

# **The transition to a Zero Emission Vehicles fleet for cars in the EU by 2050**

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## **Pathways and impacts:**

An evaluation of forecasts and backcasting the COP21 commitments

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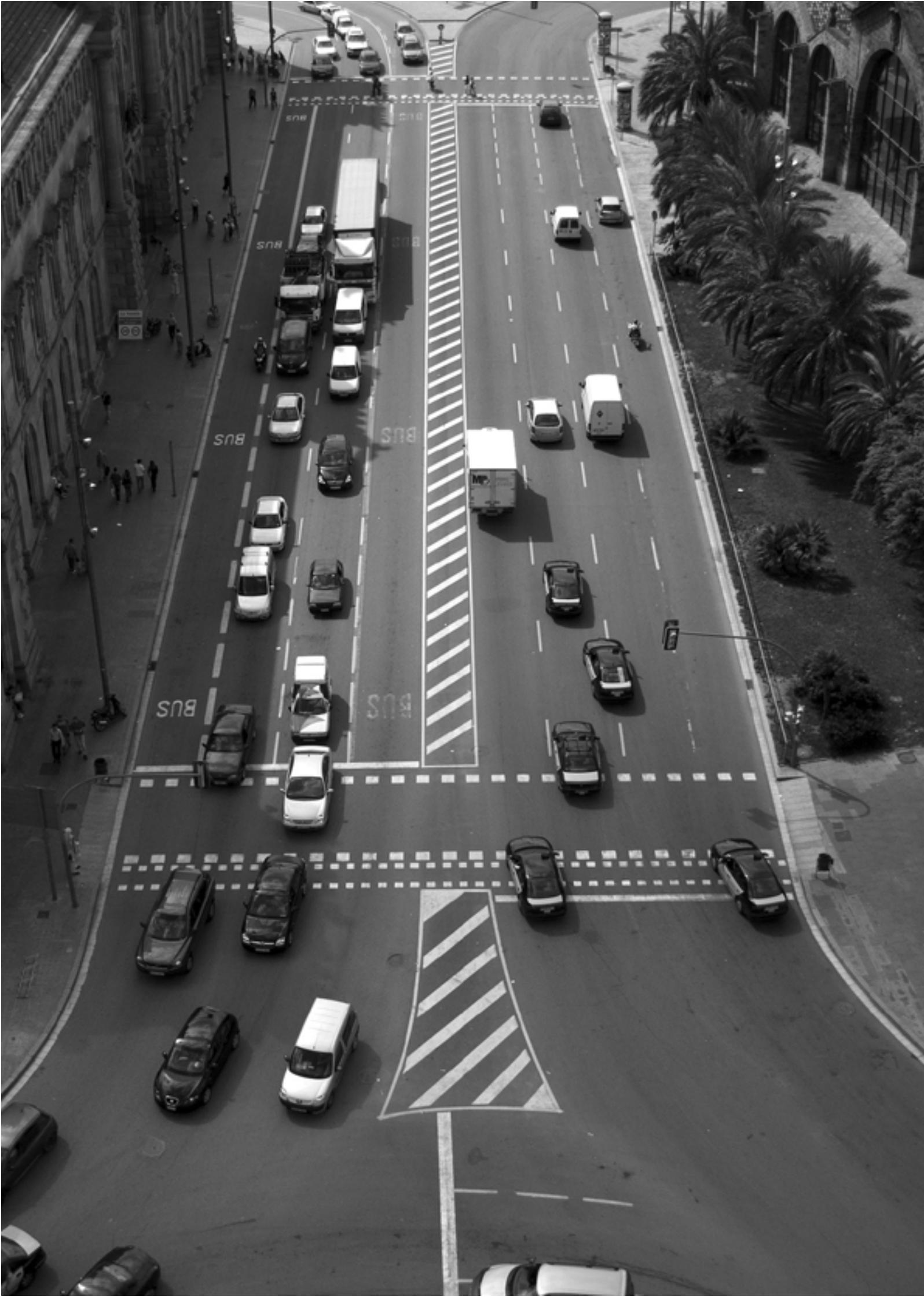
A policy support study carried out as part of the EAFO project for the European Commission Directorate General Mobility & Transport



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# Glossary of terms

<b>ACEA</b>	European Automobile Manufacturers' Association
<b>AER</b>	All-Electric Range
<b>BEV</b>	Battery Electric Vehicle
<b>EAFO</b>	European Alternative Fuel Observatory
<b>EEA</b>	European Environment Agency
<b>ERTRAC</b>	European Road Transport Research Advisory Council
<b>EV</b>	Electric Vehicle
<b>FCEV</b>	Fuel Cell Electric Vehicles
<b>GHG</b>	Greenhouse Gas
<b>GW</b>	Gigawatt
<b>GWh</b>	Gigawatt hours
<b>ICCT</b>	The International Council on Clean Transportation
<b>ICE</b>	Internal Combustion Engine
<b>ICEV</b>	Internal Combustion Engine Vehicle
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>km</b>	Kilometre
<b>kWh</b>	Kilowatt hour
<b>LCV</b>	Light Commercial Vehicle
<b>NEDC</b>	New European Driving Cycle
<b>OEM</b>	Original Equipment Manufacturer
<b>PHEV</b>	Plug-in Hybrid Electric Vehicle
<b>RDE</b>	Real-World Driving Emissions
<b>TCO</b>	Total Cost of Ownership
<b>TOE</b>	Tonnes of Oil Equivalent
<b>TTW</b>	Tank-to-Wheel
<b>V2G</b>	Vehicle-to-Grid
<b>WTW</b>	Well-to-Wheel
<b>ZEV</b>	Zero Emission Vehicle



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# Executive summary

**Decarbonising transport is central to achieving Europe’s policy commitments on climate change. The transport sector is expected to deliver a 60% reduction in greenhouse gas (GHG) emissions in the EU by 2050. Achieving these commitments is expected to require a complete decarbonisation of the passenger car fleet. The more ambitious COP21 commitment to limit temperature rises to 1.5°C will demand a complete decarbonisation of transport by 2050.**

This report is designed to help policymakers understand the impacts of a rapid transition to a zero emission car (ZEV) fleet. It considers the impacts of this transition on imported fossil fuels, GHG emissions, air quality and the overall competitiveness of EU industry.

An extensive literature review failed to identify any scenarios or forecasts that provide novel insights on the impacts of a complete transition to a ZEV fleet in the EU. To address this need, a range of scenarios were modelled to determine the financial, energy and CO<sub>2</sub> emission impacts of a transition to a ZEV passenger car fleet by 2050.

Three forecast scenarios draw on an analysis of existing literature for ZEV sales to outline low, medium and high uptakes of ZEVs. Three backcast scenarios are also presented to chart pathways to the target of 100% ZEV passenger car fleet by 2050. These backcasts consider different levels of uptake of battery electric vehicles (BEVs) and plug-in hybrid vehicle (PHEVs).



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### This analysis reveals that:

- **Achieving a 100% ZEV fleet by 2050 will require all new car sales to be ZEV by 2035** (assuming a similar vehicle lifetime as today). This is a substantially faster introduction of ZEVs and PHEVs than current and future policies will achieve.
- **The best option for a rapid reduction in emissions is to focus on BEVs rather than PHEVs** so that the EU transitions more rapidly to 100% ZEV sales. A scenario where PHEVs are the initial focus will push ZEV growth further into the future and will ultimately require a larger effort at a later time. The impact of (an early fleet of) PHEVs on reducing ZEV costs, increasing consumer acceptance and promoting investments in charging / fuelling infrastructure is difficult to forecast but could play an important role in ZEV adoption.
- **A transition to a 100% ZEV car fleet by 2050 will result in an additional reduction of cumulative CO<sub>2</sub> emissions in 2020 and 2050 of 2.2 to 3.9 gigatonnes compared to existing EU targets.** As the European power industry has committed to near 100% carbon neutral electricity production in Europe by 2050, the net “Well to Wheel” GHG emissions reduction from transport can be expected to be even higher. This energy supply analysis is outside the scope of this study.
- **Around 1,740 million barrels of oil per year could be saved by 2050** with the transition to a zero emission passenger car fleet, the equivalent of €78 billion at the current price of \$45 per barrel<sup>1</sup>.
- **The “Tank to Wheel” energy needed for transport across the EU will be reduced by 78%** from today’s level following a transition to a BEV passenger car fleet. A transition to a 100% fuel cell electric vehicle fleet will result in a 46% reduction of energy for the EU’s car fleet. The overall “Well to Wheel” efficiency will depend on the contribution of renewable and nuclear electricity production to the EU energy mix. The energy losses in the fossil fuel supply chain and refining process will more or less remain constant.
- **Purchase cost parity is assumed to be achieved in the period 2022-2026** for a BEV and a comparable internal combustion engine vehicle (ICEV), with BEVs being comparatively lower in cost after that. **Parity of Total Cost of Ownership (TCO) level will be achieved two to four years before the purchase cost parity is achieved. The average TCO for a ZEV will be €0.04 to €0.06 per kilometre less than an ICEV by 2030.** This estimate has been made at a “societal” level without attributing the gains to a specific stakeholder. This represents societal savings of €140 billion to €210 billion per year for a 100% ZEV EU car fleet. Therefore, the transition to a ZEV fleet is a very cost effective solution for reducing greenhouse gas emissions. This analysis does not take into account externalised impacts of reduced GHG emissions such as improved air quality, reduced oil imports and other economic aspects.

<sup>1</sup> At time of writing

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- The literature review identifies that **expert views developed over recent years have varied in their expectation of when price parity between ICEVs and BEVs will occur, but that it will be sometime between 2020 and 2028**. Several OEMs have stated examples of price parity for some new models in 2020, while financial institutions expect a point between 2022 and 2026, and expert consultants are slightly more conservative.
  - **A mass market for ZEV cars will create efficiencies and cost savings for the ZEV LCV (Light Commercial Vehicles) market**, which currently represents 17% of emissions from the wider light-duty fleet. It will also accelerate the development of a HDV (Heavy Duty Vehicle) ZEV / PHEV market for passenger and goods transportation, and will free up advanced biofuels for other transport sectors.
  - **A lithium-ion battery manufacturing capacity of 400 to 600 Gigawatt hours will be required** to sustain a European passenger fleet which is 100% BEV. This is the equivalent of around 10 to 14 “Giga factories” and represents a value of €40 to €60 billion per year for cars alone. This calculation assumes an average battery size of 30 kWh to 45 kWh and a battery price of €100 per kWh. Recent forecasts suggest that battery prices (per kWh) will reach significantly lower levels than currently seen but that ZEVs will use larger battery sizes. This would result in a higher battery demand but a similar overall value.

The base case assumption by stakeholders is that BEVs will become lower in cost than ICEVs in the next decade, and that the TCO of BEVs will be lower than that of ICEVs. Thus it is highly recommended that base case scenarios are prepared for a rapid economics driven transition that starts within the next decade.

In addition, a view has developed that BEVs have superior driving performance characteristics and people used to driving electric do not return to ICEVs. Therefore the transition may become demand driven once the price, range and infrastructure barriers have been removed. Electric vehicles are relatively easy to manufacture and the large value shift to electronics, software and batteries gives opportunities to new entrants, as Tesla has already shown. These opportunities are being recognised, with several tech giants from the USA and Asia already stating that they are interested in electric vehicles.

Whilst the scenarios modelled and presented are not predictions of the future, they do show possible pathways to achieving the objective of 100% ZEV passenger cars on the road in the EU by 2050. Uptake of ZEVs will be greatly affected by developments in policy, technology, market competition and consumer choices. The scenarios also reveal that bolder and faster action is required by EU policymakers to transition to a ZEV car fleet if 2050 commitments are to be met. It is recommended that the scenarios are revised with new or updated data as it becomes available. Future updates could also include data on vehicle rest values and include more sensitivity analysis.

## Considerations and context of the EAFO study

The main objective of this EAFO study is to assess the potential impact of the transition of the EU car fleet from combustion engine vehicles to zero emission vehicles. Two years ago, electric drive vehicles were considered an expensive niche solution for cities. This has now changed to mainstream policymaking and political thinking. However, to date there is a lack of data on possible impacts and scenarios of how to get to a zero emission fleet. In this study, external peer reviewed data and data used in many other publicly available reports have been used, for example on GHG emissions, vehicle purchases and operational costs. Several assumptions have been made and a conservative approach taken. Assumptions used are transparent and sensitivity analyses on the TCO (Total Cost of Ownership) have been carried out.

Biofuels are a very important part of the future of transport and for this reason it is presumed that biofuels will continue to be used in transport. The transition to zero emission cars is therefore considered to be the replacement of cars using fossil fuels.

Likewise, whilst the report considers tailpipe emissions, there is an understanding that “well to wheel” emissions also need to be reduced and that the future of zero emission vehicles goes hand in hand with the transition to zero emission power generation. This power generation transition will favour electric drive vehicles even more than modelled in this study.

A one-for-one replacement of vehicles

(ZEV for ICEV) is assumed although it is far from certain that this will happen. Developments in autonomous vehicles and connected vehicles are likely to take place alongside the technology transition to electric drive vehicles. The ownership model of vehicles may also change radically, for example moving towards a lease, rental or pay-per-use approach. Mobility is changing, including towards “Mobility as a Service (MaaS)” solutions for multi-modal transport, with examples including carpooling via apps (e.g. Uber and BlaBlaCar). These have the potential to revolutionise vehicle use, especially in cities. None of these potential changes are considered, however several studies have been published recently discussing them. These publications (for example by OECD and McKinsey/BNEF) share a common view that future developments all favour the use of electric drive vehicles as higher utilisation makes them more attractive from an economical perspective. A similar view is held on the future of autonomous cars, connected cars and MaaS. Furthermore, cities will continue to introduce zero emission zones or ban internal combustion vehicles to improve air quality and noise pollution.

The transition to zero emission vehicles will require a substantial investment in energy distribution infrastructure, for charging electric battery vehicles or refuelling hydrogen fuel cell vehicles. This challenge and cost is not considered in this report. Infrastructure investment has very different dynamics, investors and cost considerations. Infrastructure is also, in part, a cross-departmental societal responsibility, comparable to the construction of highways and airports.



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# Introduction

**The objective of this study is to evaluate the impact a transition to a ZEV car fleet by 2050 could have on the EU's main transport policy objectives. The objectives the EU has defined in the White Paper for Transport (2011) are:**

- 1** To reduce the dependence on the import of fossil fuels for transport
- 2** To reduce the GHG emissions from transport by 60% relative to 1990 emissions
- 3** To tackle problems related to air quality and congestion
- 4** To improve the competitiveness of EU industry

These objectives are currently non-binding targets. A binding target for passenger cars for 2025, and possibly for 2030, is expected by the end of 2017.



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The British and French governments have both announced their targets to transition to a zero-emission car fleet. Both countries are aiming to ban the sale of cars solely using internal combustion engines by 2040. The Dutch government is reportedly preparing a similar step, but with a target date of 2030. Norway is targeting 2025 as the year when there will be (virtually) no more sales of non-zero emission cars. China is likely to announce a timescale for a ban on combustion engine vehicles as well, and has put a ZEV mandate in place to take effect in 2019.

In this study, several scenarios of how to transition the European car fleet to a 100% zero-emission fleet by 2050 are assessed. The impacts on CO<sub>2</sub> emissions, as well as costs and energy use, have been calculated. The calculations are based on data and information obtained from an extensive literature study. For the CO<sub>2</sub> emissions, real-world driving emissions data has been applied. For the cost developments, it is assumed that somewhere between 2022 and 2026 the purchase cost of a ZEV will be equal to that of a conventional ICEV – referred to as price parity. Total costs of ownership, including variable costs, have also been calculated. The main assumptions for the scenario studies are listed in the annex.

This study deals exclusively with the transition of the passenger car fleet. However, it is important to note that light commercial vehicles (LCV, vehicle category N1) represent roughly 17% of the light-duty fleet's GHG emissions (comprising of vehicle categories M1 and N1 (EEA 2016), while representing approximately 8.4% of light-duty fleet sales (ICCT 2016). LCVs are excluded from this study as there is less detailed real-world emission data available and they are subject to less stringent emission limits than passenger cars. A transition to ZEVs of the car fleet will also impact the LCVs (for example through economies of scale from battery manufacture) and additional emissions reductions may be expected from this vehicle category as well.

The impacts of transitioning to zero-emission vehicles have been calculated, presuming that the most cost effective zero-emission technologies will be applied. It is considered that BEVs will be the most cost-effective technology until 2030. It is possible that by 2050 hydrogen fuel cell based technology or even another, yet unknown technology, will become more cost-effective. In the case of hydrogen fuel cells, that will only impact the energy efficiency and not the emissions per se. The model used in this study is focused solely on tailpipe emissions, as this is how passenger cars are currently regulated. It is expected that in the longer term only renewable energy sources will be used by zero-emission vehicles, and that European electricity producers are committed to a zero-emission power generation by 2050 (Eurelectric 2012).

## The status of the European and Global electric vehicle market



In the first half of 2017, the global market share of EVs has been 1.2% (of total passenger car sales) with 450,000 cars being sold. Of these, 65% were BEVs and the remainder were PHEVs. This is growth of 44% compared to the first half of 2016. In the EU, 97,000 EVs have been sold in the first half of 2017, a growth of 37% compared to 2016. The sales of EVs are mainly driven by government incentives as they are still expensive, infrastructure for charging is lacking and availability is poor.

Incentives are mainly at individual country level and as a result, sales are very unevenly distributed in Europe. The top 5 countries, Germany, France, Norway, The Netherlands and the UK, represent 75% of EV sales, favouring BEV or PHEV depending on the specific incentives available (EAFo). For BEVs, 5 models represent 75% of sales and for PHEVs, the top 5 models represent around 45% of the sales. More models are available however, and, in the BEVs market especially, model lifetime is relatively short and replacements or upgrades are required to maintain market share.

A significant issue is that several popular models are simply not

available. The GM Bolt, introduced a year ago, is on sale as Opel Ampera-e only in Norway and The Netherlands and in very low numbers. Another example is Romania where an effective incentive scheme led to demand outstripping supply: there was demand for 100 Smart electric cars, however only 2 cars were available in 2017.

Norway is a case study showing that if EVs are available at a similar price to ICEVs, customers will buy in very large numbers. In September, the market share for EVs was close to 50%, and including imports of second hand EVs was above 50%. Only 5 years ago the market share was 3%, and in 2015 it was 22% (EAFo). This demonstrates how quickly markets can transition to EVs when the cost is equal. Research in Norway also shows that EV drivers will not return to ICEVs.

The announced expansion in the model offering over the next few years will provide a good coverage of car categories and electric ranges. Several OEMs have announced models at price parity with ICE equivalents by 2020. On the EV sales, several bold announcements have been made by OEMs: VW for example anticipate increasing EV sales to between 2 and 3 million, or 20 to 25% of total sales, by 2025. The combination of increased offering, price competitiveness and networks of super-fast 350 KW chargers in the coming years may prove to be the tipping point towards the transition to a ZEV fleet. Customers may very well decide to switch earlier than anticipated.

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# 1.0 From EU targets to COP21 compliance: 100% ZEV passenger car fleet by 2050

**For the analysis provided in this report, 3 main categories of cars are considered, ICEVs, PHEVs and ZEVs:**

- **ICEVs** (Internal Combustion Engine Vehicles) are internal combustion engine vehicles with natural gas, LPG, diesel and gasoline as fuels and including hybrid and which are all expected to play an important role in the transition phase;
- **PHEVs** (plug-in hybrid electric vehicles);
- **ZEVs** (zero-emission vehicles) including **BEVs** (battery electric vehicles), and **FCEVs** (fuel cell electric vehicles).

Biofuels count as zero CO<sub>2</sub> for the transport sector under the IPCC definitions, however in this scenario study 100% biofuel driven cars are not considered. The amount of available second and third generation biofuels in the EU is limited. For this scenario study it is therefore presumed that second and third generation biofuels for transport will be used for heavy duty vehicles, aviation or shipping where the challenge of electrification is bigger. Power to gas or liquid (PtX) fuels are also excluded from this scenario study as these are still immature and future developments uncertain. It can also be expected that PtX solutions can be applied to the other transport sectors mentioned above.

Compliance with the 2030 target will depend on the amount of ICEVs displaced by PHEVs and ZEVs. To a lesser extent, it will also depend on the fuel economy improvement in real-world driving from ICEVs, for instance by using improved engines and transmissions, hybrid technologies, weight reduction and improved aerodynamics.

## 1.1 Current EU transport CO<sub>2</sub> emissions and long term targets

Figure 1 illustrates the historical CO<sub>2</sub> emissions produced by the entire European transport sector since 1990, along with several future scenarios. Note that CO<sub>2</sub>-equivalents represent the total GHG. For this study, the ambition to reach a 100% reduction in car (tailpipe) GHG emissions by 2050 is taken as starting point.

For the calculations and projections presented, the most recent GHG emissions data from the European Environment Agency (EEA) are used (EEA 2016). Cars typically represent about 62% of road transport's GHG emissions. For the 2050 limit, a 60%, 80% and 95% reduction for passenger cars is assumed, based on the 2011 White Paper for Transport (European Commission 2011). These specific reduction targets are also shown in the figure below. However, it is assumed that to meet the COP21 commitments, the EU will have to decarbonize its passenger car fleet completely by 2050.

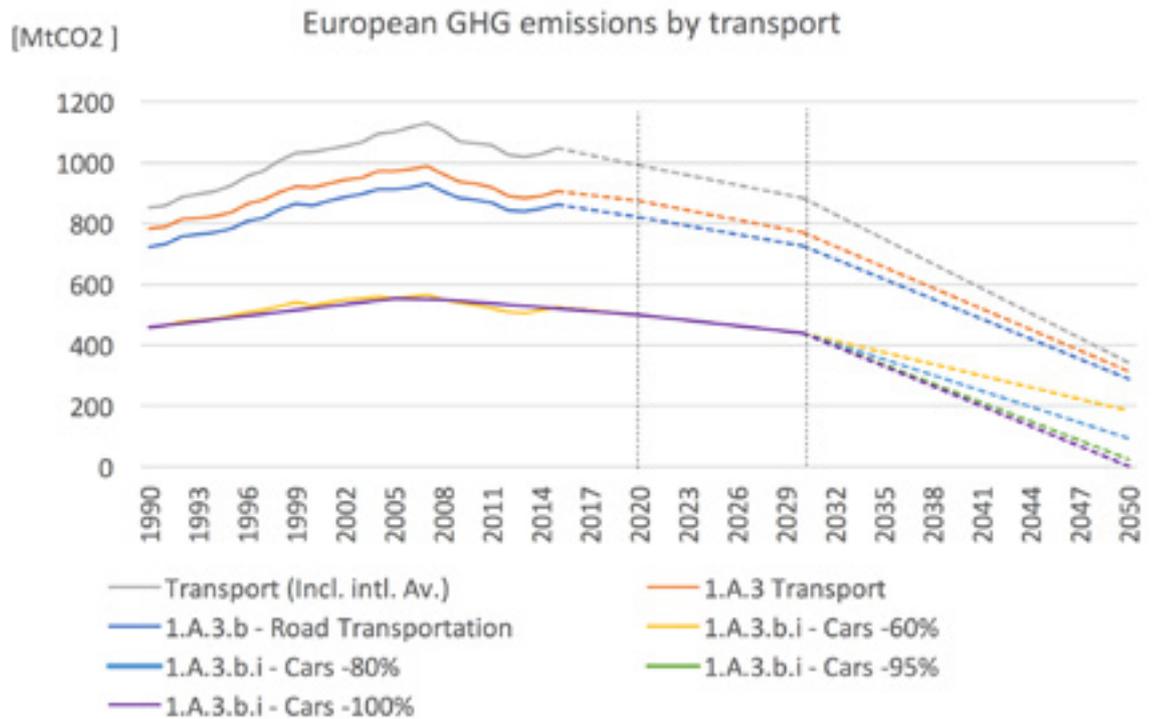
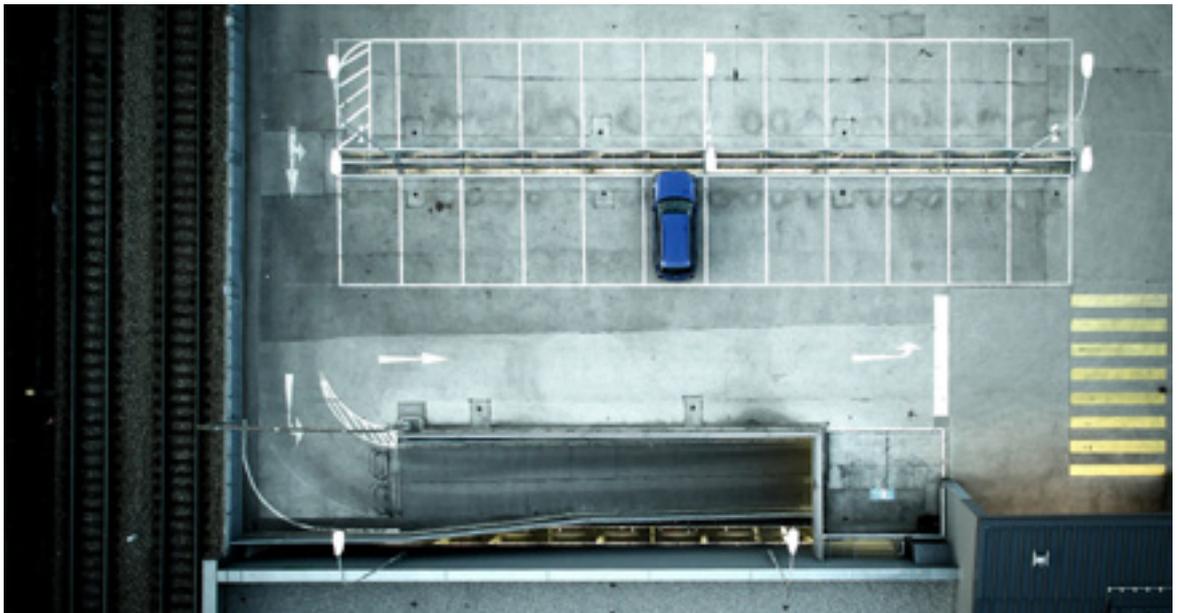


Figure 1: Historical evolution of the GHG emissions for transport, road transport and passenger cars, expressed in million tonnes of CO<sub>2</sub> equivalents. The dashed lines represent the required reduction trends for all transport and its sub-sectors. For passenger cars, the intermediary targets are given for 2020, 2030 and 2050. Several potential targets for 2050 are given, based upon the EU White Paper for Transport (European Commission 2011).

