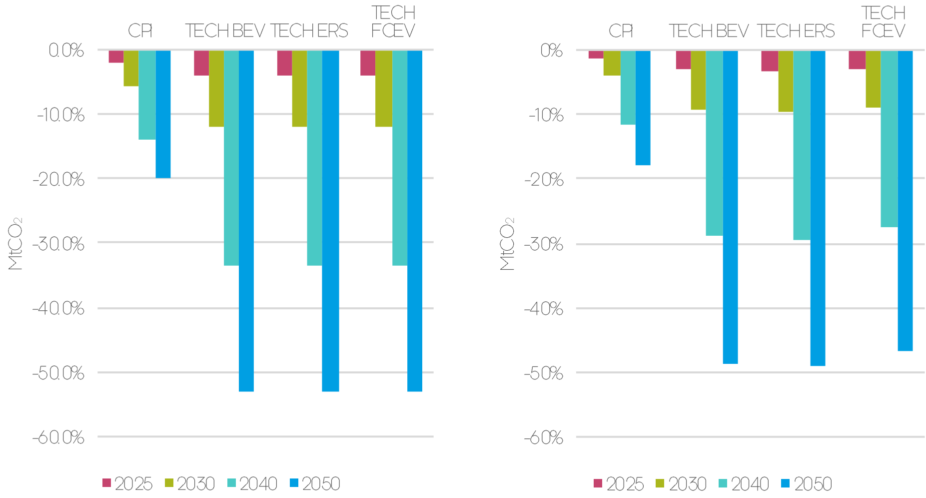
Well-to-wheel emissions

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 the electricity and hydrogen used as fuel by BEV, BEV-ERS, and FCEV vans and HGVs. Two production mix scenarios are considered. In the first scenario, named 'Green', electricity is only sourced from renewables via Green Power Purchase Agreements (Green PPA) stipulated by haulage companies with utilities, and hydrogen is largely produced via green electrolysis. In the second scenario, named 'Moderate', electricity is taken from the grid, that will be increasingly decarbonised, and hydrogen is increasingly produced via green electrolysis and SMR with CCS technology.

All TECH scenarios achieve a cumulative well-to-wheel emissions reduction greater than 45% via a combination of increased fuel efficiency and switching energy source from diesel to low-carbon electricity. Cumulative well-to-wheel emission reductions are more moderate than the annual CO_2 reductions as they are essentially an 'average' of the reductions achieved over the period – they reflect the fact that in early years, the percentage reduction in fleet emissions is much more moderate than in later years, by which point zero-carbon technologies represent a much larger proportion of the vehicle fleet.

Reductions are greatest in the case of the Green electricity and hydrogen production mixes, where a 50% reduction is achieved compared to the baseline. TECH BEV and ERS scenarios outperforms the TECH FCEV scenarios due to the indirect emissions associated with grey and blue hydrogen, which is used in particular in the early years of FCEV deployment.

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

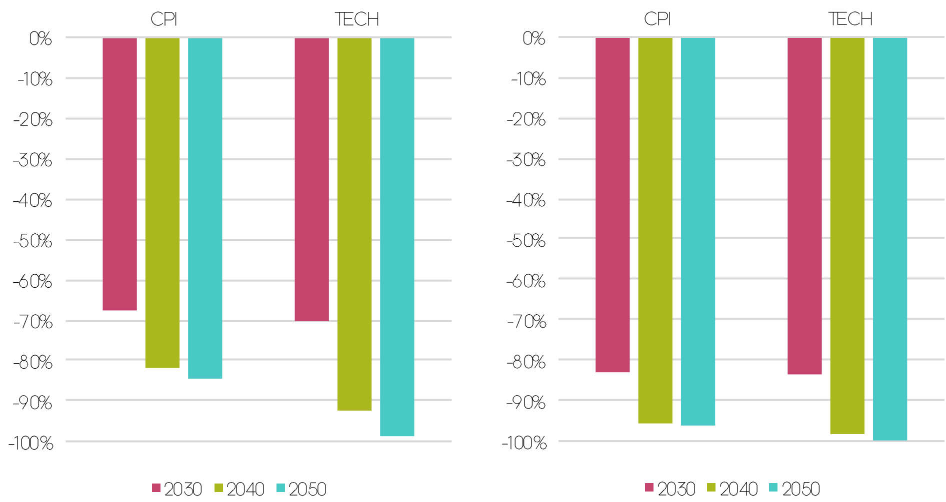


Impacts on emissions of particulate matter and nitrogen oxides

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 96% in 2050 and NO_x emissions from vehicle exhausts are cut 84% 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 future 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 PM_{10} and NO_x 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. While it would be expected that the increased deployment of regenerative brakes across all powertrains would further reduce PM emissions from this source, a quantification of this impact was not carried out.