### Assumption for this study:

Assumption for this study: The EU passenger car fleet needs to be a zero-emission fleet by 2050. As cars are much easier to decarbonise than other vehicle types they are expected to contribute proportionally more to the decarbonisation of the transport sector.



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## 2.0 Passenger car fleet characteristics for the EU: Current and forecast situation by 2030

For this study, it is assumed that the European (EU) passenger car fleet will develop in a “business as usual” manner. The possible disruptions of the use and ownership of cars are not considered, as it is too speculative at this stage to take this into account. A baseline to which the impact of ZEVs could be compared does not exist and it is outside the scope of this study to create such a baseline. From a qualitative point of view, it can be expected that these developments will have a positive impact on the transition to ZEVs, as their cost of ownership will be more favourable with a higher vehicle utilisation. This is because ZEVs have lower variable costs and are expected to allow higher vehicle mileage than ICEVs. This potential is not considered in this exercise.

### 2.1 EU passenger car fleet size 1990 - 2030

Vehicle registration data since 1990 has been used to provide insight into European fleet turnover characteristics. Currently, the European fleet consists of 256 million cars, and annual sales over the last 10 years have fluctuated around 14 million vehicles. For the presented exercise, this annual influx of new vehicles is considered to remain constant.

The annual registrations and scrapping from the European fleet register are given in Figure 2. Registration data was obtained from the European Automobile Manufacturers’ Association (ACEA) database (ACEA 2016), while scrapping was estimated using the equation below. The reason for this is that Eurostat data systematically underestimates the number of cars scrapped for recycling or sent out of the EU (Mehlhart, et al. 2011). Post-2015 annual registrations are assumed to be 14 million. These assumptions indicate a yearly fleet turnover of approximately 5.4%.

$$\text{Vehicle scrappings} = (\text{total fleet}_{\text{old}} + \text{registrations}_{\text{new}}) - \text{total fleet}_{\text{new}} \quad (1)$$

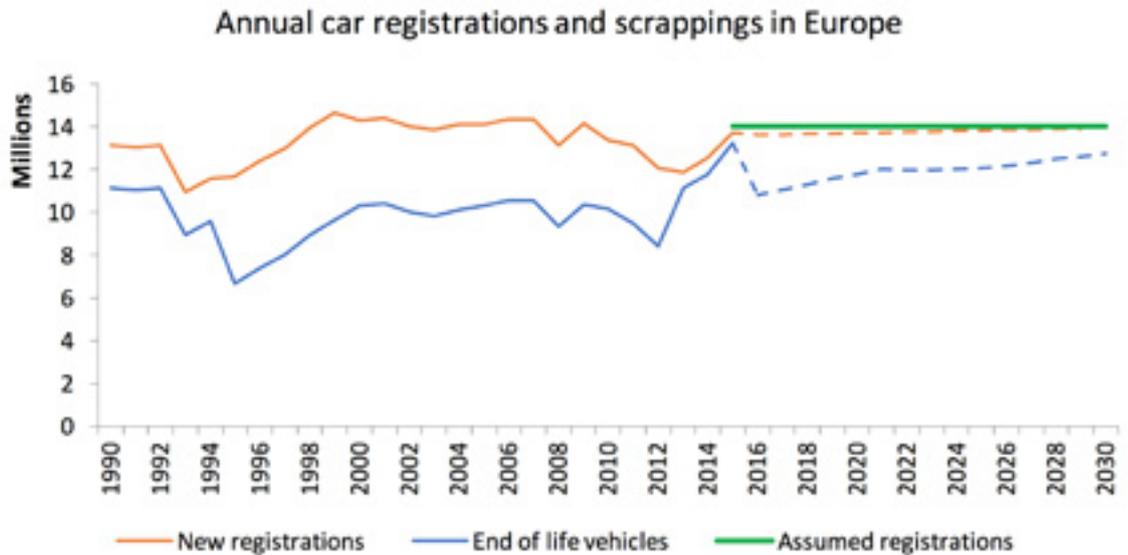


Figure 2: The evolution of the European new registrations and end-of-life vehicles (scrapping) for the 1990-2015 timespan, added with the forecasts until 2030 and a constant assumed annual registration (based on (ACEA 2016)).

Based upon Ricardo-AEA data, the annual mileage for petrol cars is assumed to be 14,000 kilometres. For the present analysis, all vehicles (petrol, diesel, battery and fuel cell electric) are assumed to perform the same annual mileage of 14,000 km/year. It is understood that diesel cars may be used slightly more as a 2012 study stated an annual mileage of 16,000 km/year (Dun, Pridmore, Gibson, Kollamthodi, & Skinner, 2012). An economic lifetime of 15 years and a mileage of 210,000 kilometres are assumed for the further calculations as well as for the TCO scenarios. For the latter, however, two scenarios are calculated; one over 15 years and a second scenario with higher mileage and depreciation in the first 4 years of the vehicle life, thus simulating a typical car lease structure for new cars. One aspect that is not accounted for in the calculations is the so-called 'age effect', which reflects the fact that newer cars are more frequently used than older cars (Dun, et al. 2012).

**Assumption for this scenario study:**

The passenger car fleet in the EU will remain constant in size and in new car sales until 2030, the economic life time of passenger cars is 15 years, and the utilisation of the vehicles remains at 14,000 kilometres per year.

## 3.0 Literature study ZEV and PHEV forecasts 2020 - 2050

To assess the total future annual CO<sub>2</sub> emissions of the entire car fleet, available market forecasts per powertrain technology were identified for the years 2020, 2025, 2030, 2035, 2040 and 2050. Each of these sources represents expert insights on the transition from a market dominated by conventional diesel and petrol cars, to a more heterogeneous composition of technologies. Figure 3 shows the forecasts for the combined PHEV+ZEV market share over the timeframe considered, as these technologies are assumed by the authors of this report to become dominant.

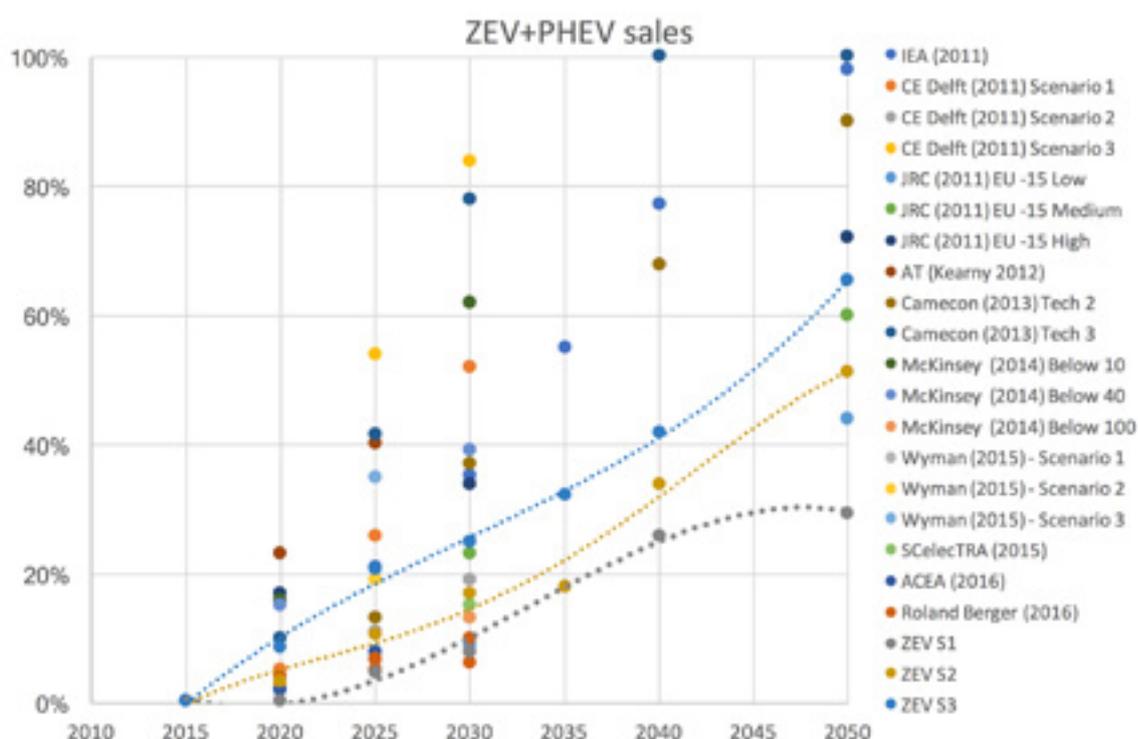


Figure 3: Results from literature study on the ZEV/EV share in new car sales 2020 – 2050. The dots represent the forecasted ZEV+PHEV sales, the 3 lines represent the ZEV only sales using the low – average – high forecast values, excluding the PHEV sales. These scenarios and forecasts from literature are based on market analysis studies and are considered in this study to be forecasts. Data points received from BNEF (2017) but not taken into account are: 2025 (8%), 2030 (24%), 2040 (54%).

Based upon the literature forecasts, three scenarios were developed (Low, Medium, High growth) representing different ratios of ZEVs to ICEVs and PHEVs. The objective of these three forecast groupings was to see if there are substantial differences in the insights of experts for growth of the EV market share up to 2050. Although the various sources present a more detailed forecast for different ICE-based technologies, these were grouped as ICEVs to ease the comparison with the two other technology types. Given a low, medium and high sales share of ZEVs (literature forecast scenarios 1, 2 and 3, respectively), a normalisation was performed for the ICEV and PHEV sales shares. This was achieved by aligning the average sales shares with the three respective ZEV scenarios. Note that the sources shown in the legend of Figure 3 are

not exhaustive and that forecasts for the (near) future are published frequently. The trend observed is that the more recent the sources are, the more optimistic they are about the ZEV penetration level. It should be noted that with the current policies in place even the “Low ZEV Forecast” may not be achieved unless the EU Commission takes decisive action.

**The three literature scenarios highlighted above are presented separately in the figures below.**

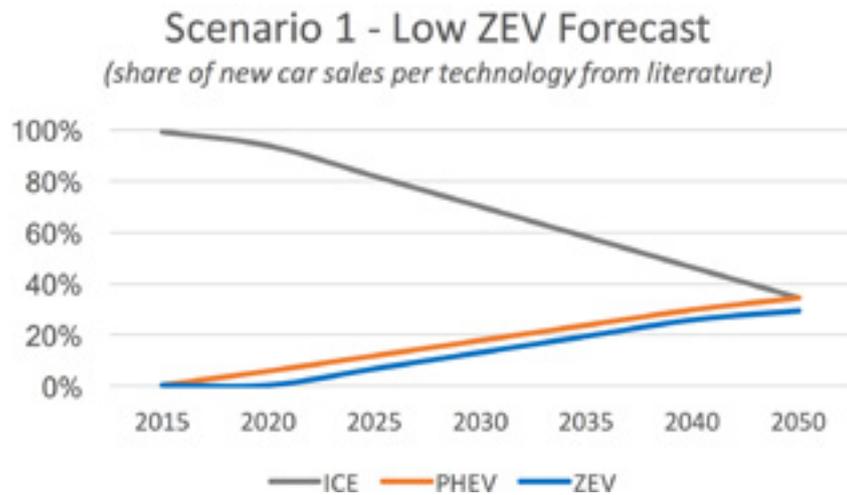


Figure 4: Scenario 1 - Low ZEV Forecast (from literature). ICE represents the conventional internal combustion engine technologies petrol, diesel, hybrids and natural gas vehicles. ZEV comprises the zero-emission technologies (battery electric + fuel cell electric vehicles) and PHEV represents plug-in hybrids. The Low ZEV Forecast is forecasting levels of ZEV sales by 2050 which are now expected by many to happen somewhere in the next decade.

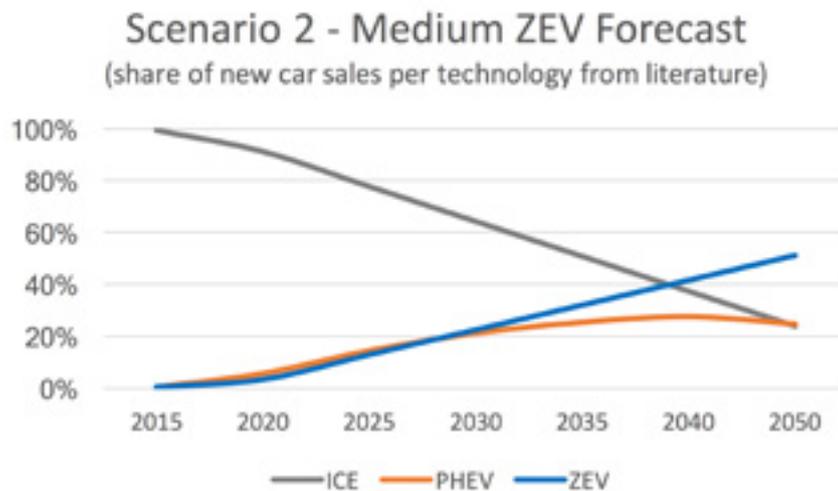


Figure 5: Scenario 2 - Medium ZEV Forecast (from literature). ICE represents the conventional internal combustion engine technologies petrol, diesel, hybrids and natural gas vehicles. ZEV comprises the zero-emission technologies (battery electric + fuel cell electric vehicles) and PHEV represent plug-in hybrids. The Medium ZEV Forecast has 50% ZEV sales in 2050, a level recently expected to be achieved in the 2030-2035 timeframe or earlier. Please note that the straight line for the ZEV sales development implies a decreasing growth in sales.

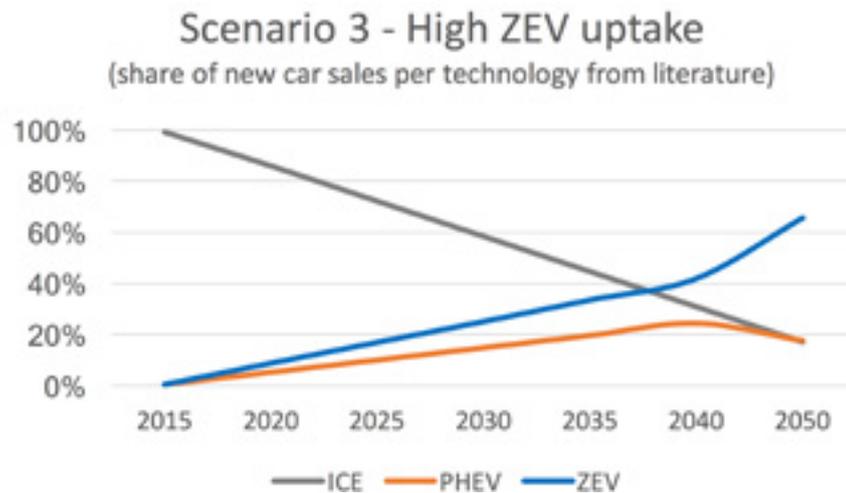


Figure 6: Scenario 3 – High ZEV Forecast (from literature). ICE represents the conventional internal combustion engine technologies petrol, diesel, hybrids and natural gas vehicles. ZEV comprises the zero-emission technologies (battery electric + fuel cell electric vehicles) and PHEV represents plug-in hybrids. In the High ZEV Forecast, ZEV sales only reach 65% in 2050. The UK and France both target 100% ZEV sales by 2040.

### 3.1 Conclusions from the literature review on ZEV sales forecasts:

- Even the most optimistic forecast evaluated in this study will not result in 100% ZEV car sales by 2050. Reaching a 100% ZEV car fleet by 2050 is something which is not considered likely to happen.
- Expert forecasts of sales data for the coming decades is much lower than the current ambitions of ZEV leader countries, as well as the stated targets for ZEV sales by OEMs.
- Policymakers and other decision makers would be prudent to prepare for significantly faster ZEV market growth than experts predict will happen. The risk of being too pessimistic may be bigger than the risk of being too optimistic.

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## 4.0 Real-world versus type-approval CO<sub>2</sub> emissions

Real-world fuel consumption typically differs from the value on a car's certificate of conformity. The reasons for this are certain flexibilities that exist in the applicable test and evaluation procedures used for type approval. The existing gap between the NEDC-based type-approval (in place until recently but as of September 2017 gradually replaced by the WLTP) and real-world driving emissions (RDE) for CO<sub>2</sub> emissions has been quantified by The International Council on Clean Transportation (ICCT) since 2001. It is reported to have increased from 9% to more than 40% in 2015. Going forward, a gap of 50% is forecast by 2020 if current practices continue, according to NEDC measures (Tietge et al. 2015). These coefficients were confirmed by TNO, which assumes an absolute divergence from type-approval CO<sub>2</sub> emissions of 45 g/km, independent of the fuel type for both conventional and hybrid powertrains (Ligterink et al. 2016). This divergence is applied to the analysis presented here and is kept constant for the ICE-based technologies. This is because there is no certainty that the recently introduced Worldwide Light Vehicle Test Protocol (WLTP) will bring down the absolute divergence with real-world fuel consumption (Ligterink et al. 2016).

Concerning the PHEV models that are currently on the market, the share of kilometres driven on electric power alone is assumed to be 30%, in contrast to the unrealistically high share of EV-driving during the NEDC type-approval test (67%). This has consequences for the emissions of both harmful pollutants and GHG emissions. The latter are typically very low on paper, although PHEVs in real-world circumstances are reported to exceed the type-approval value by a factor of 2 to 3. The former, most conservative conformity factor is used in the calculations presented in this report. The assumed post-2020 CO<sub>2</sub> type-approval (NEDC) limit values are given in the figure below.

In our model, no further reductions in type-approval CO<sub>2</sub> emissions below 95 g/km are assumed for ICEVs. This is because the cost for further reducing an ICEV's fuel consumption is expected to exceed the cost of electric vehicle (EV) technology. Moreover, due to super-credit factors for increasing a ZEV's 'weight' when determining a manufacturer's fleet average CO<sub>2</sub> emissions, the electrification of passenger cars is thought to become a key asset for reaching the imposed targets. The super-credits are a temporary arrangement and not relevant at this stage beyond 2020. This issue was identified in 2009 by TNO, as a 2020 ZEV market share of 10% was found to be more economically interesting for car manufacturers than relying on technologies to further decrease fuel consumption of conventional cars. Economies of scale and knowledge spill-over effects for battery technology are bringing down EV technology cost quicker than previously predicted. This could result in production cost parity becoming even greater than previously simulated in 2009 for the 2020 target. Following this argument, PHEV technology is not expected to reach high market share due to the high production costs for the dual technology. Instead, where PHEVs were first seen as a transition technology between ICEVs and zero-emission vehicles (ZEV), the latter are becoming attractive on their own, as battery prices have decreased significantly while energy density levels have increased.



As the passenger car fleet is not likely to be dominated by one technology by 2030, different assumed CO<sub>2</sub> targets are presented in the figure below. The values after 2035 are added for illustration only, as it is assumed in the scenarios that 100% of car sales will be ZEV. PHEV emission limits are forecast to drop, which implies a substantial part of a car's total mileage will be driven electric (e.g. 80% instead of the 30% average in 2015). Finally, irrespective of which fleet average emission level will be targeted for the years to come, the COP21 Agreement is assumed to require a complete decarbonisation of the passenger car fleet by 2050.

The forecast average emissions per drivetrain technology over the years are shown in the figure below. These are based upon the discrepancy factors discussed earlier between type-approval and RDE. The CO<sub>2</sub> reduction potential for PHEVs depends on the all-electric range (AER) and the percentage of the time the vehicle is operated in EV-mode. Based upon literature and our in-house data, a discrepancy factor of 2.14 is maintained for the calculation of the RDE emissions of PHEVs post 2030.

## Assumptions CO<sub>2</sub> emissions per technology post-2020:

### Assumed CO<sub>2</sub> emissions targets [g/km] (type approval)

	<b>Petrol</b>	<b>Diesel</b>	<b>PHEV</b>	<b>BEV</b>	<b>FCV</b>	<b>NGV</b>
<b>2015</b>	125	120	58	0	0	104
<b>2020</b>	95	95	50	0	0	95
<b>2025</b>	95	95	50	0	0	95
<b>2030</b>	95	95	50	0	0	95
<b>2035</b>	95	95	50	0	0	95
<b>2040</b>	95	95	40	0	0	95
<b>2050</b>	95	95	30	0	0	95

### RDE Multiplier Factors (conversion of NEDC to RDE)

	<b>Petrol</b>	<b>Diesel</b>	<b>PHEV</b>	<b>BEV</b>	<b>FCV</b>	<b>NGV</b>
<b>2015</b>	1.36	1.38	2.14	0	0	1.43
<b>2020</b>	1.47	1.47	2.14	0	0	1.47
<b>2025</b>	1.47	1.47	2.14	0	0	1.47
<b>2030</b>	1.47	1.47	2.14	0	0	1.47
<b>2035</b>	1.47	1.47	2.14	0	0	1.47
<b>2040</b>	1.47	1.47	2.15	0	0	1.47
<b>2050</b>	1.47	1.47	2.13	0	0	1.47

### Assumed CO<sub>2</sub> emissions [g/km]: RDE (Real Driving Emissions)

	<b>Petrol</b>	<b>Diesel</b>	<b>PHEV</b>	<b>BEV</b>	<b>FCV</b>	<b>NGV</b>
<b>2015</b>	170	165	124	0	0	149
<b>2020</b>	140	140	107	0	0	140
<b>2025</b>	140	140	107	0	0	140
<b>2030</b>	140	140	107	0	0	140
<b>2035</b>	140	140	107	0	0	140
<b>2040</b>	140	140	86	0	0	140
<b>2050</b>	140	140	64	0	0	140

Figure 7: Assumption for CO<sub>2</sub> emission target per vehicle technology: NEDC values and RDE values

Note that the emission factors presented only concern tank-to-wheel (TTW) emissions, as this is how the GHG emissions from transport are currently regulated. Since ZEVs have no TTW emissions, they become interesting assets for manufacturers in terms of fleet average emissions. By including the well-to-tank (WTT) emission in the technology comparison, the total GHG production can be targeted in a well-to-wheel (WTW) approach. In the latter case, the indirect emissions of GHG emissions related to passenger car propulsion are included, as the production of the energy carrier is considered as well. Considering these indirect emissions changes the balance when different powertrain technologies are compared, as the production of the various energy carriers has differing environmental impacts. A WTW approach can be argued by car manufacturers, as they cannot be held responsible for

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the upstream emissions in the production stage of the fuels. In case of battery electric vehicles (BEV), the way electricity is produced has a significant influence on the WTT emissions. In a WTW approach, ZEVs are no longer represented by zero emissions, although they outperform conventional powertrain by every means of electricity generation except from coal-fired or oil-powered power plants (Messagie 2014).



## 4.1 Conclusions

- Real world driving CO<sub>2</sub> emissions (RDEs) are significantly higher than test cycle (NEDC) emissions.
- PHEV test cycle emissions deviate more from RDEs.
- ICEV emissions are not expected to decrease much beyond 2020 as the electrification of cars becomes a more economical means to meet tightened LDV CO<sub>2</sub> emission targets.

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## 5.0 Three backcasting scenarios for a transition to a ZEV passenger car fleet by 2050

### 5.1 Assumptions for the ZEV transition scenarios

For the EAFO study, three scenarios have been developed (ZEV Base Case, PHEV Bridging and ZEV Leader. In these scenarios, it is assumed that the current fleet characteristics, notably the size of the fleet and the vehicle use, will not change from the current situation and will develop as discussed earlier. This does not take away the authors' recognition that significant changes may occur in vehicle ownership and use models, which may in turn impact vehicle lifetime as well as the total cost of ownership. The development of autonomous vehicles may have a very significant impact on how we use and own vehicles. It could impact the speed of the transition to electric drive, for example when large numbers of conventional vehicles are being replaced by autonomous and electrified vehicles.