7 Analysis of the Total Cost of Ownership

In the earlier analysis, we took as given the deployment scenarios, where hauliers took up available low carbon technologies to reduce the environmental impact of road freight. However, the realised take-up of the low-carbon 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 ultra-fast 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. These costs essentially cover the capital costs of infrastructure; publicly provided infrastructure (such as ERS and rapid chargers) would in actual fact be paid for through higher electricity tariffs from these particular sources which embed these capital costs – but for the sake of clarity in this analysis these costs are completely separated from the electricity prices.
- **Financial costs**: the cost of financing the purchase cost of the vehicle[9].

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

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

[9] 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	-	-

Since MHGVs and LHGVs are a very small share of the total vehicle stock of HGVs, we focus exclusively on HHGVs in the TCO analysis. To define 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 Consultation Group. 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
H_2 stored (Kg)	-	-	-	24
Diesel engine (kW)	350	-	-	-

7.2 TCO results

Vans Figure 7.1 shows the estimated total cost of ownership for vans over a 14-year ownership period[10]. In the case of vans, we consider ICE-Diesels, BEVs and FCEVs.

Figure 7.1: Total cost of ownership for vans over 14 years

Based on the calculations, BEV vans will become the cheapest powertrain to own by 2025. The main factors explaining the cost differential are the reduced

[10] Holding period represents the average age of vans reported in ACEA (2021) Vehicles in use in Europe.

fuel costs, due to the greater efficiency of these vehicles compared to ICEs and FCEVs, and the lower maintenance costs, which more than compensate the higher depreciation and financial costs. FCEV vans become price-competitive with ICE diesel in 2030, as hydrogen prices fall due to the economies of scale associated with mass production.

HHGVs In the case of HHGVs, we also consider ERS enabled BEVs in addition to the other technologies over a 12-year ownership period (Figure 7.2)[11].

Figure 7.2: Total cost of ownership for HHGVs over 12 years

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. 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. Nevertheless, FCEVs remain more expensive than BEVs. This largely reflects the fact that hydrogen fuel costs are substantially higher than obtaining the equivalent energy content directly from electricity.

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.

[11] Holding period represents the average age of HHGVs reported in ACEA (2021) Vehicles in use in Europe.

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 single 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

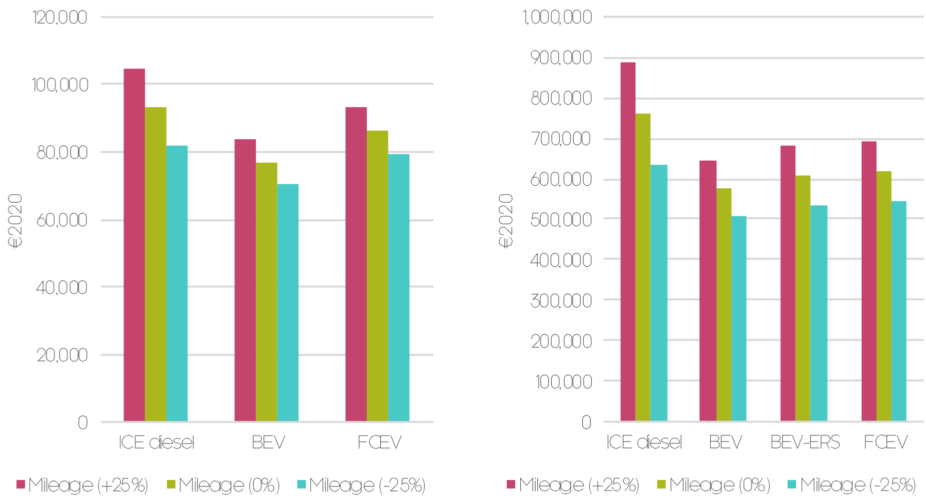
In general, we can see that fuel price changes do not affect the basic trends in the TCO analysis. There is no scenario in which ICEs become the lowest cost vehicles in 2030; BEVs remain cheaper regardless of the fuel prices used.

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 average mileages which are +/- 25% of our central values.

Based on Figure 7.4 we can see that the more the trucks are used, the more cost-effective advanced 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.

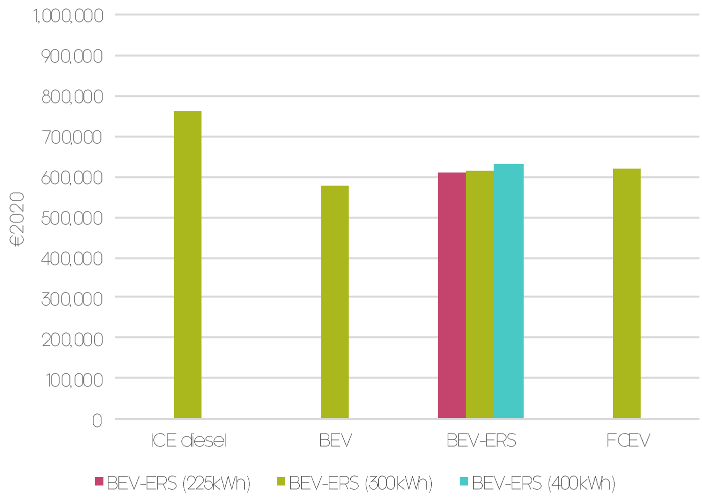
Figure 7.4: Total cost of ownership cost of use sensitivities for vans (left) and HHGVs (right) in 2030



BEV-ERS battery sensitivities

The battery size of ERS-enabled BEVs heavily depend on the use of the vehicle. If the geographical coverage of ERS is less dense, or does not meet the needs of a specific subset of users, then ERS-enabled BEVs require larger batteries to be capable of travelling further off-network. Therefore, we consider three battery options for ERS enabled BEVs: 225kWh, 300kWh and 400kWh. Battery costs are reflected in the cost of vehicles; thus, it is included in the depreciation and financing cost components 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 compared with BEVs if larger batteries are required (see Figure 7.5).

Figure 7.5: Total cost of ownership BEV-ERS battery sensitivities for HHGVs in 2030



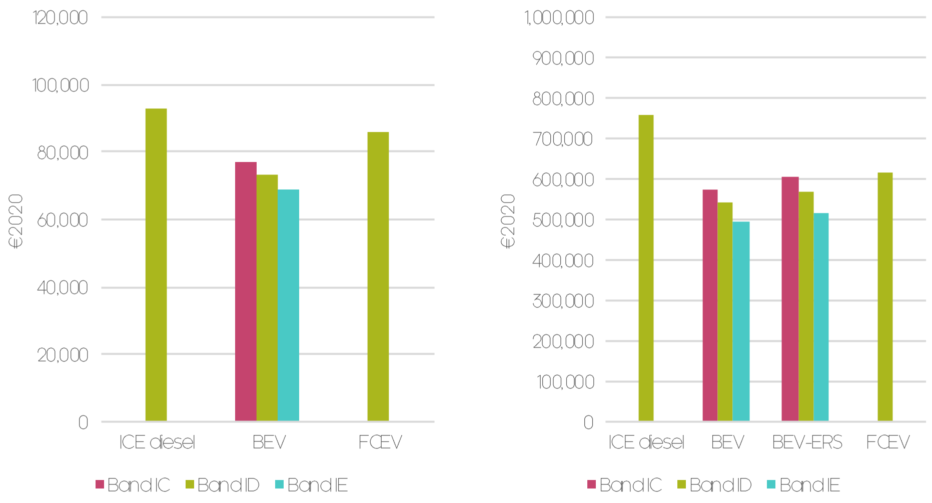
7.4 Alternative use-cases

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.

Note, as outlined earlier, that the electricity tariffs used deliberately exclude embedded capital costs of recharging/ERS infrastructure, which is included in a separate category in the TCO analysis.