**The main boundary conditions for the scenarios are:**

1. The EU passenger car fleet will transition to 100% ZEV.
2. Battery electric vehicles will become competitive in terms of purchase costs with ICEVs between 2022 and 2026.
3. The transition scenarios are technology-neutral for ZEVs, the indication of battery electric or fuel cell is for illustrative purposes only.
  - a For the financial impact analyses the BEV costs are used for the ZEV cost (at vehicle level) as these are currently the most cost attractive option for a ZEV.
  - b FCEVs as ZEVs will not impact the CO<sub>2</sub> emission at fleet level (tail pipe emission) but it will impact the overall energy efficiency and energy use.
4. ICEVs will lose their competitive monetary advantage when the average CO<sub>2</sub> emissions targets are decreased beyond 95 g CO<sub>2</sub>/km. In addition to the CO<sub>2</sub> emissions target, ICEVs will also have to comply with other increasingly stringent emissions criteria.
5. Assumptions regarding fuel price development, operational costs, lifetime, mileage and maintenance costs are, unless mentioned otherwise, based on in-house data.

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## 5.2

### Three transition backcasting scenarios resulting in a ZEV passenger car fleet in 2050



The starting point for the following 3 scenarios is that the EU passenger car fleet will be 100% ZEV by 2050. This implies an (almost) complete transition to ZEV for new registrations by 2035, considering the assumed average 15-year economic life time of passenger cars.

Three distinctive scenarios (4, 5 and 6) were developed, which each lead to this objective, albeit through different pathways. Thus, different impacts are obtained, for example on the cumulative CO<sub>2</sub> emissions or fossil fuel imports over the period until 2050. Each of the three scenarios assumes all sold vehicles to be ZEV from 2035 onwards. The scenarios nonetheless differ in the initial adoption speed and in the extent to which PHEVs form an intermediate solution. Scenario 4 - ZEV Base Case assumes a sales share of 7.5% ZEV by 2020, while scenario 6 - ZEV Leader considers 10% ZEV sales by 2020. Finally, scenario 5 - PHEV Bridging assumes a strong market share of PHEVs towards 2030.

In Figure 8, the 5-year target values for the 3 scenarios are given as well the NEDC and RDE CO<sub>2</sub> emission targets for 2020, 2025 and 2030. As the current NEDC 2020 target is 95 g CO<sub>2</sub>/km it is evident that the EAFO scenarios already require an additional effort before 2020. The focus in the EAFO scenarios is on the RDE as the objective is to reduce the real CO<sub>2</sub> emissions. The NEDC values are lower than the RDE values. This difference is more or less a constant value of 45 g CO<sub>2</sub>/km, achieved by the “optimisation” of the emission test. The difference between NEDC and RDE for PHEVs is even larger, hence the increasing difference with increasing PHEV share.

## New car sales 2020 - 2050 (EAFO scenarios) & CO<sub>2</sub> emissions targets

<b>Scenario 4 - ZEV Base Case (backcasting)</b>				g CO <sub>2</sub> /km targets	
	<b>ICE</b>	<b>PHEV</b>	<b>ZEV</b>	<b>NEDC</b>	<b>RDE</b>
<b>2015</b>	99.3%	0.4%	0.4%		
<b>2020</b>	80.0%	12.5%	7.5%	82	125
<b>2025</b>	50.0%	15.0%	35.0%	55	86
<b>2030</b>	10.0%	20.0%	70.0%	20	35
<b>2035</b>	0.0%	0.0%	100.0%		
<b>2040</b>	0.0%	0.0%	100.0%		
<b>2050</b>	0.0%	0.0%	100.0%		

<b>Scenario 5 - PHEV Bridging (backcasting)</b>				g CO <sub>2</sub> /km targets	
	<b>ICE</b>	<b>PHEV</b>	<b>ZEV</b>	<b>NEDC</b>	<b>RDE</b>
<b>2015</b>	99.3%	0.4%	0.4%		
<b>2020</b>	92.0%	5.0%	3.0%	90	134
<b>2025</b>	65.0%	25.0%	10.0%	74	118
<b>2030</b>	35.0%	35.0%	30.0%	51	86
<b>2035</b>	0.0%	0.0%	100.0%		
<b>2040</b>	0.0%	0.0%	100.0%		
<b>2050</b>	0.0%	0.0%	100.0%		

<b>Scenario 6 - ZEV Leader (backcasting)</b>				g CO <sub>2</sub> /km targets	
	<b>ICE</b>	<b>PHEV</b>	<b>ZEV</b>	<b>NEDC</b>	<b>RDE</b>
<b>2015</b>	99.3%	0.4%	0.4%		
<b>2020</b>	87.0%	3.0%	10.0%	84	125
<b>2025</b>	50.0%	10.0%	40.0%	53	81
<b>2030</b>	5.0%	15.0%	80.0%	12	23
<b>2035</b>	0.0%	0.0%	100.0%		
<b>2040</b>	0.0%	0.0%	100.0%		
<b>2050</b>	0.0%	0.0%	100.0%		

Figure 8: Backcasting scenarios to reach an EU ZEV car fleet by 2050, including the required NEDC and RDE CO<sub>2</sub> fleet targets in 2020, 2025, 2030. In 2035 all new car sales are zero-emission. The sales forecasts for the different technologies in combination with the values for the RDE emissions for the corresponding technologies and years result in RDE and NEDC emission target values. For the calculations, the RDE targets are used as the objective is to reduce real emissions.

Figure 9, Figure 10 and Figure 11 show in graph form developments of the shares of ICEVs, PHEVs and ZEVs in new car sales up to 2050 for scenarios ZEV Base Case, PHEV Bridging and ZEV Leader.

### ZEV Base Case (new car sales - backcasting from a 100% ZEV fleet by 2050)

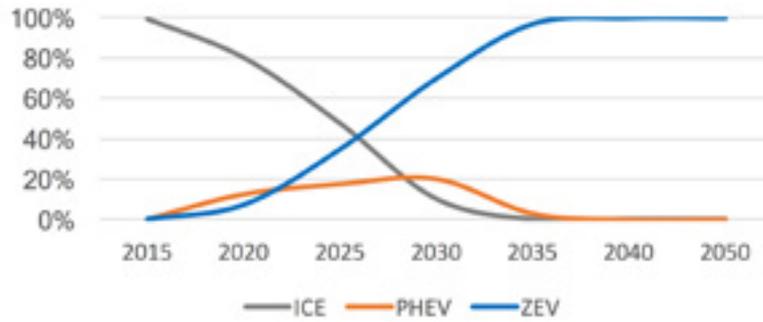


Figure 9: Scenario 4 – ZEV Base Case (backcasting), with a 2020 ZEV market share for new car sales of 7.5% and PHEV share of 12.5%. ICE represents the conventional internal combustion engine technologies petrol, diesel, hybrids and natural gas vehicles. ZEV comprises the zero-emission technologies (battery electric + fuel cell electric vehicles) and PHEV represents plug-in hybrids.

### PHEV Bridging (new car sales - backcasting from a 100% ZEV fleet by 2050)

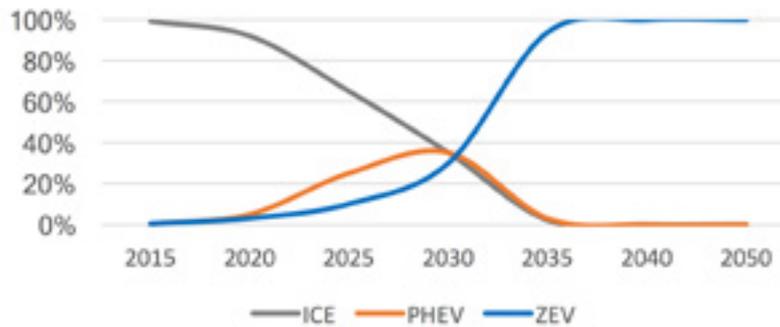


Figure 10: Scenario 5 – PHEV Bridging (backcasting), with a 2020 PHEV market share for new car sales of 5% and ZEV market share of 3%. ICE represents the conventional internal combustion engine technologies petrol, diesel, hybrids and natural gas vehicles. ZEV comprises the zero-emission technologies (battery electric + fuel cell electric vehicles) and PHEV represents plug-in hybrids.

### ZEV Leader (new car sales - backcasting from a 100% ZEV fleet by 2050)

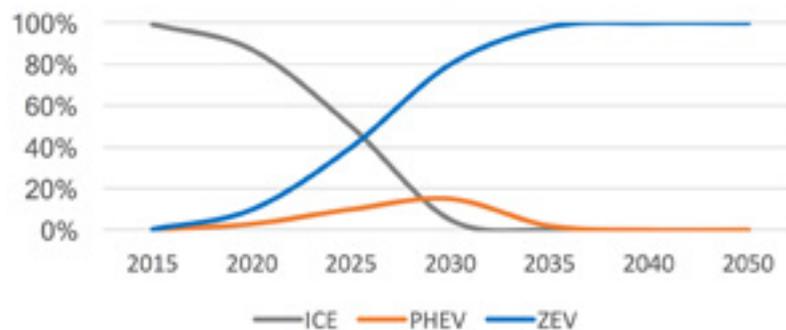


Figure 11: Scenario 6 – ZEV Leader (backcasting), with a 2020 ZEV market share of 10%. ICE represents the conventional internal combustion engine technologies petrol, diesel, hybrids and natural gas vehicles. ZEV comprises the zero-emission technologies (battery electric + fuel cell electric vehicles) and PHEV represents plug-in hybrids.

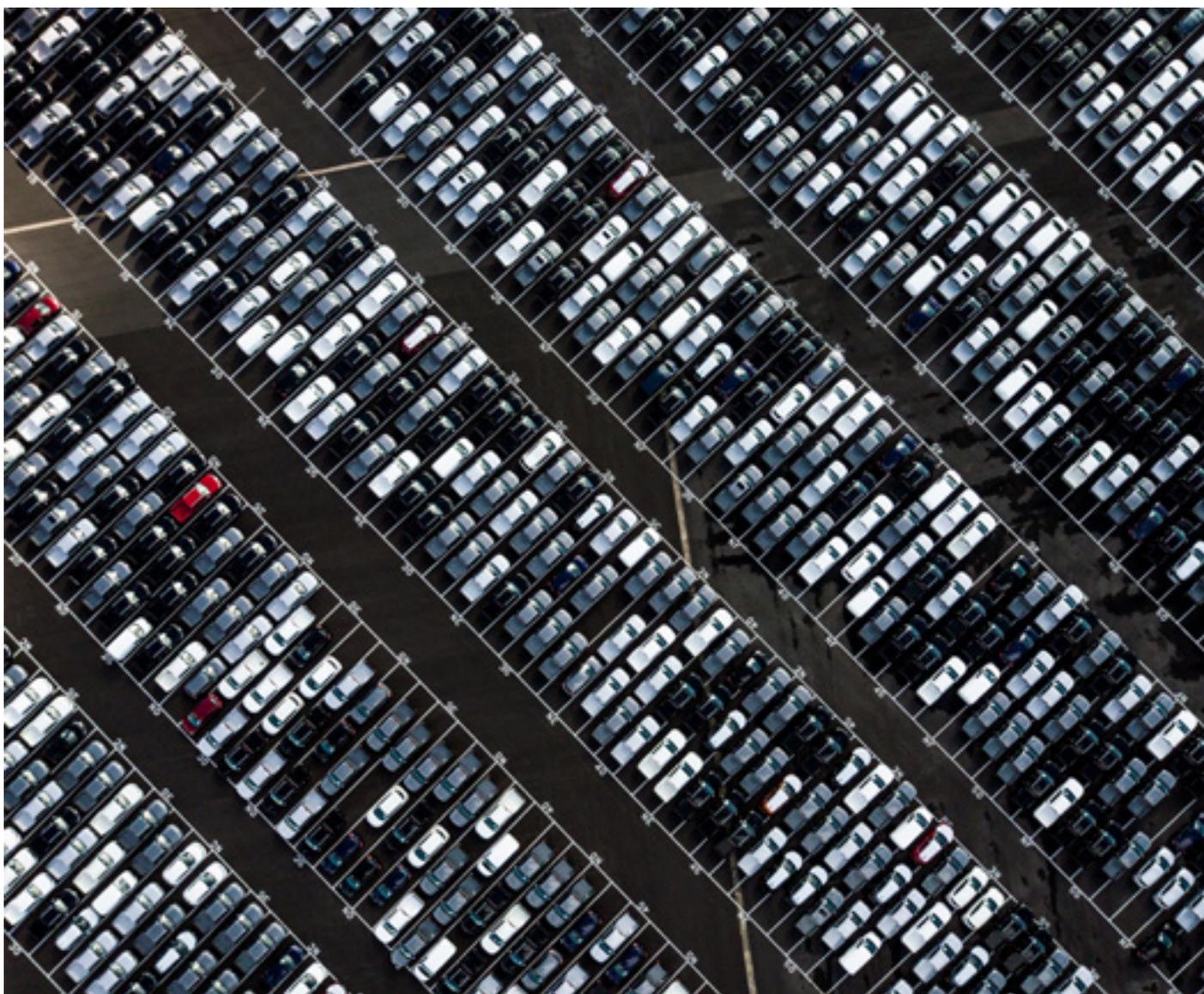
### 5.2.1

#### **Fleet composition for the 3 transition scenarios**

The projections of sales figures for the backcast scenarios ZEV Base Case, PHEV Bridging and ZEV Leader have an influence on the fleet composition, as new cars enter the fleet and old ones are disposed of. Although for the scenarios the types of technologies (ICEV, PHEV and ZEV) are considered, the fleet model uses a more detailed fleet distribution for the different ICE technologies, including hybrids. The figures below illustrate the impact on the fleet composition assessment, based on sales assumptions for the different ICE technologies.

Figure 12, Figure 13 and Figure 14 show the fleet compositions over time for scenarios 4, 5 and 6 and for the 3 main technologies ICEV, PHEV and ZEV.

For the calculations, we have presumed that the lowest cost technology will dominate. The ratio between BEV and FCEV sales is for illustration only and is not a view on how the sales might develop.



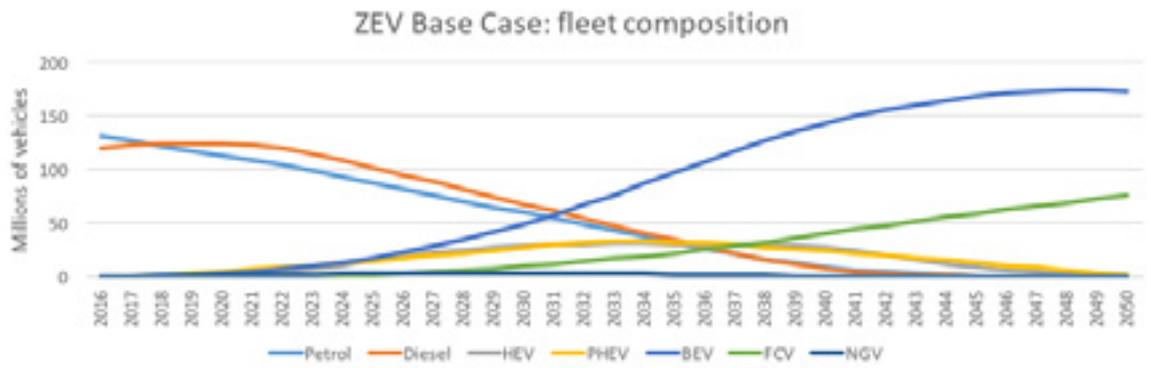


Figure 12: EU passenger car fleet composition 2016 - 2050 linked to scenario 4 ZEV Base Case (backcasting). The Hybrid and PHEV curves are almost overlapping.

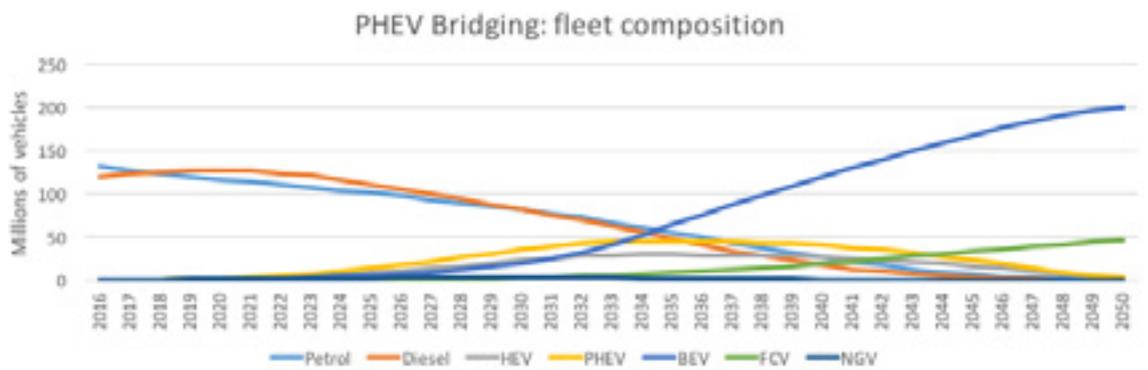


Figure 13: EU passenger car fleet composition 2016 - 2050 linked to scenario 5 PHEV Bridging (backcasting)

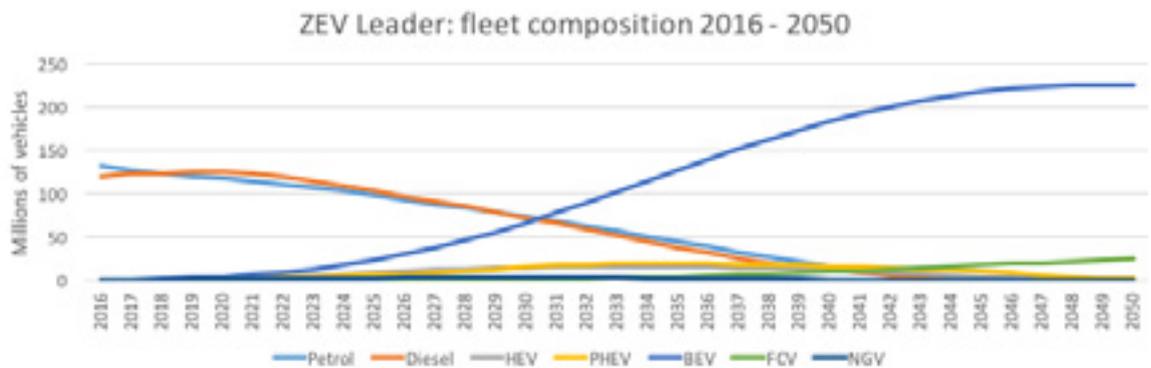


Figure 14: EU passenger car fleet composition 2016 - 2050 linked to scenario 6 ZEV Leader (backcasting)

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## 5.3 CO<sub>2</sub> emission impacts for the scenarios (2015-2050) and EU targets

In light of the Paris Agreement and the necessity to stay below a global temperature rise of 1.5°C, a so-called 'carbon budget' has been brought to life. This budget can be seen as a threshold for remaining global GHG emissions in the long-term and differs from the short- to mid-term approach as adopted under the Kyoto Protocol (Cames, Graichen, Siemons, & Cook, 2015). The Intergovernmental Panel on Climate Change (IPCC) estimated that from the Industrial Revolution onwards (with 1870 as a reference year), a global carbon threshold of 2,900 gigatonnes of CO<sub>2</sub>-equivalents would be the maximum allowable to keep to global temperature rise to 2°C, with a probability of 66%. By 2010, 1,900 gigatonnes of this budget was already 'spent', leaving 35% of the budget for all GHG emitting sectors globally. Expressing this budget into years, the 66% probability to stay below 2°C leaves roughly 20 years before this target is passed. If 1.5°C is targeted, the 'time budget' decreases to less than 5 years, indicating that if no drastic measures are taken, the carbon budget will be spent by 2021. The idea is that the more measures that are taken to bring down global GHG emissions, the more time is given before the carbon budget is spent. This indicates the need to bring down GHG emissions from every contributing sector as soon as possible.

To give an indication of the current situation, roughly 32 gigatonnes of CO<sub>2</sub> was emitted by the global energy sector in 2016, a total that is broadly in line with the totals from the two preceding years. Concerning the contribution by transport, the IPCC's 5th assessment report indicated a total of 7 gigatonnes of CO<sub>2</sub> in 2010, of which road transport represented roughly 5 gigatonnes (IPCC, 2014). Europe contributes roughly 9 percent to the absolute total of GHG emissions worldwide, with passenger cars represent nearly 12% of the EU's total emissions.

In this regard, it is important to look at the cumulative emissions of every contributing (sub)sector, as presented here for the European passenger car sector. It should be noted that, as previously demonstrated, the literature-based forecasts offer no sustainable solution towards 2050. This is different for the backcast scenarios 4 to 6, as they reduce the impact of passenger cars to zero by mid-century.

### 5.3.1 The annual CO<sub>2</sub> emissions for the different scenarios

The two figures below show the impact of the three literature based forecast scenarios and the three EAFO backcast scenarios on the CO<sub>2</sub> emissions per year. A close-up of the situation in 2020 shows that within a few years the CO<sub>2</sub> emissions already deviate from one scenario to another. The EU targets GHG reductions for the entire transport sector although there are to date no binding targets for this. The reduction targets in the charts below are the generic targets for transport. The data shows a 10% reduction compared to the 2005 level of CO<sub>2</sub> emissions by 2020; 30% by 2030; and a 60% decrease relative to the 1990 level by 2050. In reality, the emissions reduction for cars will have to go faster and deeper than those of transport as whole.

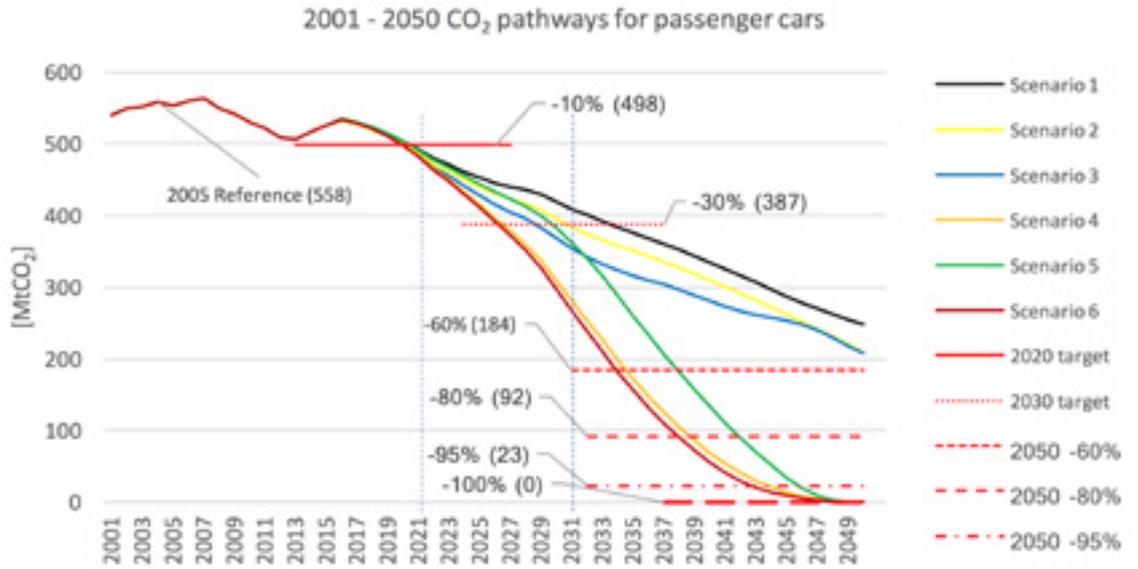


Figure 15: Overview of different targets and the impacts of the annual CO<sub>2</sub> emissions for the 6 scenarios

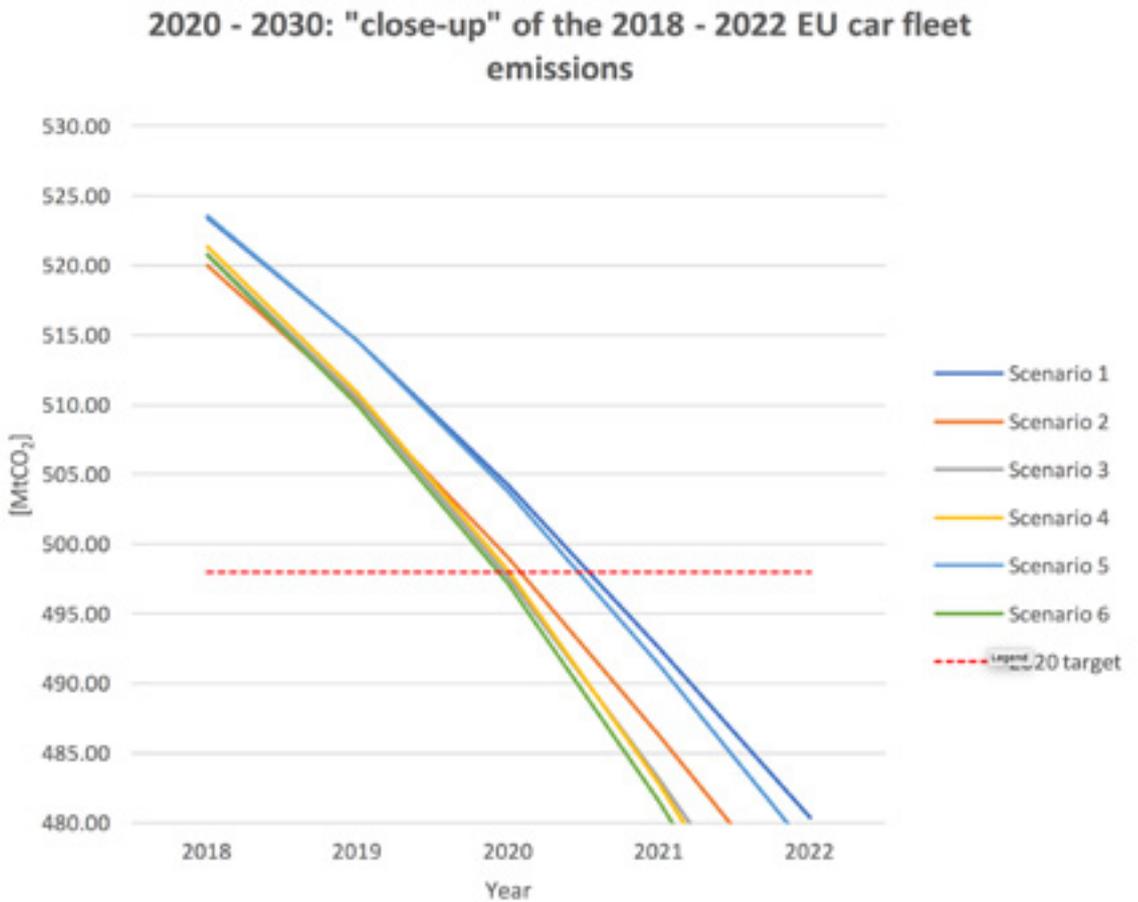


Figure 16: Details of the CO<sub>2</sub> emissions 2018 – 2022, in million tonnes CO<sub>2</sub> emissions per year for the EU car fleet. Scenario 1, 2, 3: Literature Low, Medium and High. Scenario 4: ZEV Base Case, scenario 5: PHEV Bridging, scenario 6: ZEV Leader.

### The cumulative CO<sub>2</sub> emissions for the period 2020 - 2050

The cumulative CO<sub>2</sub> emissions of the EU car fleet over the period 2020 to 2050 are modelled in the different EAFO backcast scenarios and compared to: the current EU 60% reduction target; the average value from the literature forecast scenarios; and the BAU (Business As Usual) scenario presuming no further reduction after 2020. The EAFO backcast scenarios of a transition to a ZEV car fleet in 2050 resulted in between 2.2 and 3.9 gigatonnes lower CO<sub>2</sub> emissions compared to the EU -60% policy scenario. The scenarios with a high PHEV stock resulted in the lowest CO<sub>2</sub> reduction. In addition, in the EAFO scenarios the total car fleet emissions in 2050 are zero, whereas in the EU -60% scenario the annual emissions are still 180 million tonnes in 2050. The annual and cumulative emissions data from this study are presented in table form in Annex 2.

#### Cumulative CO<sub>2</sub> emissions

##### EU car fleet 2020 - 2050

Scenario	Giga ton CO <sub>2</sub>	Giga ton CO <sub>2</sub>	Mio ton CO <sub>2</sub>
	2020 -2050	delta with EU -60%	per year in 2050
<b>BAU 2020</b>	15	-4	500
<b>MEDIUM ZEV</b>	11	-1	225
<b>EU -60%</b>	10	0	184
<b>ZEV Base case</b>	6.4	3.6	0
<b>PHEV Bridging</b>	7.8	2.2	0
<b>ZEV Leader</b>	6.1	3.9	0

Figure 17: Cumulative EU car fleet CO<sub>2</sub> emissions 2020 – 2050 and remaining annual emissions in 2050. The annual emissions in 2050 as illustrated in figure 15 are added to demonstrate that cumulative emission will continue to increase after 2050 for all but the EAFO scenarios.

## 5.4

### Conclusions from the backcasting scenarios

- Backcast scenarios resulting in a 100% ZEV fleet by 2050 require a 100% ZEV sales by 2035, assuming a similar vehicle lifetime as today.
- Backcasting the 2050 objective of having a 100% ZEV fleet requires a substantially faster introduction of ZEVs and PHEVs than current policy and predicted 2025 policy will achieve. Real Driving Emissions (RDE) targets (g/CO<sub>2</sub>/km) which are required are:
  - ZEV Base Case: 125 (2020), 86 (2025), 35 (2030)
  - PHEV Bridging: 134 (2020), 118 (2025), 86 (2030)
  - ZEV Leader: 125 (2020), 81 (2025), 23 (2030)
- The ZEV backcast scenarios result in 2.2 to 3.9 gigatonnes of CO<sub>2</sub> lower cumulative emissions over the period 2020 – 2050 than the EU -60% scenario.

## 6.0 The economics of the transition to ZEVs

### Vehicle Purchase Cost Parity: what do OEMs say?

The question around purchase price parity between BEVs and ICEVs seems to be a question of when it will happen more than if it will happen. Several statements by OEM representatives have been published recently which indicate that this may even happen within the next few years.

**Renault's** head of electric vehicles believes EVs like the ZOE will cost about same as similarly sized, conventionally-powered cars by the year 2020. Gilles Normand, senior vice-president for electric vehicles at Renault, said that sales of the firm's small EV, the ZOE, have jumped 90% between 2016 and 2017, thanks to the introduction of a larger battery capacity. And he believes that as more manufacturers and suppliers invest in battery development and manufacturing, the prices of EVs will take only a couple of years to reach the same level as ICEV cars. Speaking at the Financial Times Car of the Future Summit in London, Normand said, "We are moving faster than we expected. When we introduced the first ZOE back in 2012, we didn't think the new battery capacity would come in 2016; we expected it by 2018. "So we mustn't forget that the prices of combustion-engine cars will go up, and EV prices will come down. If you go for B-segment [cars like the

Ford Fiesta], by early next decade we consider the prices of EVs will be on par with combustion-engined cars (quote from AutoExpress, May 10th, 2017).

At a press conference in Wolfsburg, VW confirmed its intention to bet heavily on electricity. **Volkswagen** announced the real revolution is to come in 2020. That's when the new platform MEB will be launched. Especially developed for electric vehicles with an estimated range between 400 and 600 km. It will underpin four models, one of which, the I.D., will cost about the same as a Golf diesel (quote from Gopressmobility, May 8th, 2017).

In the German language "bimmertoday.de", May 8th, 2017 it was reported that BMW engineers at the Vienna Motorsymposium have stated that by 2020 BEVs will be offered at the same price as gasoline cars from the same segment.

"We see this tipping point happening around 2025. By then for the customer to buy petrol or EV it will be practically same cost," Nissan Executive Vice President Daniele Schillaci said. **"And then ... if you have the same price for EVs and petrol why would you buy traditional technology?" (Tokyo Motor Show, October 2017, Reuters 25-10-2017).**

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## 6.1 Fleet purchase costs and vehicle total cost of ownership

**The transition to a zero-emission passenger car fleet will lead to changes in costs for society as well as for the owner and user of the vehicle. To give insight in possible changes, costs were calculated at two levels:**

**A** Fleet level: Purchase costs

**B** Vehicle level: Total Cost of Ownership (TCO)

In Part A the total purchase costs of the European fleet is calculated from year to year. Assumptions were made for changes in vehicle costs over time. This gives insights into the additional costs or benefits (after the cost parity year) at a fleet level of the uptake of ZEVs. These additional costs differ from scenario to scenario.

The Vehicle TCO Model (Part B) operates on the level of a single vehicle. The total cost of ownership has been calculated for an “average” battery electric vehicle and a functionally comparable ICEV and PHEV, as a function of the year of purchase. This allows calculation of the year of purchase in which a BEV has lower lifetime running costs than its ICEV counterpart. It also shows the position of plugin hybrids in terms of operational costs. Part A and B are described in the following sections.

## 6.2 EU fleet purchase costs

### 6.2.1 Introduction

The cumulative purchase costs of all new vehicles in Europe have been calculated for each calendar year between 2016 and 2050, for three ZEV uptake scenarios. By comparing the three scenarios with a scenario without ZEVs, it can be demonstrated how ZEVs could affect Europe’s total passenger car purchase costs.

The three scenarios are the three backcasting scenarios of chapter 5: ZEV Base Case, PHEV Bridging and ZEV Leader. Each has projections for the propulsion technology share in each year’s sales (ZEV/PHEV/ICEV). For each vehicle technology the purchase costs were estimated using price development functions for glider, engine, motor and EV electronics (such a function is for instance: a 10% price drop each year until 2020). The total purchase costs are calculated by multiplying the projected sales numbers of each technology by their respective price for a calendar year. This is compared to a situation where all ZEVs would have been ICEVs, to calculate the cost difference.

The cumulative purchase costs will increase in the first years, because the prices of electric vehicles are still higher than those of ICEVs with similar function. However, due to the price decrease of EVs, a crossover point can be expected after which the cumulative purchase costs will be lower than without EV sales.

New predictions are being published almost weekly for the cost competitiveness of electric vehicles. These are issued by major consultancies, banks, OEMs or industry

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experts. They show that the purchase cost of ZEVs will become lower than ICEVs at a certain point in time. Based on a review of these forecasts it was estimated that the purchase costs of a zero-emission vehicle and a comparable ICEV will be equal somewhere between 2022 and 2026. A selection of the cost predictions and curves that substantiate this conclusion is included in the annex. The two boundary years of the predictions, 2022 and 2026, were used here as the starting points for two purchase cost scenarios.

At the time of writing this report, more optimistic forecasts and statements have been made which provides confidence that the scenarios identified are realistic. Both VW and BMW have announced earlier this year that by 2020 they will offer full electric models for the same price as similar gasoline (BMW) or diesel (VW) cars, hinting at an even earlier price parity. In addition to this, the UK, France and possibly China have announced to aim for a ZEV sales only policy around 2040 for passenger cars.

The driving force behind the swift approach towards cost parity is the rapid decrease in battery cost for electric vehicles. Both at battery cell level and battery pack level manufacturing costs have dropped rapidly. This rate of battery cost reduction has been consistently underestimated in studies in recent years.

The present analysis focuses on the impacts in the period until 2035. After 2035 it is assumed that all vehicles sold will be ZEVs, which makes the differences less relevant.

## 6.2.2

### **Assumptions for vehicle cost developments**

Cost parity of electric vehicles and ICEVs somewhere between 2022 and 2026, as foreseen by experts, seems plausible and is taken as the timeframe for the calculations. This is in part based on the assumption that the battery cost curve will continue its trend and that battery cost reductions will continue at close to their historical pace over the last 5 years.

The assumptions for the vehicle costs are provided in the table below. These are based on in-house data and fit the cost parity in 2022 and 2026 respectively. It is assumed that the cost decrease of EVs will stop 5 years after the cost parity year has been reached. This is a conservative assumption as it may be expected that the large value items of BEVs, batteries, electronics and software may continue the cost reduction curve.

## Assumptions for non-battery cost developments ICE / BEV / PHEV

For ICEV	% change in costs per year	
2017 - 2020	0.8	
> 2020	0	
<b>Scenario with BEV cost parity in 2022</b>	<b>up to 2027</b>	<b>after 2027</b>
glider	0	0
BEV specific non-battery parts	-8	0
PHEV specific non-battery parts	-7	0
<b>Scenario with BEV cost parity in 2026</b>	<b>up to 2031</b>	<b>after 2031</b>
glider	0	0
BEV specific non-battery parts	-5	0
PHEV specific non-battery parts	-4	0

Figure 18: Assumptions used to calculate the future vehicle costs for EVs and ICEVs, excluding the costs for batteries. It is assumed that the EV specific parts cost reduction will continue for 5 years after cost parity at vehicle level is reached between ICEV and EV. It is presumed that after 2020 ICE technology improvements will not be cost effective

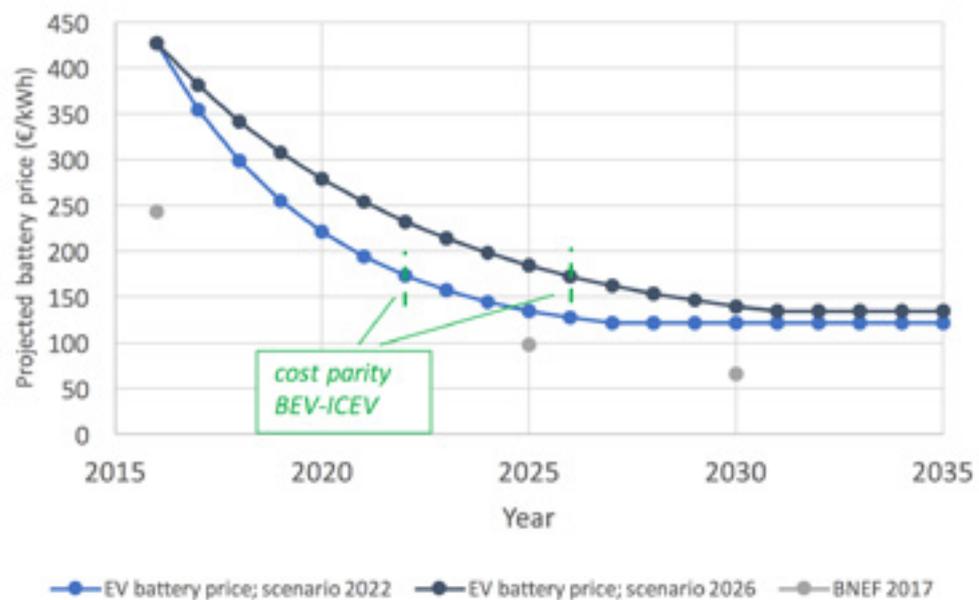


Figure 19: Projected battery price for cost parity in 2022 and 2026. In the cost model, it is assumed that 5 years after reaching price parity with ICEVs, the battery price will not reduce further. For the battery cost reduction, BNEF forecast an average cost reduction for EV batteries of 19% per year, the values are represented by the grey dots (BNEF). Cost reductions for large volume users and for BEV batteries can therefore reduce even faster in cost. This may explain why some OEMs seem more bullish on achieving cost parity than experts working with average costs for average batteries. It is assumed that EV cost reductions stop 5 years after purchase price parity is reached. Looking at recent developments, the EAFO battery cost price development is most likely too pessimistic. A battery price of € 427 per kWh for 2016 is taken.

Using the fleet purchase cost model as described above, the total purchase cost impacts of the transition from the current car fleet in Europe to a 100% ZEV fleet by 2050 has been calculated. For the three EAFO transition scenarios as discussed in

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chapter 5.2, the additional cost per year as well as the cumulative costs until 2050 are calculated. This has been carried out for the two use cases for cost parity BEV – ICEV achieving parity in 2022 and 2026 respectively. The assumption in the model is that the average battery size for BEVs is 30 kWh, and for PHEVs is 16 kWh. At the time of finalising this report these assumptions can be considered conservative compared to the real world. However, the impact of a larger average battery size like 45 or 50 kWh will not be very large in the model as the leading parameter is the price parity year 2022 or 2026. In addition, the battery cost assumption of the price in € per kWh is too conservative (too high). A large range in future battery sizes can be expected with larger cars having significantly larger batteries. A TCO sensitivity analysis is therefore made for a larger BEV battery. Returning to the main assumption that BEVs will be cost competitive with ICEVs between 2022 and 2026, the larger battery sizes will necessitate a faster battery price decrease. On the other hand, the need for higher battery capacities is partly a result of the current weak charging infrastructure and range anxiety; 30 kWh will deliver a real range of at least 200 km for small and medium sized cars.

The transition of the European car fleet can be considered as an investment towards a lower cost situation, as the vehicle cost of ZEVs is expected to become lower than that of ICEVs. The operational costs of ZEVs are already lower than those of ICEVs. The calculated benefits of the transition can be considered as societal benefits as they are not allocated to specific stakeholders.

### 6.2.3

#### **The capital requirement for the transition to ZEV fleets (purchase cost parity BEV – ICEV in 2026)**

Assuming a purchase cost parity between BEVs and ICEVs in 2026, the financial impact is given in the figures below:

- Depending on the scenario, the maximum cost per year ranges from €2 to €8 billion.
- The maximum cost per year is reached in 2023.
- The cumulative cost maximum ranges from €20 to €70 billion and is reached in the cross-over year (2026).
- The cumulative costs are €0 in 2031.
- The cumulative benefit of the transition to ZEVs would reach between €340 and €450 billion in 2050.
- The most “aggressive” transition scenario gives the highest benefit by 2050.
- The benefits per year at vehicle level decrease in the calculations as 5 years after the cost parity year is reached no further cost decrease for EVs is assumed at vehicle level.

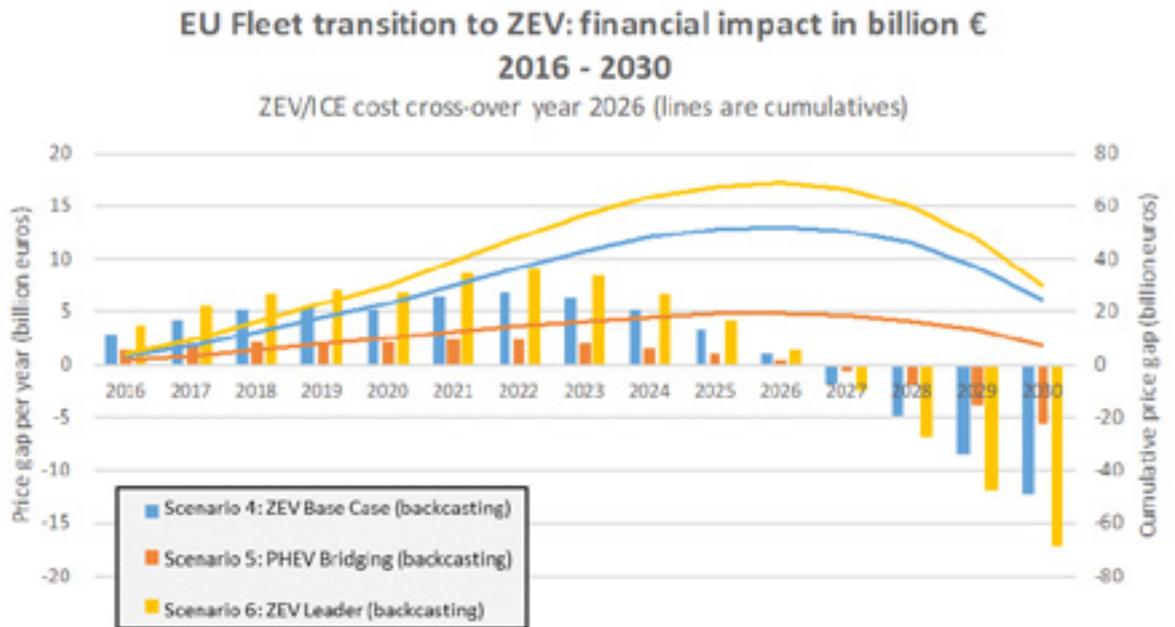


Figure 20: Financial impacts until 2030 for the transition to 100% ZEV: cost parity BEV-ICEV in 2026.

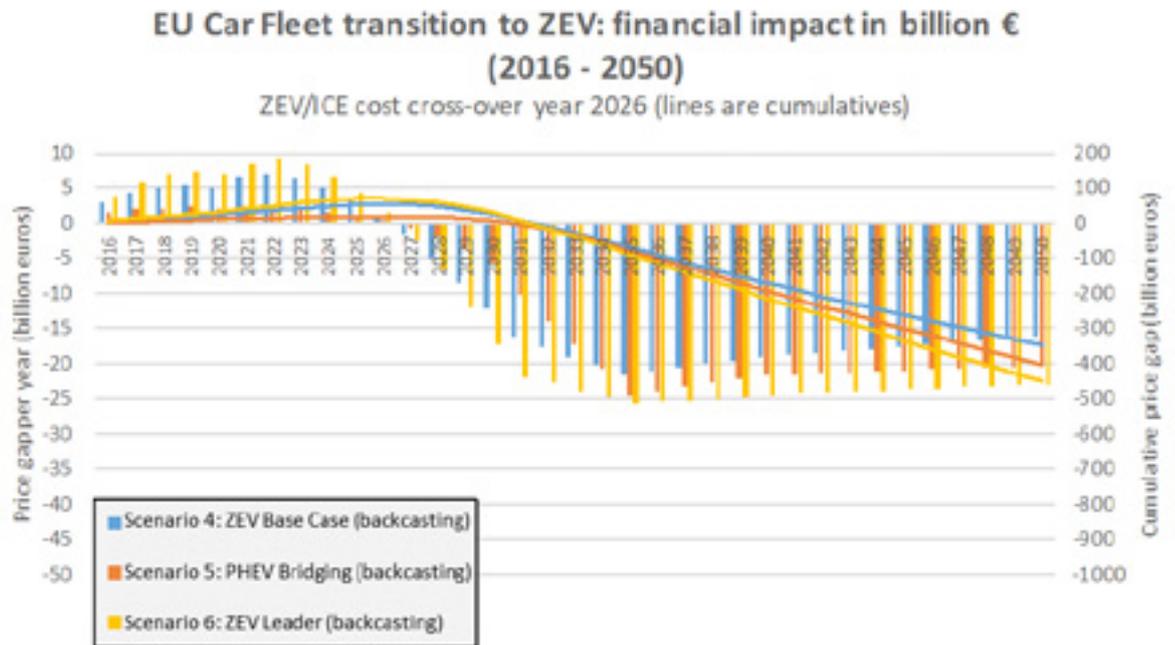


Figure 21: Financial impacts until 2050 for the transition to 100% ZEV cost parity BEV - ICEV in 2026

6.2.4

**Capital requirement for the transition to ZEV fleets  
(purchase cost parity BEV - ICEV in 2022)**

With a purchase cost parity between BEVs and ICEVs in 2022, the financial impact is given in the figures below:

- Depending on the scenario, the maximum cost per year ranges from €2 to €5 billion.
- The maximum cost per year is reached in 2018
- The cumulative cost maximum ranges from €8 to €26 billion and is reached in the cross-over year (2022).
- The cumulative costs are €0 in 2026.
- The cumulative benefit of the transition to ZEVs would reach between €600 and €800 billion in 2050.
- The most “aggressive” transition scenario gives the highest benefit by 2050.
- The benefits per year at vehicle level decrease in the calculations as 5 years after the cost parity year is reached no further cost decrease for EVs is assumed at vehicle level.