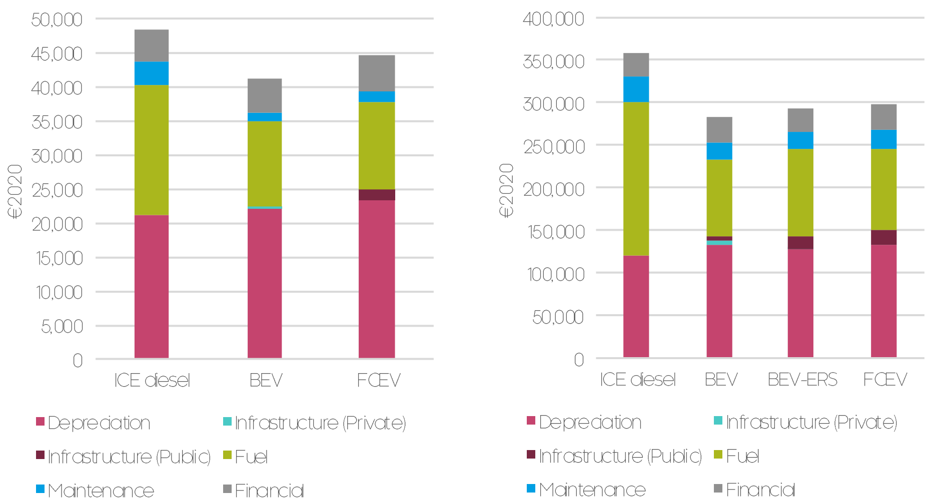
Figure 7.6: Total cost of ownership with different electricity tariffs for vans (left) and HHGVs (right) in 2030



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 and financing cost components increases compared to the fuel, maintenance, and infrastructure costs as can be seen in Figure 7.7. Although the purchase price of vehicles with advanced powertrains is higher, even over a shorter holding period the total cost of ownership is higher for conventional ICEs.

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



7.5 The role of policies

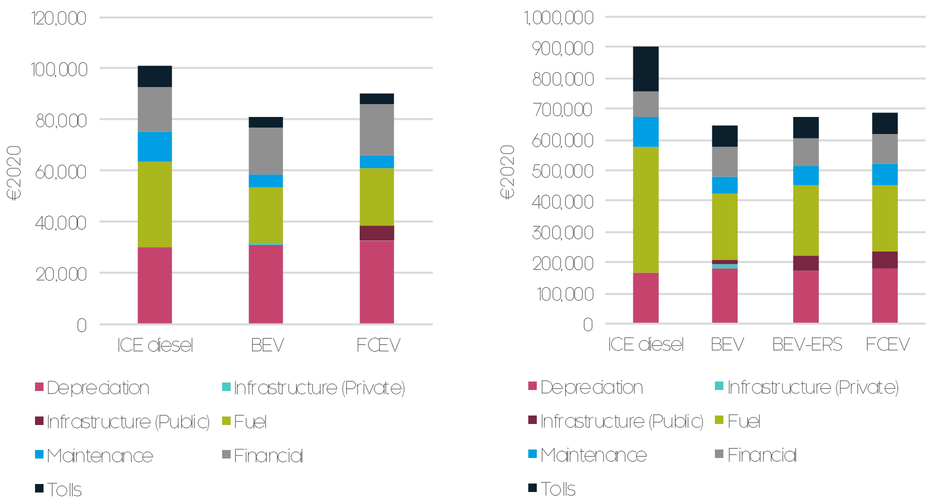
The EU has set ambitious targets to decarbonise all parts of its economy to move towards climate neutrality by 2050, and as part of this has started to set out policy proposals that may influence hauliers' costs.

Eurovignette directive

Incentivising cleaner trucking, the European Parliament have guaranteed a 50% discount on road charges for zero-emission trucks by 2023 as part of an overhaul of road tolls in Europe[12]. As road charges represent a substantial share of hauliers' costs, zero-emission 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)[13]. Vans are mostly used for urban transport, with only 28% of distance travelled on highways. By contrast, the share of distance covered on highways is 63% for HHGVs. Consequently, tolls can substantially increase the 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



ETS extension to transport

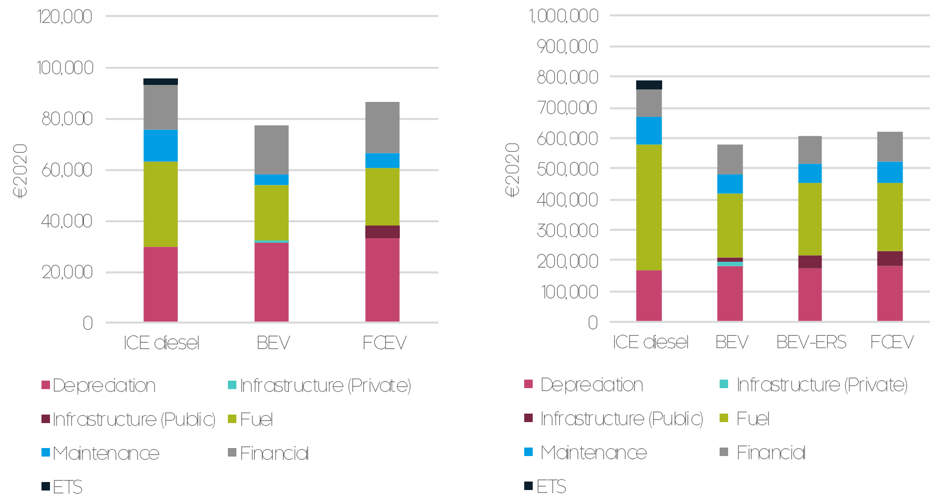
The current energy and climate legislation package of the European Commission proposes the extension of the Emissions Trading Scheme (ETS) to the road transport sector. A carbon price applied on road freight would increase the cost of fuels such as gasoline and diesel and provide an incentive for road 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,