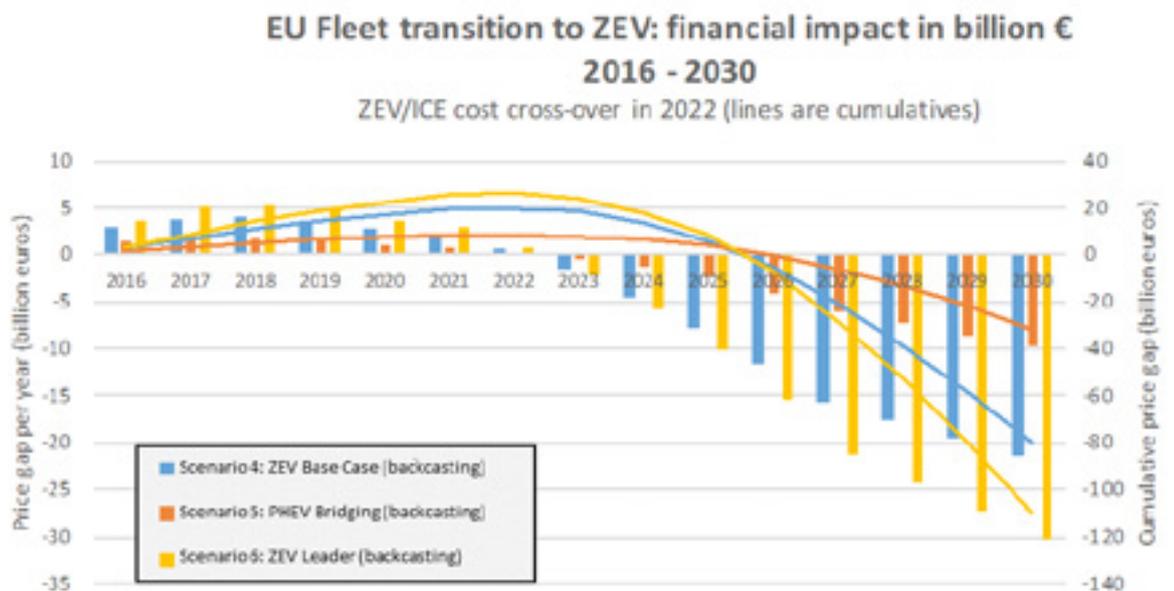


Figure 22: Financial impacts until 2030 of the transition to 100% ZEV by 2050: cost parity BEV - ICEV in 2022

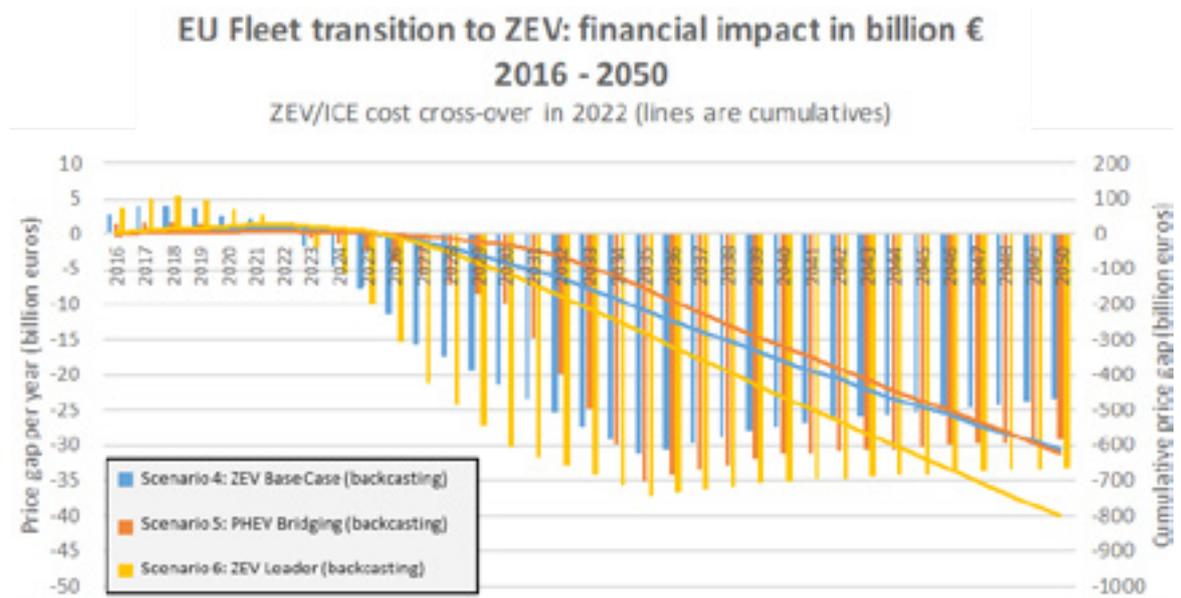


Figure 23: Financial impacts until 2050 of the transition to 100% ZEV by 2050: cost parity BEV - ICEV in 2022

## 6.3 The Total Cost of Ownership (TCO) analysis model

### 6.3.1 Introduction

The EAFO TCO model has two components: capital costs and operational costs. Capital costs represent the total commissioning costs of a vehicle, and the operational costs include costs such as fuel/electricity costs, maintenance costs, insurance and road tax. These two components form the input for the capital costs model and the TCO model.

Taxing and duties for energy carriers and / or vehicle types remain important as they will impact the total cost of ownership of the vehicles. The purpose of the analysis was primarily to look at the impact at fleet level. At vehicle level, cost parity may be achieved in slightly different years depending on the car model, specific conditions in the different EU countries, and policies to support ZEVs.

The costs have been calculated for the total fleet for each calendar year. Vehicle related information such as its purchase price and its energy consumption is combined with annually changing information, such as energy prices.

The costs are calculated for the two scenarios of cost parity (2022 and 2026) that were defined in the purchase cost model. The two scenarios demonstrate the effect of different rates of ZEV cost reductions on the TCO. The present analysis focuses mainly on the impacts over the period until 2035. After 2035 all vehicles sold are assumed to be ZEVs which implies that differences in TCO are not as relevant beyond this date.

### Assumptions for the TCO developments

In this analysis, the TCO (Total Cost of Ownership) is calculated for a vehicle sold in any given year and for different technologies.

The TCOs are presented in €/km. At fleet level in the EU with 256 million cars and an average of 14,000 km per car per year, every € and cent (difference) in TCO present a value of €36 billion per year.

For the variable costs, depreciation, and cost of capital, the main assumptions are in Figure 23. The category 'ICEV' is the total of petrol, diesel, natural gas and hybrid vehicles. For the diesel/petrol ratio Scenario 2 from the literature review is used, with a share of 45% petrol in 2016 increasing towards 2030, as well as increasing numbers of hybrid cars. The vehicle cost is taken from the fleet analysis. For the calculation of depreciation, a relatively high depreciation rate is taken for the first four years, and a lower depreciation rate for the subsequent 11 years to fulfil the assumed average economic lifespan of 15 years. The average lifespan of the European fleet is higher, but it is assumed that few kilometres are driven in the last few years of a vehicle's life. Old/classic cars are kept out of the present analysis. If a zero-emission fleet is to be reached in 2050 without exception or exemption, old/classic cars on the road will need to be modified to use biofuels or be scrapped in special schemes.

The fuel costs are based on today's costs. An estimated change in electricity prices based on an extrapolation of the increases seen over the last 10 years (Eurostat data) is used. For ICEV fuel costs (per litre) it is assumed that these will remain stable at the 2016 price level (partly because price levels have fluctuated too much in recent years to make a robust projection). Compared to the average over the last 10 years, fuel in 2016 was relatively cheap. A possible reduction or elimination in diesel fuel subsidies (such as tax breaks), currently around 15 to 20 cents (euro) per litre compared to petrol, was not assumed. In the sensitivity analysis the impacts of changing fuel cost, financing costs and fuel efficiency improvements are assessed. The other costs are estimated to remain at today's value and do not fluctuate in the model. In future projects, it would be of interest to conduct a sensitivity analysis for, among other things, a possible shift away from diesel cars and for variations from country to country.

## Variable cost assumptions TCO model

	value	unit
<b>Vehicle use</b>	14,000	km per year
<b>Electric drive PHEV</b>	30%	of km driven
<b>Fuel costs and efficiency</b>		
Petrol price 2016	1.29	€ per litre
Diesel price 2016	1.12	€ per litre
Petrol / diesel price increase	0%	
Electricity price 2016	0.22	€ per kWh
Annual electricity price increase	0.0073	€ per kWh
Fuel efficiency improvement ICEV 2016-2020	15%	
Fuel efficiency improvement ICEV after 2020	0.0%	
Fuel efficiency improvement BEV	1.5%	
<b>Other variable costs</b>		
Maintenance costs ICEV/PHEV	0.026	€ per km
Maintenance costs BEV	0.014	€ per km
Road tax ICEV/PHEV	300	€ per year
Road tax BEV	150	€ per year
Insurance costs	303	€ per year
<b>Financial costs and depreciation</b>		
Cost of capital (interest)	8%	per year
Economic vehicle life time	15	year
Depreciation year 1 - 4	65%	4 years
Depreciation year 5 - 15	35%	11 years

Figure 24: Variable vehicle costs, depreciation and cost of capital for ICEVs and EVs

The literature review identified several studies predicting parity in cost of ownership. As the variable costs such as fuel, maintenance and (often) taxes are lower for ZEVs, the cost of ownership parity will be reached earlier than purchase cost parity. According to in-house data TCO parity for the average use case (14,000 km per year) is reached about 3 to 5 years before vehicle cost parity is reached. For specific use cases, like taxis, cost parity can be reached even earlier and may already have been reached by the time of writing.

For maintenance costs, it is still difficult to confidently estimate how much lower these are as reliable information is scarce. In the EAFO analyses a conservative estimate was used.

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In their report “Evidence Lab Electric Car Teardown” the bank UBS reported a 60% lower maintenance cost for the Chevrolet Bolt compared to a VW Golf. Over a 15-year vehicle lifetime, this would result in around € 5,000 lower maintenance costs. The most important factor in this difference is the very low number of moving and wearing parts in the EV powertrain, the lack of need to use lubrication oils, and lower use of the brake-pads.

### **The growing relevance of Total Cost of Ownership for cars**

People in Europe used to own the vehicle they use, however drivers now increasingly just want to use the car. The car is then leased or financed in a different way with the ownership in the hand of the financing company. Often this includes maintenance, insurance and other services. This form of car use can be considered as a form of MaaS, Mobility as a Service. Financing a car becomes cheaper as interest rates in Europe are at historic lows. These MaaS constructions

where the driver pays a monthly fee make the use of ZEVs more attractive, as the higher purchase costs do not have to be paid at once, while the operational costs are lower than for ICEVs. With this trend continued, the shift to ZEVs might happen earlier than expected as the TCO parity between ZEV and ICEV will occur earlier than the purchase price parity. This is comparable to the costs situation between gasoline and diesel vehicles on the European market: diesel cars are more expensive to buy, but cheaper to use with the incentivised diesel price in Europe.

### 6.3.3

#### **TCO comparisons over the total vehicle life and the first 4 years**

Figure 25 shows the TCO over the entire life span of a vehicle, for the 2026 cost parity scenario. Figure 26 shows the TCO for the first four years (65% depreciation). Assuming cost-parity at vehicle level in 2026, the TCO over the total economic lifetime of 15 years of the vehicle will reach break-even with ICEVs in 2020. The TCO for a PHEV will remain higher than that of an ICEV as it bears the cost of both technologies while the fuel cost advantage is relatively low. Our data [Ligterink, 2016] shows that PHEVs on average drive 30% of their kilometres on the battery. The TCO of PHEVs will improve when the electric kilometres driven, both as a percentage and in absolute terms, increases significantly. The fact that the TCO break-even is 6 years earlier than the vehicle cost parity indicates a large potential for a successful introduction of BEVs where TCO is an important factor in the purchase decision.

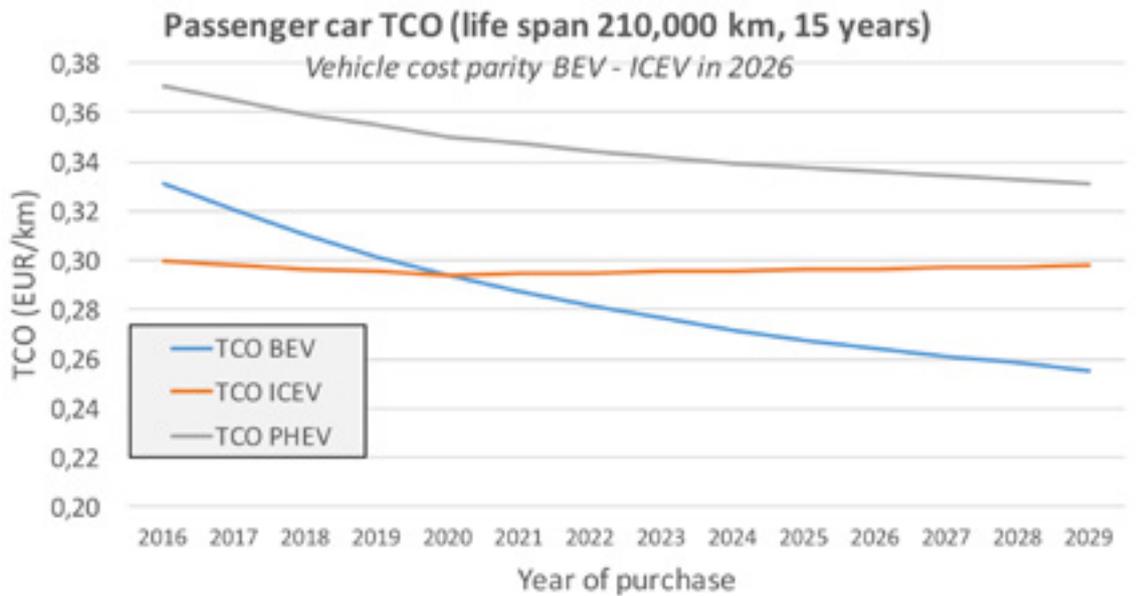


Figure 25: TCO comparison ICEV - PHEV - BEV achieving cost parity at vehicle level in 2026

Many new cars are financed through leasing or other financing contracts, referred to as company cars or leased cars. A typical period for this contract is four years with a relatively high depreciation in that period. In the TCO model a 65% depreciation in this period is used. The result of this is that the TCO break-even year will be later, but still two to three years before the cost parity at vehicle level (Figure 26).

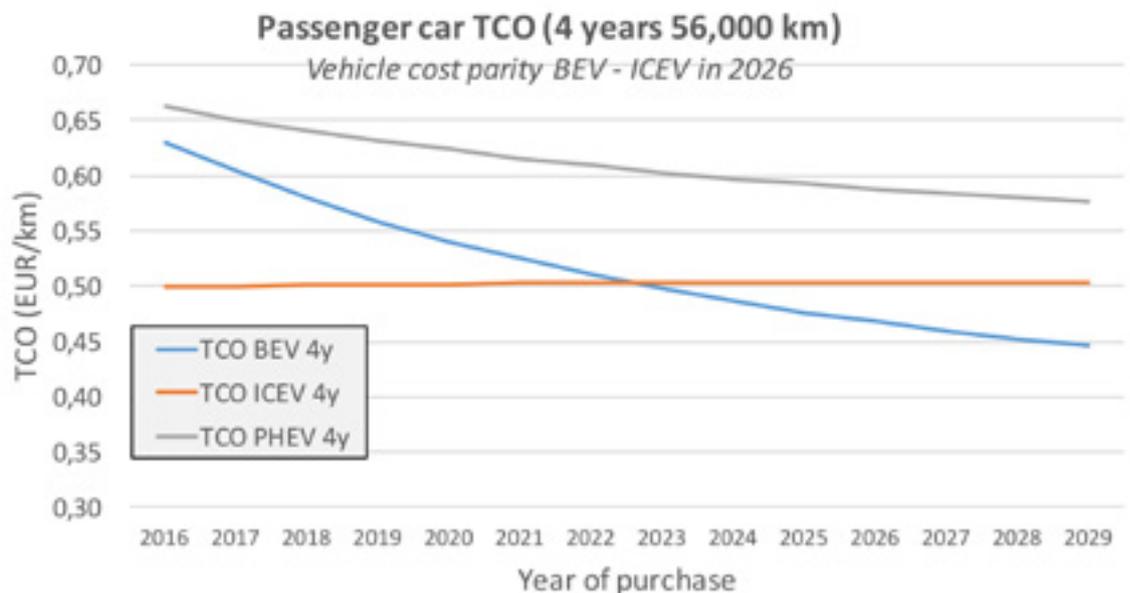


Figure 26: TCO calculation for the first 4 years of a vehicle, depreciation 65%

Figure 27 shows the TCO over the entire life span of a vehicle, for the 2022 cost parity scenario. Figure 28 shows the TCO for the first four years (65% depreciation). With a vehicle cost parity in 2022, BEVs are expected to be cost competitive at the

end of this decade. This demonstrates the importance for policy makers to have up to date data available; a transition driven by economics could already be a reality within a few years. The analysis is based on the average annual mileage for (petrol) cars in Europe of 14,000 km. For new cars and especially the company or leased cars the yearly distances travelled are often much higher. This makes a TCO more attractive, or alternatively a larger battery can be financed while maintaining the economic advantage of the ZEV of the ICEV.

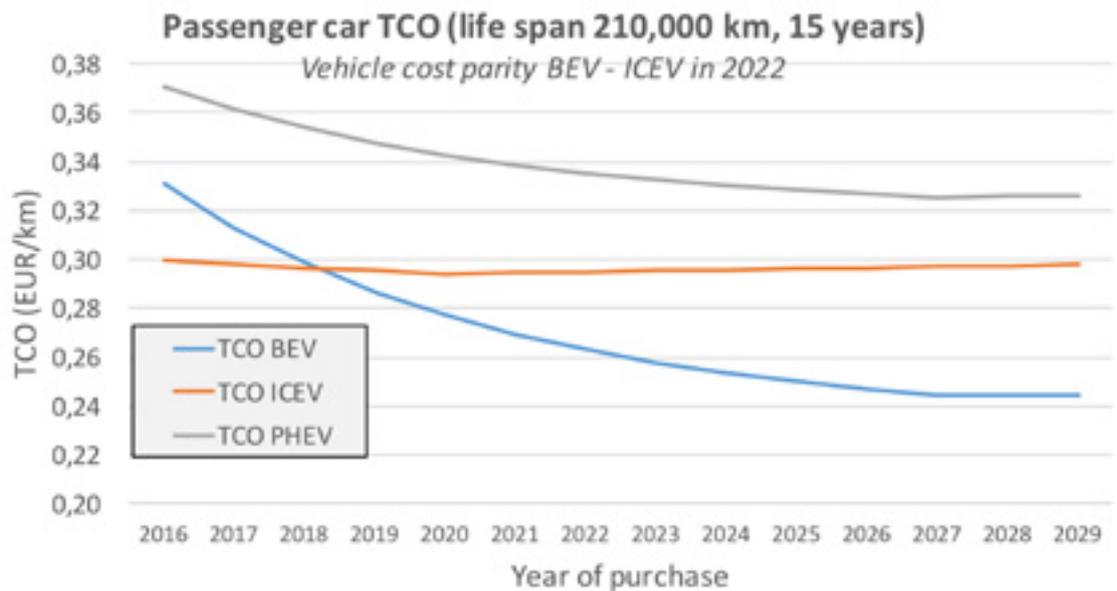


Figure 27: TCO calculation for a vehicle cost parity in 2022

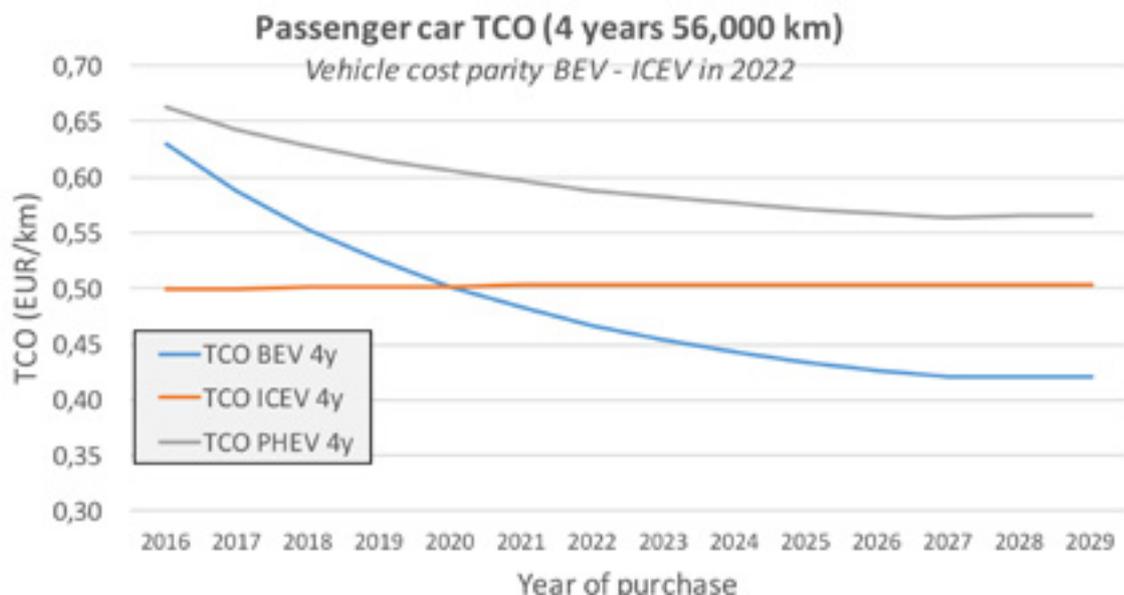


Figure 28: TCO calculation for the first 4 years, cost parity in 2022, depreciation 65%

### Impact of battery size and distance travelled per year on the TCO

The table below illustrates the effect on the total cost of ownership of:

- 50% larger and thus more expensive battery
- 50% higher annual mileage

This was carried out for vehicle cost parity in 2026. The main analysis undertaken is for the use case of four years for which higher distances are more common. The higher annual distance over the entire vehicle lifetime surpasses the average economic life span of an ICEV, but is included in the table to demonstrate the low-cost potential of BEVs when used more intensively.

#### TCO sensitivities:

#### Impact of battery capacity, annual distance driven, and TCO period

##### Vehicle purchase cost parity in 2026

##### Scenarios (deviations from base case in bold)

TCO period	year	15	15	15	4	4	4	4
TCO distance	1 000' km	210	210	<b>315</b>	56	56	<b>84</b>	<b>84</b>
Battery capacity	kWh	30	<b>45</b>	<b>45</b>	30	<b>45</b>	30	<b>45</b>

##### TCO parity year and cost per km

TCO break-even year								
BEV/ICEV		2020	2023	2023	2022	2026	2022	2026
TCO in break-even year	€/km	0.29	0.29	0.20	0.50	0.48	0.34	0.33

Figure 29: Impact of period, distance and battery capacity on TCO break-even year and level. In the shaded area the data which deviate from the base case are marked. As can be seen, increasing the battery size delays the TCO break-even year but increased use of the vehicle advances the TCO break-even year.

The analysis identifies the year the TCO for the BEV is the same as for the ICEV. Longer distances travelled result in a lower TCO but do not change the year in which parity is reached. Higher BEV vehicle cost (due to larger batteries) results in a delay in TCO cost parity of three to four years. Details of the TCOs for the scenarios are presented in Figure 30 up to Figure 35.