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

[13] 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.

levels, they further increase the costs of ICE diesel vehicles compared to the low-carbon equivalents.

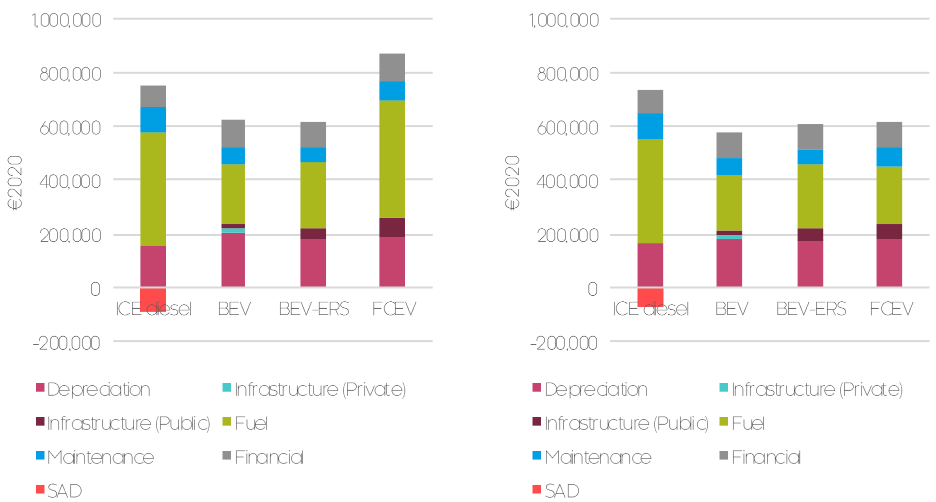
Figure 7.9: Total cost of ownership with Transport ETS for vans (left) and HHGVs (right) in 2030



Phase-out of Environmentally Harmful Subsidies

Besides interventions at the European level, the phase-out of Environmentally Harmful Subsidies at the national level would also impact the TCO of road freight vehicles and support the electrification of the sector. Currently the Government grants a reduction in the excise duty paid by haulage companies on the diesel used to fuel ICE vehicles for transporting goods, which corresponds to a 17.2% reduction in the final diesel price. This subsidy is represented in Figure 7.10 as 'SAD' (Sussidio Ambientalmente Dannoso) and provides a substantial reduction in the overall TCO of diesel ICEs. While we expect EVs to become more competitive than ICE in the 2020s, even when considering this subsidy, the analysis shows that its progressive phase-out would provide an important boost to the competitiveness of EV HGVs and would accelerate the decarbonisation of the road freight sector. If reductions in highway fees (not quantified) that are currently in place were also not phased out, then the TCO of the diesel vehicles would fall still closer towards that of zero carbon powertrains.

Figure 7.10: Total cost of ownership with reduction on diesel VAT for HHGVs in 2025 (left) and in 2030 (right)



8 Conclusions

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

- A rapid transition to zero tailpipe powertrains can substantially reduce the CO_2 emissions associated with 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 a zero carbon fleet 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 zero carbon emissions across the sector. It is however important to highlight that conventional ICE vehicles will become more and more expensive over their lifetime compared to electric equivalents, with the likely result that hauliers will rely less and less on these vehicles.
- The deployment of zero-emission 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 and TECH FCEV scenarios require greater expenditure on such infrastructure than the TECH BEV scenario.
- The analysis of the total cost of ownership of different options 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 economies of scale are achieved and low electricity and hydrogen prices make vehicles with advanced powertrains more cost-efficient. Zero carbon trucks can further benefit from additional policies which lower the cost of these technologies, or increase the costs of diesel vehicles.