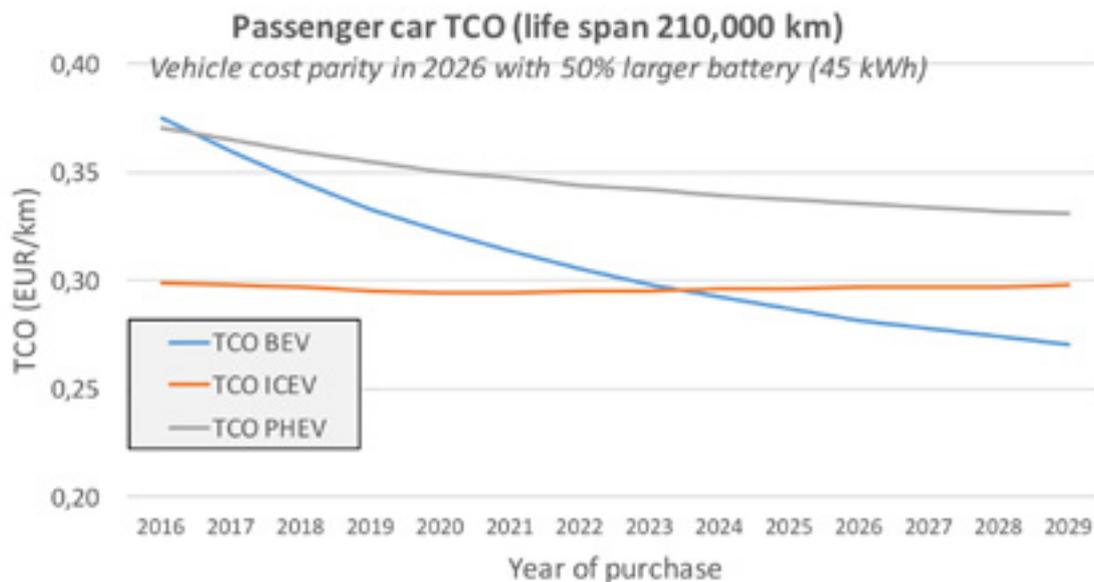


Figure 30: TCO: 15-year, 210 000 km, 2026 cost parity BEV-ICEV, 45 kWh battery pack

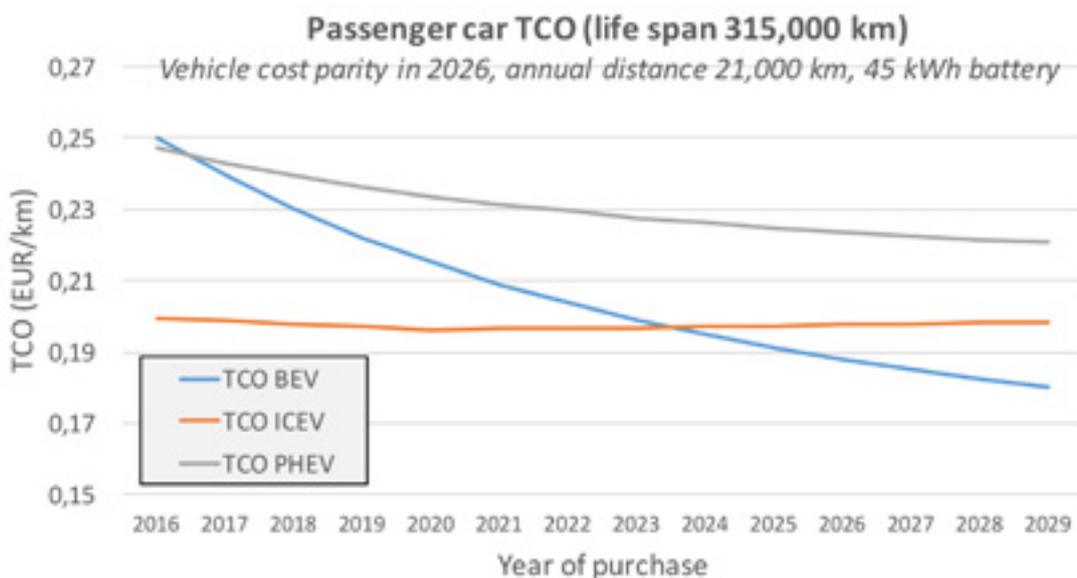


Figure 31: TCO: 15-year, 315 000 km, 2026 cost parity BEV-ICEV, 45 kWh battery pack

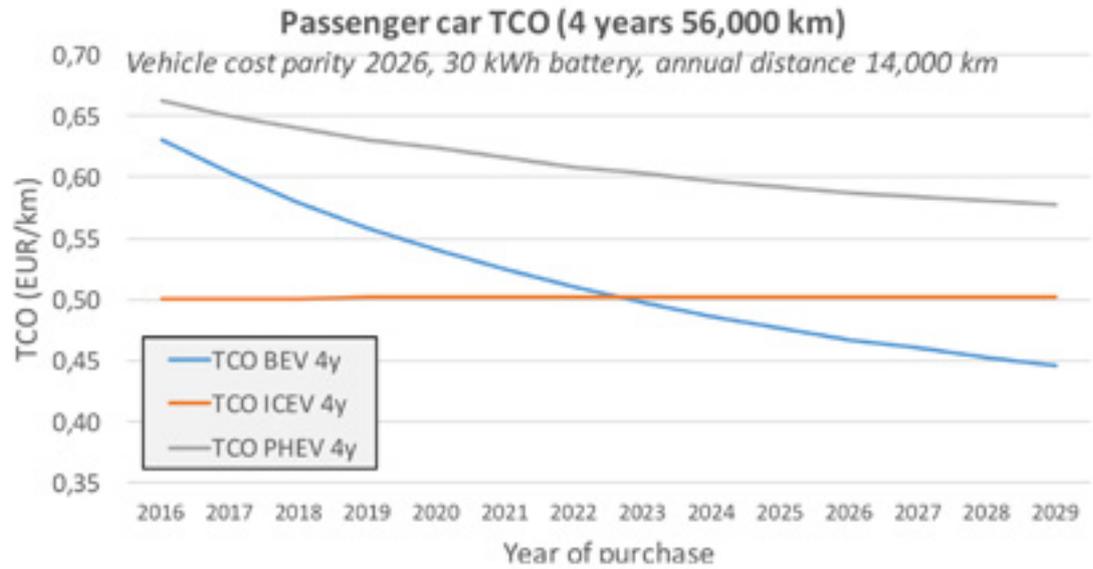


Figure 32: TCO : 4-year, 56 000 km, 2026 cost parity BEV-ICEV, 30 kWh battery pack

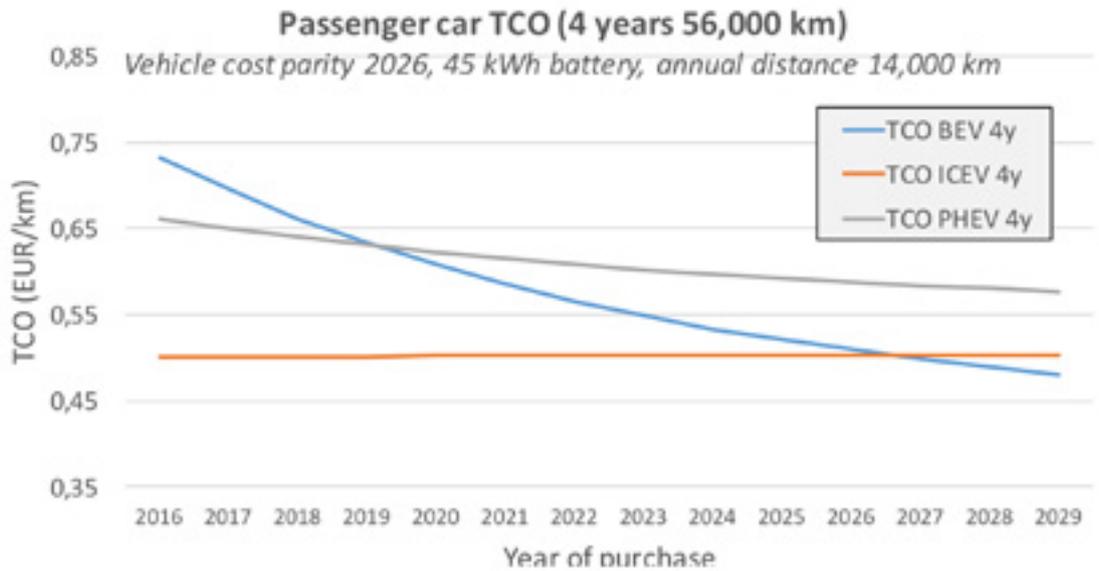


Figure 33: TCO: 4-year, 56 000 km, 2026 cost parity BEV-ICEV, 45 kWh battery pack

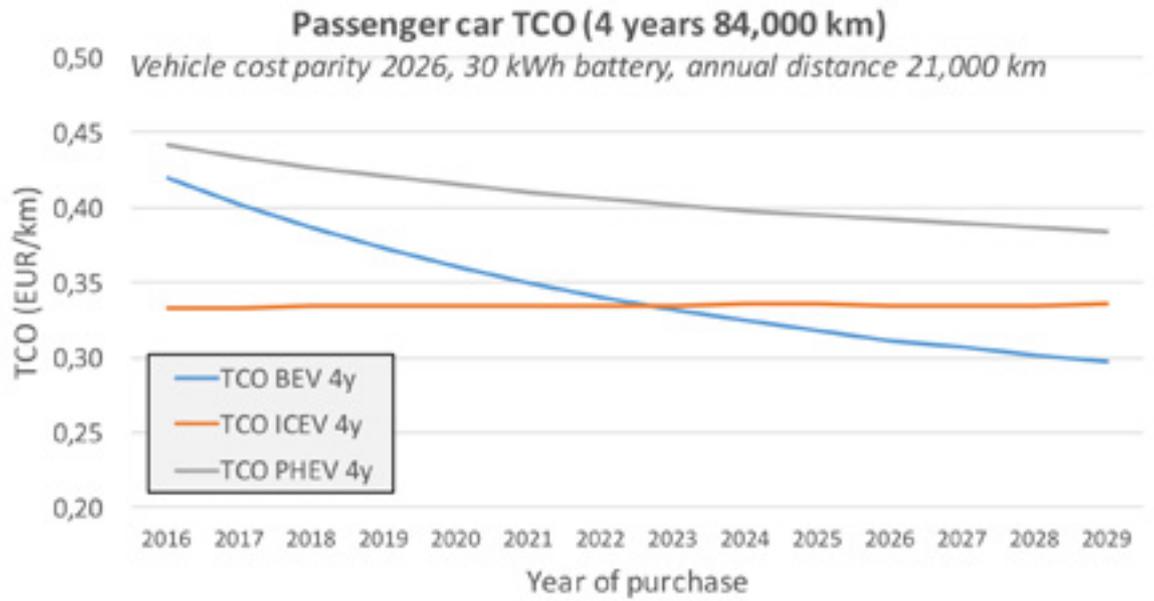


Figure 34: TCO: 4-year, 84 000 km, 2026 cost parity BEV-ICEV, 30 kWh battery pack

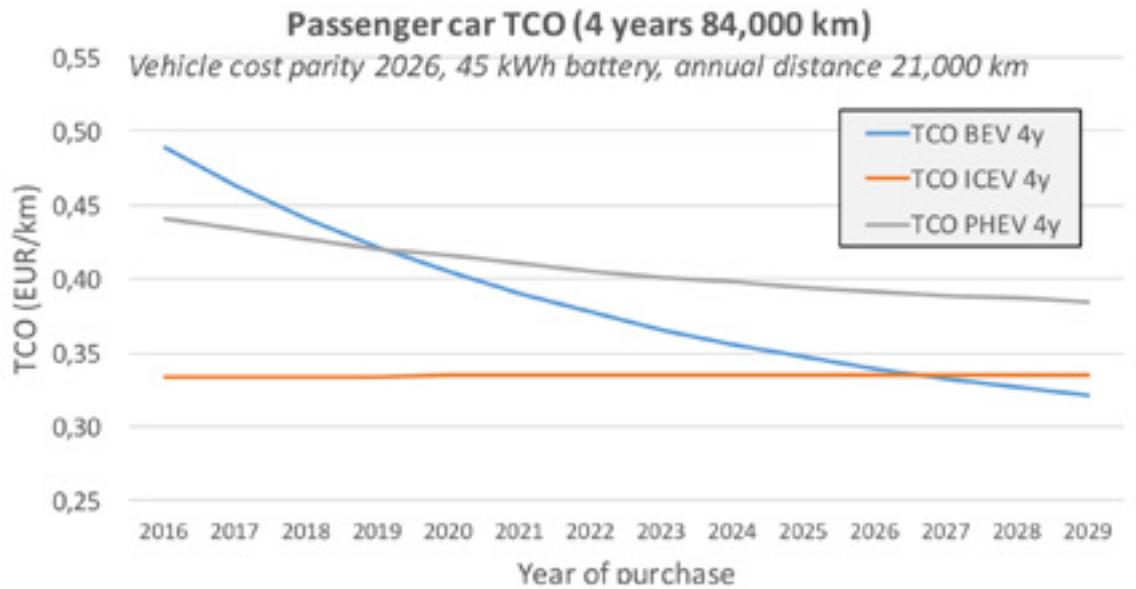


Figure 35: TCO: 4-year, 84 000 km, 2026 cost parity BEV-ICEV, 45 kWh battery pack

### Impact of model parameters on the TCO

The TCO calculations are dependent on the starting points behind the calculation model. Three important parameters are varied during the analysis to assess their influence and provide insight in the mechanisms. The variables selected are those which can often be influenced by policymakers.

The parameters are:

1. The cost of capital
2. The fuel efficiency development of internal combustion engines after 2020
3. Fuel prices

The analysis has been carried out for the TCO over the total vehicle life time as well as over the first four years of the vehicle.

The results are displayed in Figure 36 (life span) and Figure 37 (first four years).

The variable costs of BEVs are lower than those of ICEVs. This remains the case with the introduction of the three additional variables. This implies that changing fuel costs or efficiencies within a realistic range will not change the longer-term impacts. It may however advance or delay the TCO parity between BEV and ICEV for one or two years.

The cost of capital in the base case is 8%. Compared to current borrowing costs this is very high as financing of cars can be currently arranged at a capital cost of a few percent in most European countries. A reduced cost of capital will positively influence the situation for BEVs as the share of capital costs in the TCO is larger for these vehicles. On the other hand, rapidly increasing battery capacities require a higher capital cost for the vehicle.

Energy costs are very difficult to predict, especially for fossil fuel based fuels. In the base case it is assumed that the ICEV fuels do not increase in cost whereas electricity does increase in cost.

**TCO (€/km) and TCO cost parity (BEV-ICEV) year sensitivities: over 15 year vehicle life-span (210.000 km)**  
*Impact of capital cost, fuel cost/efficiency and year of vehicle cost parity (2022/2026)*

Cost of capital 8%					Cost of capital 4%					Cost of capital 0%				
Scenario: base case					Scenario: 4% capital cost (+50% of base case)					Scenario: no capital cost				
	2022		2026			2022		2026			2022		2026	
	BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV
TCO 2016	0,33	0,29	0,33	0,29	TCO 2016	0,30	0,27	0,30	0,27	TCO 2016	0,26	0,25	0,26	0,25
TCO 2025	0,25	0,29	0,27	0,29	TCO 2025	0,23	0,27	0,24	0,27	TCO 2025	0,21	0,24	0,22	0,24
TCO 2030	0,25	0,29	0,25	0,29	TCO 2030	0,22	0,27	0,23	0,27	TCO 2030	0,20	0,25	0,21	0,25
TCO 2035	0,25	0,29	0,26	0,29	TCO 2035	0,23	0,27	0,23	0,27	TCO 2035	0,21	0,25	0,21	0,25
Crossover year	2019		2021		Crossover year	2019		2021		Crossover year	2018		2019	
Scenario: ICE fuel cost +2% per year					Scenario: ICE fuel cost +2% per year					Scenario: ICE fuel cost +2% per year				
	2022		2026			2022		2026			2022		2026	
	BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV
TCO 2016	0,33	0,31	0,33	0,31	TCO 2016	0,30	0,28	0,30	0,28	TCO 2016	0,26	0,26	0,26	0,26
TCO 2025	0,25	0,32	0,27	0,32	TCO 2025	0,23	0,29	0,24	0,29	TCO 2025	0,21	0,27	0,22	0,27
TCO 2030	0,25	0,33	0,25	0,33	TCO 2030	0,22	0,31	0,23	0,31	TCO 2030	0,20	0,28	0,21	0,28
TCO 2035	0,25	0,34	0,26	0,34	TCO 2035	0,23	0,32	0,23	0,32	TCO 2035	0,21	0,30	0,21	0,30
Crossover year	2018		2019		Crossover year	2017		2018		Crossover year	2017		2017	
Scenario: ICE fuel efficiency +1.5% after 2020					Scenario: ICE fuel efficiency +1.5% after 2020					Scenario: ICE fuel efficiency +1.5% after 2020				
	2022		2026			2022		2026			2022		2026	
	BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV
TCO 2016	0,33	0,29	0,33	0,29	TCO 2016	0,30	0,27	0,30	0,27	TCO 2016	0,26	0,25	0,26	0,25
TCO 2025	0,25	0,29	0,27	0,29	TCO 2025	0,23	0,26	0,24	0,26	TCO 2025	0,21	0,24	0,22	0,24
TCO 2030	0,25	0,28	0,25	0,28	TCO 2030	0,22	0,26	0,23	0,26	TCO 2030	0,20	0,23	0,21	0,23
TCO 2035	0,25	0,28	0,26	0,28	TCO 2035	0,23	0,25	0,23	0,25	TCO 2035	0,21	0,23	0,21	0,23
Crossover year	2019		2021		Crossover year	2019		2021		Crossover year	2018		2019	
Scenario: no increase in electricity price					Scenario: no increase in electricity price					Scenario: no increase in electricity price				
	2022		2026			2022		2026			2022		2026	
	BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV		BEV	ICEV	BEV	ICEV
TCO 2016	0,33	0,29	0,33	0,29	TCO 2016	0,30	0,27	0,30	0,27	TCO 2016	0,26	0,25	0,26	0,25
TCO 2025	0,26	0,29	0,28	0,29	TCO 2025	0,24	0,27	0,25	0,27	TCO 2025	0,22	0,24	0,23	0,24
TCO 2030	0,26	0,29	0,27	0,29	TCO 2030	0,24	0,27	0,25	0,27	TCO 2030	0,22	0,25	0,23	0,25
TCO 2035	0,27	0,29	0,28	0,29	TCO 2035	0,25	0,27	0,25	0,27	TCO 2035	0,23	0,25	0,23	0,25
Crossover year	2020		2022		Crossover year	2019		2022		Crossover year	2018		2021	

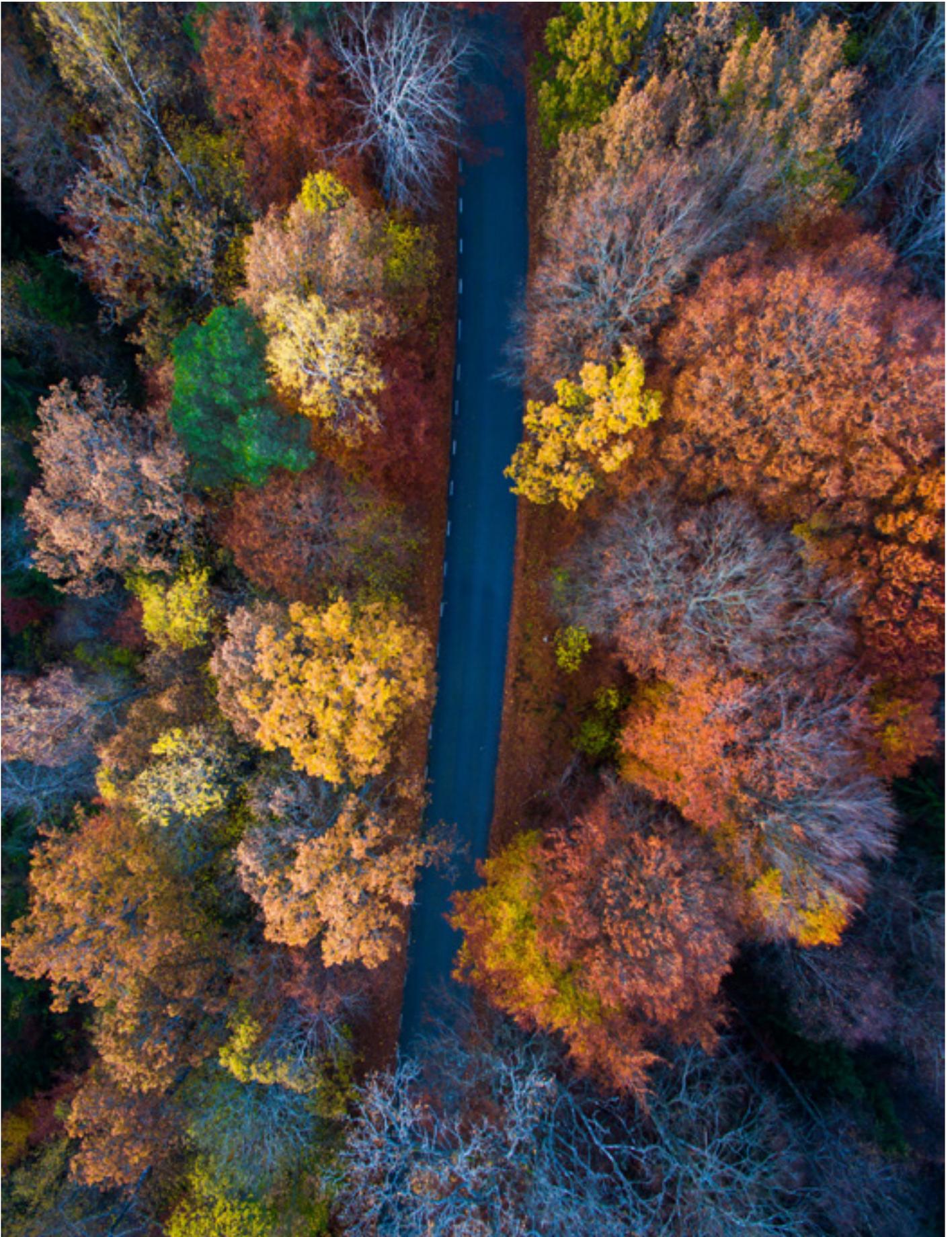
Figure 36: Sensitivity analyses of life-time TCO of BEVs and ICEVs

**TCO (€/km) and TCO cost parity (BEV-ICEV) year sensitivities: over first 4 years (56.000 km)**  
*Impact of capital cost, fuel cost/efficiency and year of vehicle cost parity (2022/2026)*

Cost of capital 8%						Cost of capital 4%						Cost of capital 0%					
Scenario: base case						Scenario: 4% capital cost (-50% of base case)						Scenario: no capital cost					
		2022		2026				2022		2026				2022		2026	
TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV
TCO 2016	0.63	0.49	0.63	0.49	TCO 2016	0.56	0.45	0.56	0.45	TCO 2016	0.48	0.40	0.48	0.40	TCO 2016	0.48	0.40
TCO 2025	0.43	0.50	0.48	0.50	TCO 2025	0.39	0.45	0.42	0.45	TCO 2025	0.34	0.40	0.37	0.40	TCO 2025	0.34	0.37
TCO 2030	0.42	0.50	0.44	0.50	TCO 2030	0.38	0.45	0.39	0.45	TCO 2030	0.33	0.40	0.35	0.40	TCO 2030	0.33	0.35
TCO 2035	0.43	0.50	0.44	0.50	TCO 2035	0.38	0.45	0.39	0.45	TCO 2035	0.34	0.40	0.35	0.40	TCO 2035	0.34	0.35
Crossover year	2021		2024		Crossover year	2020		2023		Crossover year	2020		2023		Crossover year	2020	
Scenario: ICE fuel cost +2% per year						Scenario: ICE fuel cost +2% per year						Scenario: ICE fuel cost +2% per year					
TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV
TCO 2016	0.63	0.50	0.63	0.50	TCO 2016	0.56	0.45	0.56	0.45	TCO 2016	0.48	0.40	0.48	0.40	TCO 2016	0.48	0.40
TCO 2025	0.43	0.51	0.48	0.51	TCO 2025	0.39	0.46	0.42	0.46	TCO 2025	0.34	0.41	0.37	0.41	TCO 2025	0.34	0.37
TCO 2030	0.42	0.52	0.44	0.52	TCO 2030	0.38	0.47	0.39	0.47	TCO 2030	0.33	0.42	0.35	0.42	TCO 2030	0.33	0.35
TCO 2035	0.43	0.54	0.44	0.54	TCO 2035	0.38	0.49	0.39	0.49	TCO 2035	0.34	0.44	0.35	0.44	TCO 2035	0.34	0.35
Crossover year	2020		2023		Crossover year	2020		2022		Crossover year	2020		2022		Crossover year	2020	
Scenario: ICE fuel efficiency +1.5% after 2020						Scenario: ICE fuel efficiency +1.5% after 2020						Scenario: ICE fuel efficiency +1.5% after 2020					
TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV
TCO 2016	0.63	0.49	0.63	0.49	TCO 2016	0.56	0.45	0.56	0.45	TCO 2016	0.48	0.40	0.48	0.40	TCO 2016	0.48	0.40
TCO 2025	0.43	0.49	0.48	0.49	TCO 2025	0.39	0.44	0.42	0.44	TCO 2025	0.34	0.39	0.37	0.39	TCO 2025	0.34	0.37
TCO 2030	0.42	0.49	0.44	0.49	TCO 2030	0.38	0.44	0.39	0.44	TCO 2030	0.33	0.39	0.35	0.39	TCO 2030	0.33	0.35
TCO 2035	0.43	0.49	0.44	0.49	TCO 2035	0.38	0.44	0.39	0.44	TCO 2035	0.34	0.39	0.35	0.39	TCO 2035	0.34	0.35
Crossover year	2021		2024		Crossover year	2020		2023		Crossover year	2020		2023		Crossover year	2020	
Scenario: no increase in electricity price						Scenario: no increase in electricity price						Scenario: no increase in electricity price					
TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV	BEV	ICEV	TCO	BEV	ICEV
TCO 2016	0.63	0.49	0.63	0.49	TCO 2016	0.56	0.45	0.56	0.45	TCO 2016	0.48	0.40	0.48	0.40	TCO 2016	0.48	0.40
TCO 2025	0.44	0.50	0.49	0.50	TCO 2025	0.40	0.45	0.43	0.45	TCO 2025	0.35	0.40	0.38	0.40	TCO 2025	0.35	0.38
TCO 2030	0.44	0.50	0.46	0.50	TCO 2030	0.39	0.45	0.43	0.45	TCO 2030	0.35	0.40	0.36	0.40	TCO 2030	0.35	0.36
TCO 2035	0.44	0.50	0.46	0.50	TCO 2035	0.40	0.45	0.43	0.45	TCO 2035	0.36	0.40	0.37	0.40	TCO 2035	0.36	0.37
Crossover year	2021		2024		Crossover year	2021		2023		Crossover year	2020		2023		Crossover year	2020	

Figure 37: Sensitivity analyses of the first 4 years of the TCO of BEVs and ICEVs

- The literature review identified that expert views developed over the past year have varied in their expectation of when price parity between ICEVs and BEVs will occur, but that it will be sometime between 2020 and 2028. Several OEMs have stated examples of price parity for some new models in 2020, while financial institutions expect a point between 2022 and 2026, and expert consultants are slightly more conservative.
- Based on the lower operational costs of ZEVs (BEVs), the TCO parity year always comes before the purchase price parity year, typically by 2 to 6 years. In many cases this TCO parity will happen within the next few years. The TCO advantage is expected to reach 4 to 6 € cents per kilometre, resulting in a (societal) cost advantage of € 140 to € 210 billion per year comparing a ZEV fleet with an ICEV car fleet.
- At a vehicle cost price parity in 2026, the cumulative additional costs required for the introduction of ZEVs reaches a maximum of € 20 to € 70 billion in 2026, depending on the transition scenario. The maximum annual additional cost is reached in 2023. Beyond 2026, the transition pathways have a cost advantage over the BAU scenario and the cost break-even is reached in 2031. A net present value of the transition is not calculated as the boundary conditions were not defined. For the price parity year 2022, a maximum of € 25 billion additional cost for the transition is reached in the ZEV Leader scenario in 2022 and the cost break-even is reached in 2026.
- The TCO reaches parity between BEV and ICEV in 2020 for the ZEV with a price parity in 2026 when looking at the 15-year economic lifetime of the vehicle. When looking at the first 4 years TCO and with the 65% depreciation in that period, TCO parity is reached in 2022. For the TCO of the vehicle with price parity in 2022, TCO parity is reached in 2018 (15-years) or 2020 (4-years). In all cases, the TCO advantage in the vehicle price parity year is 3 € cents per kilometre or € 400 per year.
- A sensitivity analysis of the different TCO scenarios shows that parity years may shift a few years but that the overall picture does not change. The Fleet Purchase Cost and TCO models can be very useful tools for policymakers to gain insights into the costs and benefits of the transition and of specific measures taken.
- Given that: 1) the base case assumption by stakeholders appears to be or to become that BEVs will become lower in cost than ICEVs in the next decade; 2) the TCO of BEVs is always lower than that of ICEVs; it is highly recommended that base case scenarios are prepared for a rapid transition starting within the next decade. In addition, as BEVs have superior driving performance characteristics and people used to driving electric do not return to ICEVs, the transition may become demand driven once the price, range and infrastructure barriers have been removed.



## 7.0 Impacts of a transition to ZEV car fleet on the EU transport policy drivers

It is beyond the scope of this report to make an extensive assessment of the economic impacts of a complete transition of the car fleet in the EU to ZEVs. The impacts directly related to the purchase and the use of the vehicles are described in section 6.4 and show a clear financial benefit. However, the transition will also indirectly impact the EU economy and in a larger sense EU society. In this section, several of these expected impacts will be discussed in a mainly qualitative manner.

The EU has defined its main policy drivers related to transport.



**Main problems to fix (Policy Drivers)**

- 1) Energy supply at risk**  
Oil accounts for 94% of transport fuels, causing an enormous EU import bill of up to one billion Euros a day.
- 2) GHG emissions reduction necessary**  
According to the White Paper on Transport 2011, the sector has to reduce 60 % of its CO2 emissions by 2050 (benchmark 1990).
- 3) Air quality and congested infrastructure**  
New and clean forms of mobility need to be established.
- 4) Competitiveness of EU industry**  
Growth and jobs can be created by restoring world leadership of the EU transport industry.

Figure 38: EU Policy drivers related to transport

### 7.1 Energy supply at risk: Impact on oil consumption and energy efficiency

The transition of cars to ZEVs using electric drive helps to achieve a number of EU strategic goals at the same time. Electric drive is much more energy efficient, and uses electricity which is targeted to become carbon neutral by 2050, with the majority from renewable sources. As it eliminates the use of oil products as a direct energy source, it reduces the consumption and therefore the import of oil. ZEVs also improve the air quality in cities.

### 7.1.1

## Impact of the transition to a ZEV passenger car fleet on oil consumption and import

Eurostat provides data for oil trade and consumption for the EU. In 2015, the EU had an oil consumption of around 430 million TOE (Tonnes of Oil Equivalent). One TOE is around 7.3 barrels of oil (OPEC). The oil consumption in transport was 336 million TOE in the EU in 2015 or close to 80% of all oil consumption in the EU. In the EAFO model, the energy requirement calculation (see next section) translates into an oil use of 238 million TOE for cars or 70% of the total EU transport oil consumption. This is excluding refinery and other losses. The transition to a ZEV passenger car fleet will reduce the oil consumption for transport by 238 million tonnes by 2050 compared to 2015. The EAFO model assumes ICEVs will exclusively use biofuels.

The Eurostat data provides the consumption of oil in transport and does not account for biofuels which are used in transport. In 2015 this biofuel use was around 14 million TOE, almost exclusively liquid biofuels used in cars. In the EAFO study, it is assumed that the biofuel used for cars will be shifted to other transport means like trucks, buses, shipping or planes. As the potential for biofuels for transport is limited in the EU, a transition of the car fleet to ZEVs will not negatively impact the use of biofuels for transport in Europe.

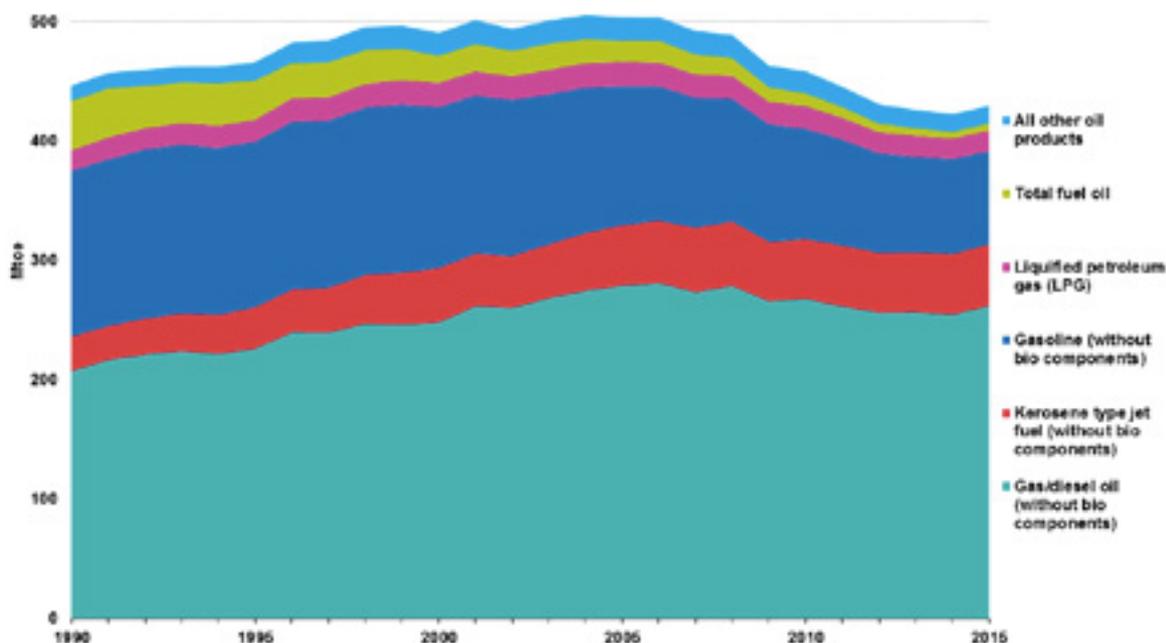


Figure 39: Consumption of oil in transport in the EU in million TOE, 1990 -2015, Eurostat

The transition to ZEVs (car fleet) results in a reduction of about 1,740 million barrels of crude oil consumed per year compared to 2015. At the current oil price of \$45 per barrel, this represents around €78 billion less imports of crude oil. In the EAFO

transition scenarios the cumulative reduction in consumption in the period 2020 – 2050 is around 26,000 million barrels of crude oil representing a value (at current prices of \$45 per barrel) of €1,170 billion. At 2008 peak prices this represents around €3,000 billion.

As the EU is currently importing almost all oil consumed, the total savings from the transition to a ZEV car fleet can be considered to be a reduction of oil imports.

The transition to a ZEV car fleet in the EU will positively impact the trade balance with €42 billion per year at current oil prices by 2050. Concerning oil prices, the only certainty we have is that they fluctuate very heavily and it would be safe to say this will probably remain so. The reduced consumption will also have an impact on the oil price, so the benefits can be expected to be much larger than only the reduction on import.

## 7.1.2

### Impact on energy efficiency and energy use

For the calculation of energy efficiency, an estimate has been made of the total energy requirement at the fleet level.

The EAFO model shows that a transition to 100% BEVs in 2050 will reduce the energy need at fleet level from the current 9,985 Peta Joules to 2,197 Peta Joules, a reduction of 78%. For current energy consumption, the energy content from the fossil fuels is assumed and the estimated real world driving quantity is used. The energy needed for the production, transport or conversion of the fuels is not considered and therefore the real energy use will be higher. However, ICEV technology will improve which may compensate for this effect. For the FCEVs, the value (0.33) of hydrolysis and fuel cell efficiency was used, as given in the 2017 European Road Transport Research Advisory Council (ERTRAC) Roadmap for electrification. For BEVs, the grid efficiency and all vehicle efficiencies have also been taken from the ERTRAC source, presuming a 100% renewable energy production by 2050 (or at least carbon neutral production). It is recommended that a more detailed well-to-wheel energy analysis for the different technology options is carried out.

### Energy use and efficiency EU passenger car fleet

Year	Technology	Fleet PJ energy	Oil consumption Mio TOE	Consumption kJ/km	Relative Energy Use
2016	99.8% ICE	9985	238	2786	100
2050	100% FCEV	5392	0	1513	54
2050	100% BEV	2197	0	605	22

**Fleet passenger cars 2016, 2050: 256 million**  
**Energy content: diesel 38.6 MJ/l; gasoline 34.2 MJ/l; oil 41.87 GJ/TOE**  
**Electricity: renewables, including transmission and distribution**  
**Hydrogen from renewable electricity**

Figure 40: Energy use and relative efficiencies of the ICEV, BEV and FCEV technology options

With a large BEV fleet, the combination of smart charging and vehicle-to-grid (V2G) technologies can allow the BEV to become linked to the electricity generation, distribution and storage network. The increasing generation of renewable energy from wind and solar creates a need for storage of electricity, decoupling generation and consumption in time. The batteries of BEVs linked to the grid can serve as back-up power for grid stabilisation and storage, creating additional value for BEV owners. A 100% BEV passenger car fleet connected to the grid with a 5 KW (low power) connection has the same power capacity as the total EU power generation capacity of 3,000 GW. A large part of the spinning reserves and standby capacity can potentially be eliminated if even a modest part of the fleet is connected to the grid through V2G.

The electricity for the ZEV fleet is assumed to be mostly (or all) produced in Europe. In the figure below, the fuel sources for electricity generation are given. Part of the fuel used for the production of electricity in the EU will be from imported fossil fuels or nuclear fuel. This is expected to reduce with the increasing share of renewable energy.

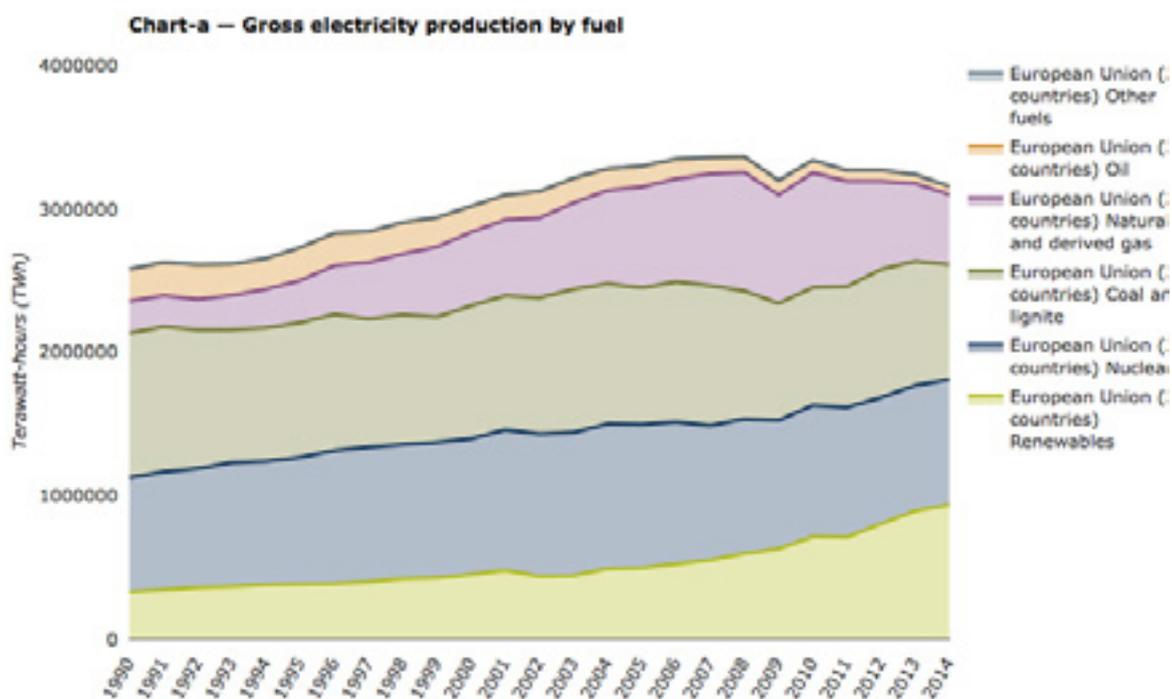


Figure 41: Electricity production in the EU by fuel type (source: EEA)

## 7.2 Greenhouse gas emissions reductions

A transition to a ZEV passenger car fleet will reduce the Tank-to-Wheel CO<sub>2</sub> emissions by 680 million tonnes on a yearly basis. The current EU target, which does not consider the impacts of the higher ambition of the COP21 agreement, requires a reduction of the total transport related emissions to 340 million tonnes per year. This is 60% below the 1990 emissions and 72% below current emissions. Compared to 1990, emissions have increased by 44% making even the 60% reduction by 2050 a major challenge to achieve.

Even with a zero-emission car fleet, the remaining transport will still require a reduction of 208 million tonnes of CO<sub>2</sub> from the 2015 level, a reduction of 38%. However, the current trend for non-car road emissions is that they increase before decreasing. As the COP21 requirements will impact all transport emissions, it can be expected that road transport will have to go a long way towards full decarbonisation as well. Of other vehicles, city buses and the light commercial vehicles are where CO<sub>2</sub> can be most easily reduced. As LCV sales are between 1.5 and 2 million vehicles per year and as they are less regulated and have often a higher mileage, they represent an important potential for improvement.

The ZEV Base Case and ZEV Leader scenarios result in cumulative emissions over the period 2020 – 2050 of 8 gigatonnes of CO<sub>2</sub>. PHEV Bridging will lead to around 10 gigatonnes of cumulative CO<sub>2</sub> emissions in the same period. Not acting will result in 20 gigatonnes of CO<sub>2</sub> emissions in this period and a continuing increase thereafter. The scenarios from the literature review lead to 10 to 12 gigatonnes of CO<sub>2</sub> emissions but will also continue to accumulate after 2050.

### EU CO<sub>2</sub> emissions and reduction targets from transport

Excluding additional COP21 reductions

	1990	2015	2015 Current Emissions	2050 Cars 100% ZEV	2050 Cars -60% CO <sub>2</sub>
<b>Total</b>	851	1048	1228	340	340
<b>Non-road</b>	69	186	186	28	28
<b>Road</b>	782	862	1042	313	313
<b>Road excluding cars</b>	322	362	362	313	129
<b>Cars</b>	460	500	680	0	184
All data in million tons					
<b>Target for Transport 2050</b>			340	340	340
<b>Change in emissions</b>		23%	44%	-60%	-60%

Figure 42: CO<sub>2</sub> emissions and targets from transport in million tonnes per year. This table demonstrates the impact of a 100% ZEV car fleet by 2050 compared to a car fleet which decarbonizes 60%, the total transport target for 2050 (White Paper for Transport, "pre-COP 21"). A 100% ZEV car fleet reduces the required emission reduction for the non-car road transport by 184 million tons of CO<sub>2</sub> per year, in the table "allocated" to road transport excluding cars.

## 7.3 Air quality and congested infrastructure

The air quality in most European cities is below WHO (World Health Organisation) recommendations. In many cities, air quality emissions are also above the less stringent EU norm.

A transition to ZEVs will result in zero emission of tailpipe pollutants such as NOx

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and fine particles (PM10 and PM2.5). Electric drive will also reduce noise levels, especially at lower speeds in cities. Car free days in cities like Paris and Brussels have demonstrated a radical drop in NOx pollutants within hours of the ban being effective. Not all air pollution is of course related to transport, and electric drive vehicles still generate PM emissions related to the wear of brakes, tyres and other parts.

Financial consequences of the bad air quality are difficult to assess. As an example, a report by the French Sénat, the upper house of parliament, found that air pollution costs France €101.3bn (£75bn) a year in negative health, economic and financial consequences. It said illnesses created or worsened by pollution included Alzheimer's disease, heart disease, respiratory disease and some cancers, and that air pollution is also linked to foetal development problems. The report – entitled Air Pollution: The Cost of Inaction – estimated that pollution caused up to 45,000 premature deaths in France a year, from asthma, chronic bronchitis, heart attacks, lung cancer and strokes.

It goes beyond the scope of this report to elaborate more on this topic, however the example shows the importance of improving the air quality especially in cities. A holistic approach from an economic and health and well-being perspective is recommended.

Replacing vehicles with electric equivalents does not solve the congestion problem of course. However, electric drive is very suitable for two wheelers and other small vehicles which might provide solutions in some places.

## **7.4 Competitiveness of EU industry (ICEV-EV) on global level & jobs**

The transition towards ZEVs has started. The figure below illustrates the volume and growth of the market. Market growth has been around 50 to 70% per year. However, as mentioned earlier, the most significant changes have taken place since 2016 with the announcements of ZEV targets by countries and the EV model launches announced by OEMs. The largest market for ZEVs is the passenger car (M1 category) market. Other markets like the light commercial vehicles (N1 category) and buses for public transport (M2/M3) are also starting to grow but the volumes are still much lower. The transition of the passenger car market to ZEVs will drive the cost reduction for the EV batteries or fuel cell systems and thus enable other markets to transition as well.

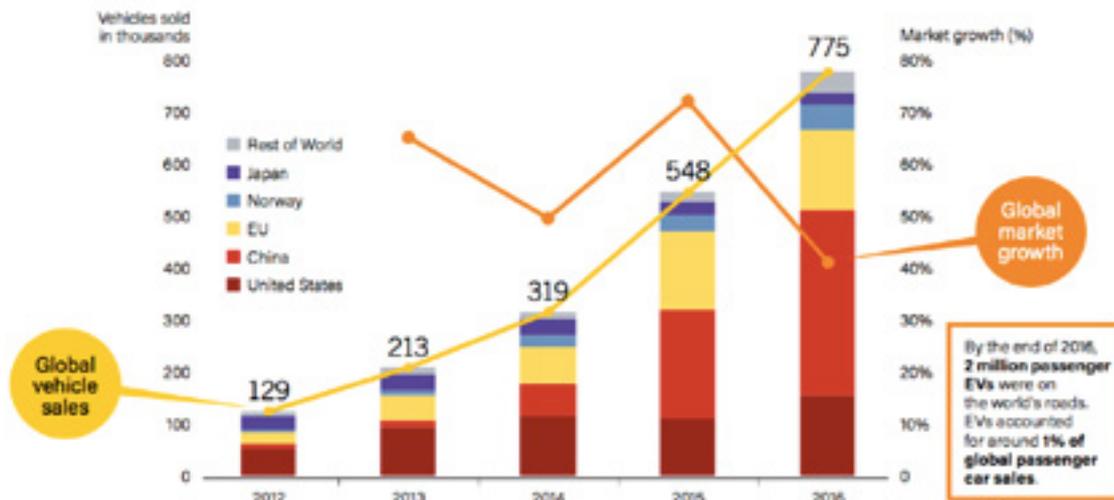


Figure 43: Development of the global EV market 2012 - 2016 (source: REN21 Renewables Global Status Report 2017)

A breakdown of jobs related to transport in general is given in the figure below. The total of 12.6 million jobs covers manufacturing jobs as well as taxi drivers and road construction jobs. A more detailed analysis is needed to know the number of jobs which will be impacted by the transition to ZEVs.

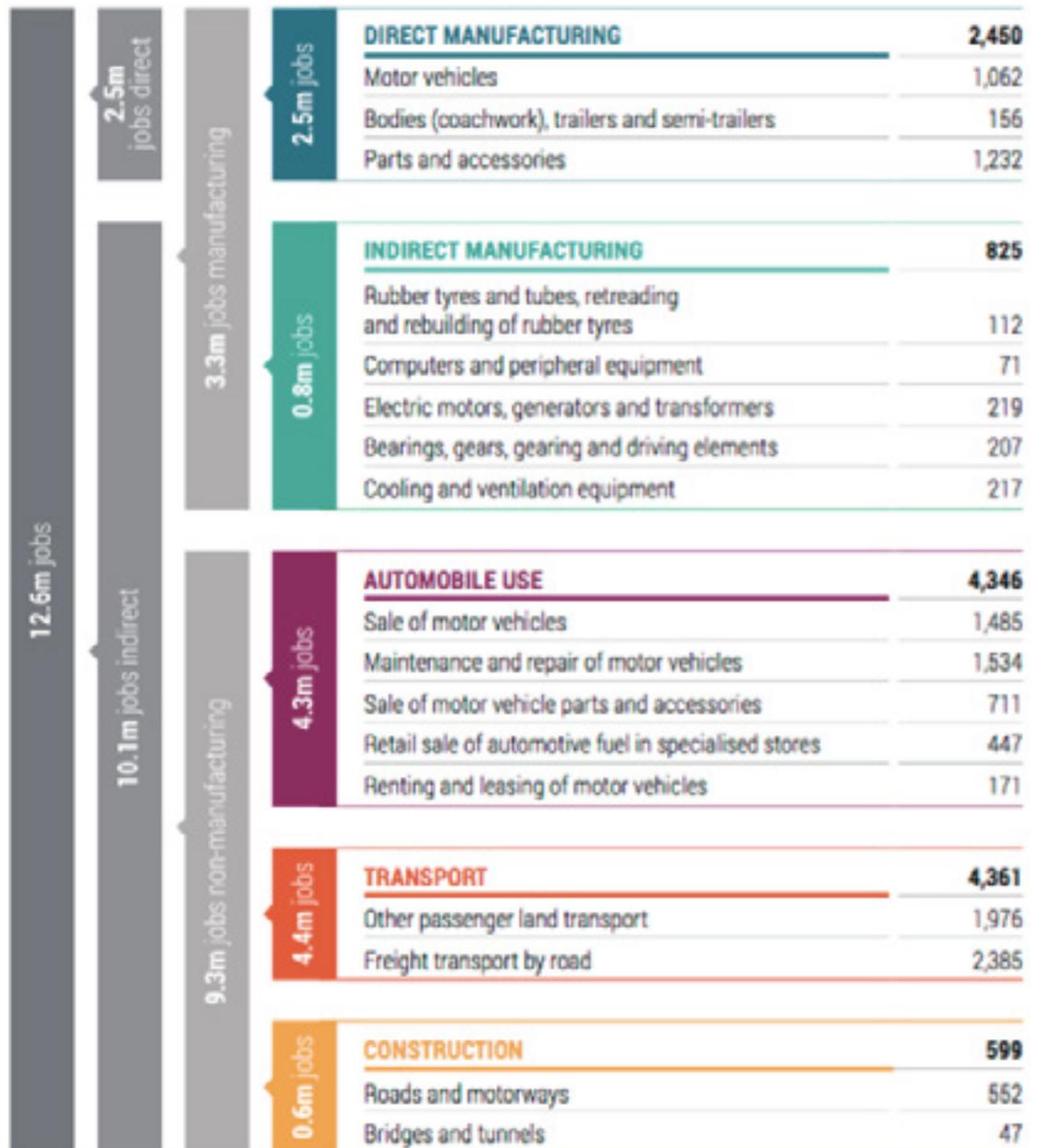
Jobs can be at stake for several reasons. Goods or services provided through these jobs may no longer be needed. As Europe is a net exporter of vehicles, changes in European competitiveness may also impact the number of jobs. Categories which can expect reductions in jobs are “parts & accessories (in direct manufacturing)”, “bearings, gears, gearing and driving elements”, “maintenance and repair”, “sale of motor vehicle parts and accessories” and “retail sale of automotive fuels”. The total of these categories is around 3.5 million jobs. The category “electric motors, generators and transformers” can be expected to increase. In general, EVs require less labour to produce as the manufacturing processes can be highly automated. But job loss is only a temporary problem and only if the transition happens at a fast pace. All efficiency improvements in the economy lead to loss of (old) jobs, but innovations that add value and lead to economic growth produce new jobs.

New jobs will be created in battery chemicals, battery cells and battery pack components and software as well as other specific EV items like charging equipment. The question is whether these jobs will be created in the EU or not.

Besides impacts in the jobs (categories) as given in the figure below, other jobs will be impacted as well. An example is the machine tool industry which is an important €25 billion net exporting industry in Europe. It can be expected that investment in machine tools used for the manufacturing of ICEV specific parts will drop relatively fast when the transition starts to pick up.

Automotive sector:  
direct and indirect employment in the EU

IN THOUSANDS / 2015<sup>1</sup>



SOURCE: EUROSTAT

1. Provisional figures

Figure 44: Jobs related to transport (source: ACEA pocket guide 2017-2018)

In 2016, the EU had a positive trade balance of €90 billion related to motor vehicle trade with €125 billion in exports related to passenger cars. A transition to ZEVs is likely to happen globally, although not in all regions simultaneously. Depending on the competitive position of the European based manufacturing capability of the ZEV supply chain this may impact the industrial activities and jobs in the automotive sector. Export to regions strongly promoting ZEVs and/or promoting the local manufacturing of ZEVs will probably be at risk if European competitiveness is not good enough. The

recent slump in diesel car sales, both in Europe and outside Europe, demonstrates the vulnerability of the European OEMs in the changing competitive positions of the drive train technologies. In other words, if European OEMs do not invest fast in enough in ZEVs manufacturing in Europe while the whole world goes to ZEVs to reach climate goals, the EU automotive industry manufacturing base will lose the battle with foreign manufacturing competitors. Whereas the EU is now a net exporter of ICEVs, delayed action may result in the EU becoming a net importer of EVs.

EU motor vehicle trade		BY TYPE, IN MILLION € / 2016			
Trade in value	PC <sup>1</sup>	LCV <sup>2</sup>	CV & BC <sup>3</sup>	TOTAL	
<b>2016</b>					
Imports	37,991	5,874	1,828	45,693	
Exports	125,005	4,088	6,305	135,398	
Trade balance	87,014	-1,786	4,476	89,704	
<b>2015</b>					
Imports	32,528	5,018	1,561	39,107	
Exports	129,100	3,957	6,367	139,424	
Trade balance	96,572	-1,061	4,806	100,317	
<b>% change 16/15</b>					
Imports	16.8%	17.1%	17.1%	16.8%	
Exports	-3.2%	3.3%	-1.0%	-2.9%	
Trade balance	-9.9%	68.3%	-6.9%	-10.6%	

SOURCE: EUROSTAT

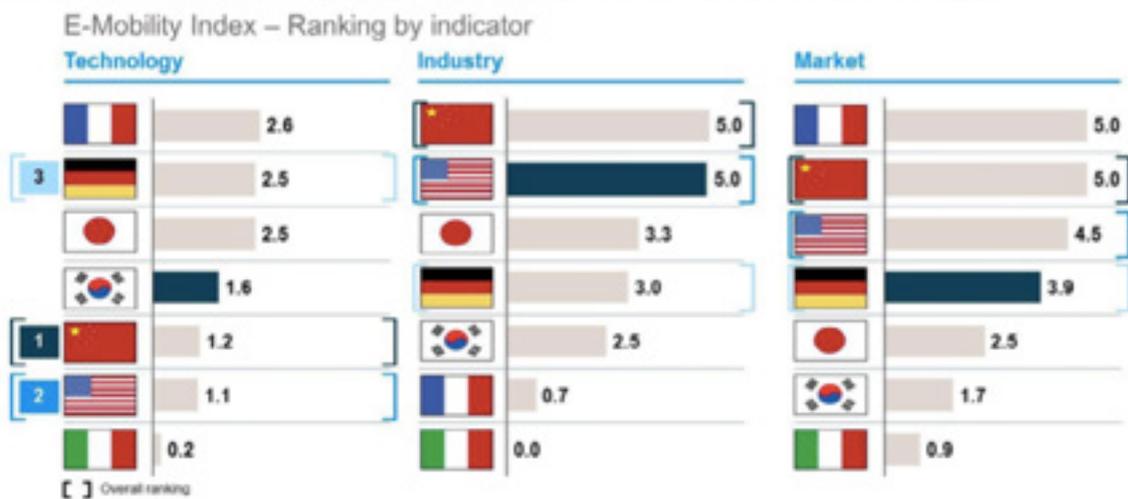
Figure 45: EU motor vehicle trade (source: ACEA pocket guide 2017 - 2018)

For a few years, Roland Berger has been publishing its E-mobility index; measuring competitiveness at technology, industry and market levels. In the latest index (Q2, 2017) China has taken over first place from the USA, with Germany as first European country and in third place overall. Although qualitative and subjective, it does show that European countries do not have the same competitive position in EVs as they have in the traditional ICEVs. It also demonstrates the fast rise of China in EVs. Bloomberg New Energy Finance publishes an annual quantitative report based on EV sales, revenue and model availability. In 2016 all of the top 5 OEMs were Chinese. The question for Europe is more if and how it can catch up, particularly for the production of battery components but also sensors and microchips for automotive applications.

Where the UK and France have set targets to ban ICEVs by 2040, China is evaluating options for an ICEV ban, as is California. China has decided on a ZEV mandate which will start in 2019 and quickly ramp up to 12% ZEV (through a credit system) by 2020. Leading OEMs are increasing their investments in EV production in China. GM, VW, Daimler, Toyota, and more recently Ford, have all announced new electric vehicle ventures in China.

## E-MOBILITY INDEX Q2 2017

Figure 2: Japan loses its overall pole position to China, while 2nd placed USA increase their industry; Germany on overall third place



Source: fka; Roland Berger

Figure 46: Roland Berger E-mobility index Q2-2017 – ranking by indicator

The UBS Bank has published its assessment of the impact of a shift to EVs on the automotive sector value chain (UBS Evidence Lab Electric Car Teardown, May 2017). As can be seen in the figure below, the UBS Bank does not see a positive impact for the traditional OEMs and suppliers on revenue, margin or overall evaluation of the companies. This illustrates the dilemma the OEMs are faced with. They know the transition is coming and will happen but they do not see a clear winning strategy on how to capitalise on this transition. This may result in resisting the change rather than embracing it, through a short term strategy which may end up with a long term loss.

Figure 15: Sector map – impact from EVs at a glance

EV impact on ...	Revenue growth	EBIT margin	ROIC	Valuation	Sector impact & UBS positively/negatively impacted by the theme
Auto OEMs	→	↘	→	→	<b>Sector impact:</b> Better EV profitability, CO <sub>2</sub> tailwinds, more Finco risk <b>Positively impacted:</b> Daimler, Volkswagen, Renault, GM <b>Negatively impacted:</b> FCA, PSA, Subaru
Auto suppliers	→	↘	↘	→	<b>Sector impact:</b> Top line impact varies, risk of content loss to new entrants, aftermarket risk <b>Positively impacted:</b> Valeo, Delphi, Conti, Hyundai Mobis <b>Negatively impacted:</b> Schaeffler, Faurecia, Tenneco
Battery producers	↗	↗	→	→	<b>Sector impact:</b> Strong top-line growth to drive EBIT break-even in 2018/19 <b>Positively impacted:</b> LG Chem, Samsung SDI <b>Positively impacted but priced in:</b> Panasonic
Capital goods	Varies widely by company				<b>Sector impact:</b> Mixed. Auto capex winners but some players lose content (bearings) <b>Positively impacted:</b> Siemens, Atlas Copco, Hexagon, GKN <b>Negatively impacted:</b> SKF, Rheinmetall, Sandvik, Kennametal
Chemicals	→	→	↘	→	<b>Sector impact:</b> EV winners in battery value chain; ICE losers (catalyst materials) <b>Positively impacted:</b> Umicore, LG Chem, Asahi Kasei, Sumitomo Chem, Albemarle, Sika <b>Negatively impacted:</b> Johnson Matthey, BASF, Clariant, EMS Chemie
LG companies	↗	→	→	→	<b>Sector impact:</b> 55% content in the Bolt from LG Group as automotive new entrant <b>Positively impacted:</b> LG Chem, LG Display <b>Positively impacted but priced in:</b> LG Electronics
Commodities	↗	↗	→	↗	<b>Sector impact:</b> Positive for most commodities <b>Positively impacted:</b> Lithium, cobalt, graphite, nickel, rare earths <b>Negatively impacted:</b> Platinum and palladium
Semiconductors	↗	↗	↗	→	<b>Sector impact:</b> Electric and autonomous cars as a key growth driver <b>Positively impacted:</b> Most autos semis – we favour Infineon, Texas Instruments <b>Positively impacted but priced in:</b> Melexis, STMicro

Source: UBS estimates

Figure 47: UBS Bank assessment of the impact from EVs on companies in the value chain

### EV battery manufacturing

The global production capacity of lithium-ion batteries is set to grow from the current 100 GWh per year to around 270 GWh per year by 2021, of which 65% will be produced in China. The bulk of the growth will be driven by EVs.

#### Chinese Battery Boom

Elon Musk gets all the attention, but China is building factories that will swamp the market

MWh capacity of manufacturing factories  
■ Under construction ■ Announced



Source: Bloomberg New Energy Finance

Bloomberg

Figure 48: Lithium-ion battery production with the forecasted capacities for 2021

(source: Bloomberg New Energy Finance) Production capacity in Europe is almost non-existent and expansion plans are very limited. European OEMs prefer to source in Asia. “We have to recognise that the United States and China are moving a lot faster on electric mobility than we are,” European Commission Vice-President in charge of energy Maroš Šefčovič told Germany’s Sueddeutsche Zeitung newspaper on September 18th 2017. He also stated, “we need an Airbus for batteries, this technology is too important to import it from overseas”.

In the figure below, an estimation of the battery requirement for the EU sales of BEVs is given. To reach the objective of having a 100% ZEV fleet for passenger cars, a battery manufacturing capacity anywhere between 400 and 600 GWh would be needed. This would represent a value of €40 to 60 billion on a yearly basis and would require 14 to 20 “Giga factories” to be built and operational by 2035. Anything less than that would imply that the EU would become a net importer of lithium-ion batteries for cars.

### Battery requirements for the ZEV transition

Year	BEV sales Million cars	GWh total 30 kWh/car	Value @100€/kWh € billion	GWh total 45kWh/car	Value @100€/kWh € billion
2025	3.5	105	11	158	16
2030	7	210	21	315	32
2035	14	420	42	630	63

By 2025: 3 to 5 “Giga factories @ 35 GWh needed for EU BEV sales

By 2035: 14 to 20 “Giga factories @ 35 GWh needed for EU BEV sales

Figure 49: Battery manufacturing capacity requirements for the ZEV transition. For this calculation, a cost of €100 per kWh is taken. In the study, the battery price reduction is limited to € 120 per kWh as bottom price however recent indications are that prices as low as € 65 per kWh could be reached by 2030.

A recent reported statement from the CEO of Volkswagen demonstrates the scale and the urgency of battery related investments for the automotive sector:

**“Volkswagen updated its plans for electric cars with a complete overhaul of its investment strategy. After announcing an initial investment of \$10 billion in EVs earlier this year, which was still smaller than the German automaker’s investments in gas-powered cars, they now promise to spend up to 70 billion euros (~\$84 billion USD) in order to bring 300 electric vehicle models to market by 2030. More interestingly, most of the investment 50 billion euros (~\$60 billion) will be in battery production in order to support their electric car ambitions for the next decade. Volkswagen CEO Matthias Mueller said to guests gathered at an event in Frankfurt today ahead of the launch of the annual motor show (via BBC):**

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***“A company like Volkswagen must lead, not follow. We have got the message and we will deliver. This is not some vague declaration of intent. It is a strong self-commitment which, from today, becomes the yardstick by which we measure our performance.”***

A quote from Elektrec.co, 11th, September, 2017.

## **7.5 Conclusions**

- A complete transition to ZEV cars will reduce European oil imports by 238 million TOE or 1,740 barrels of oil per year by 2050.
- A ZEV car fleet will use 78% less energy than the current ICEV fleet if replaced by BEVs, and 46% less energy if replaced by FCEVs.
- A transition to a ZEV fleet will reduce CO<sub>2</sub> emissions by 184 million tons more than the EU target of a 60% reduction of the 1990 emissions.
- The EU automotive industry is not leading the transition to electric drive, meaning the export position of the EU may be at risk.
- Investing in battery manufacturing capability will represent a value of €63 billion per year by 2035.



# 8.0 ANNEXES: Background information

## 8.1 Annex 1: Battery and vehicle cost prices (data from literature)

In this section, several forecasts on battery prices, TCO and vehicle price parities are given. Additional slides give information on maintenance costs (UBS Bank) as well as a BNEF forecast on battery size (range) and power requirements for EVs.

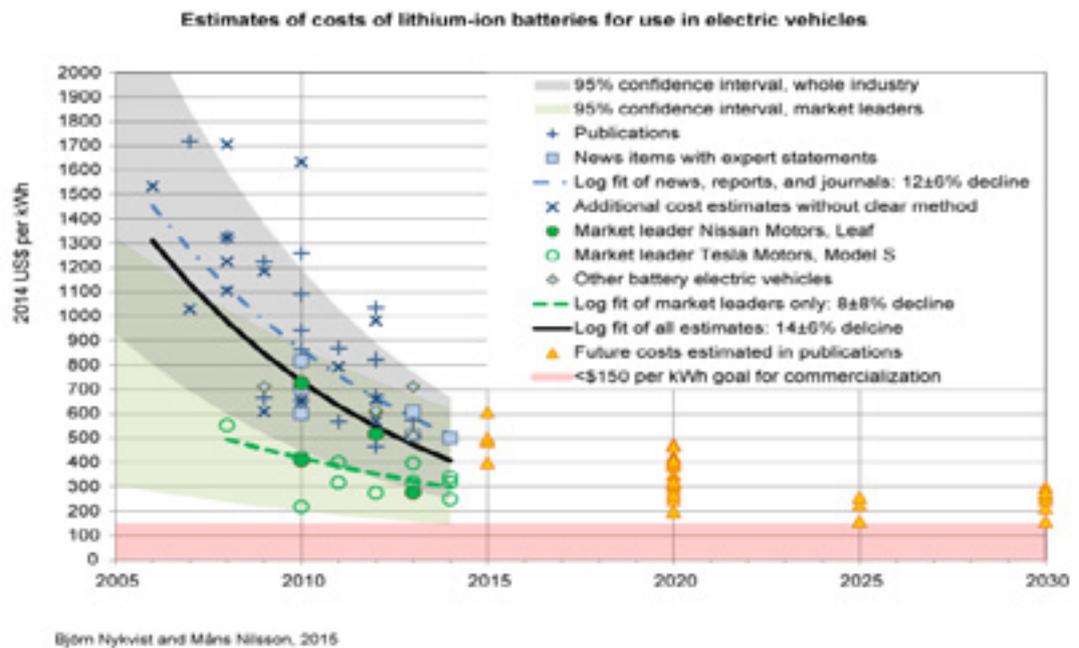


Figure 50: Bjorn Nykvist and Mans Nilsson 2015: battery price declines faster than predicted

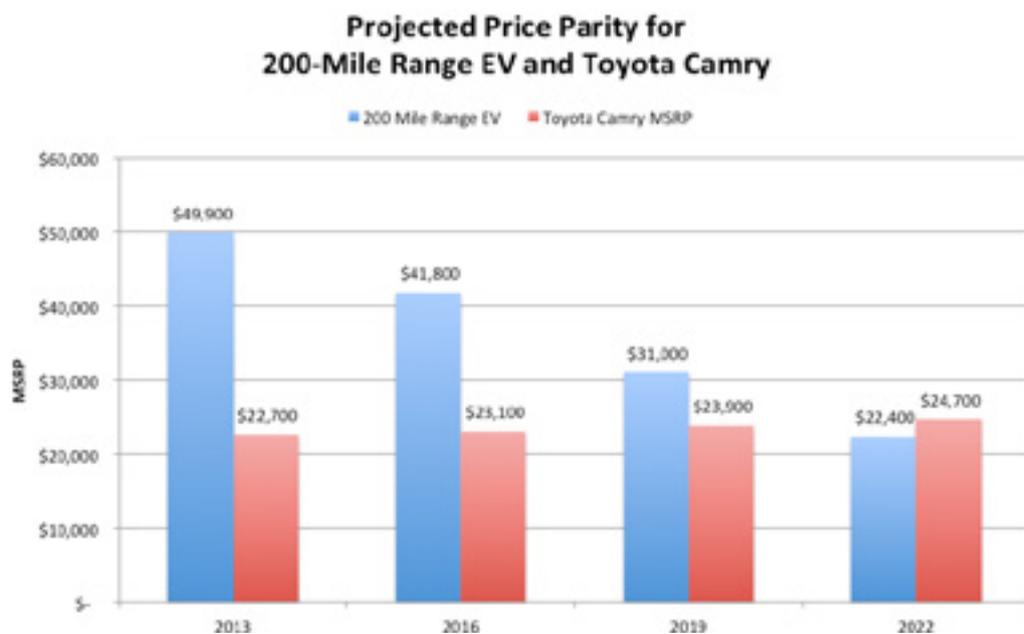


Figure 51: ARK Investment: price parity 2021-2022. Source: NADA Guides, ARK Investment Management LLC

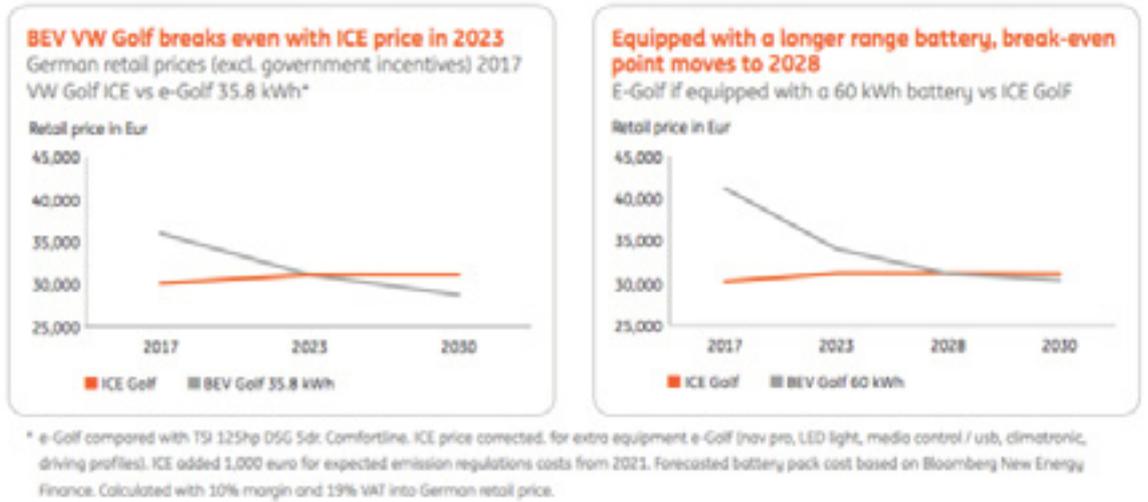


Figure 52: ING Bank cost parity prediction July 2017

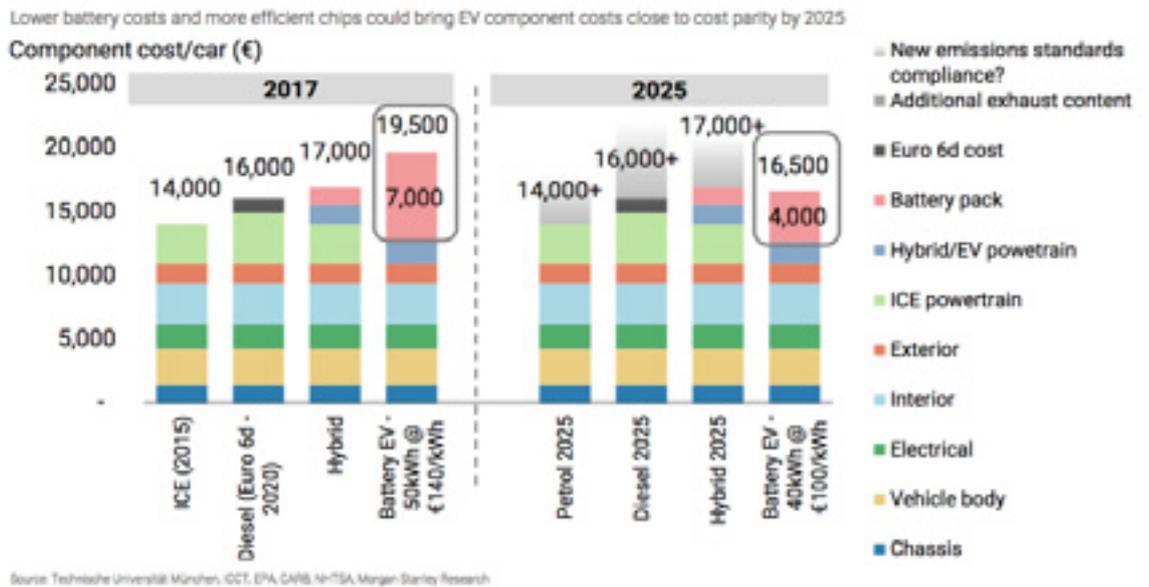


Figure 53: Morgan Stanley September 2017

## BEV AND ICE PRE-TAX PRICES IN **THE EU** AND THE SHARE OF BATTERY COSTS IN THE VEHICLE PRICE

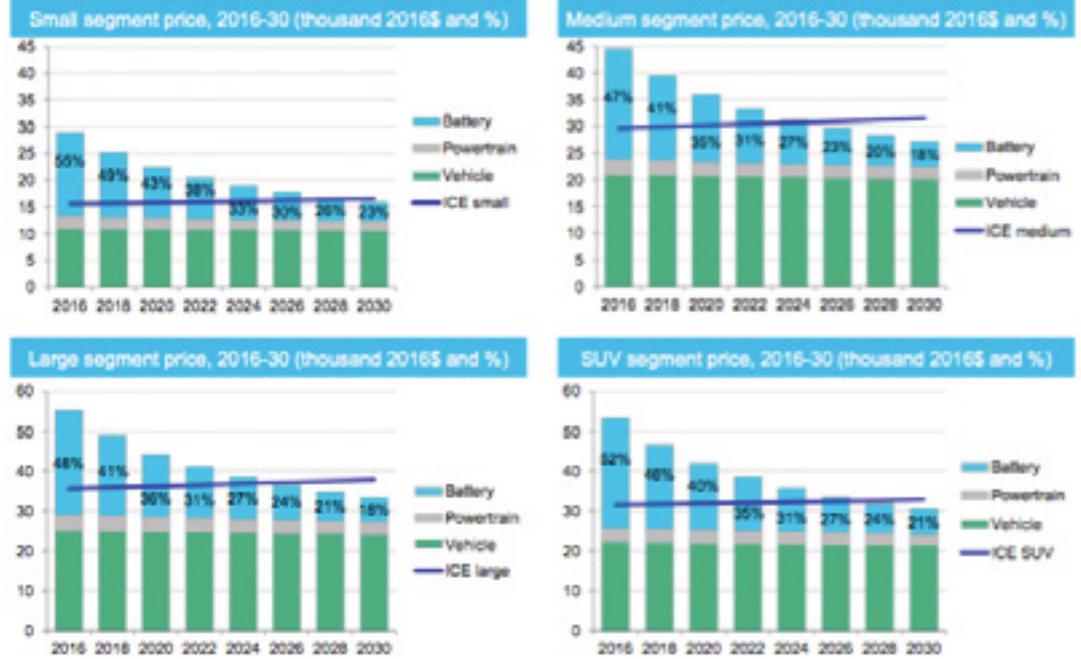
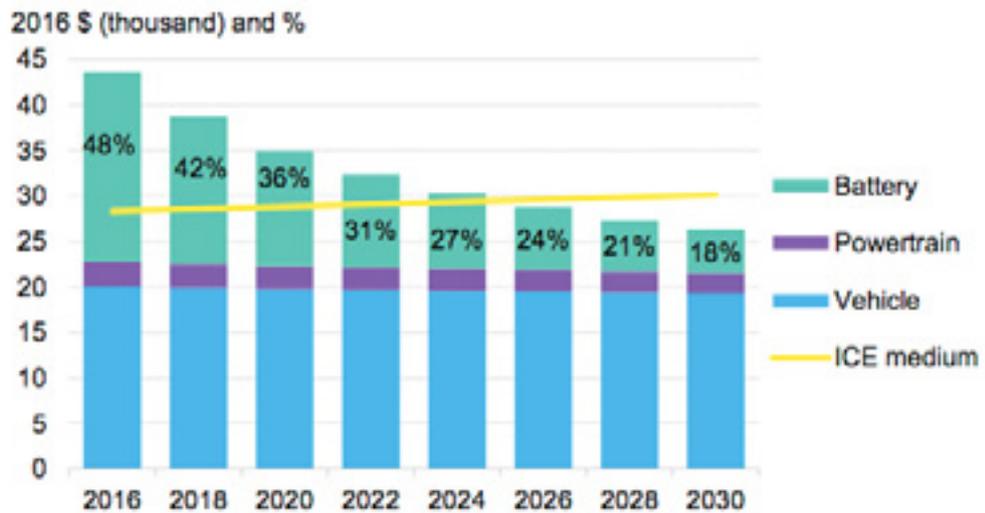


Figure 54: BNEF Forecast BEV and ICEV price developments for various segments in Europe (12th April, 2017). Price parity reached between 2024 and 2028 for the small car segments. This even though BNEF uses significant larger battery capacities (ranges) for its estimates. An interesting observation from this graph is whereas BNEF is less bullish about the small car segment, Renault states a cost parity within the next few years (see insert in chapter 6).

## US medium BEV price breakdown, ICE price and share of battery costs



Source: Bloomberg New Energy Finance Note: Estimated pre-tax retail prices

Figure 55: BNEF 2024-2025 cross-over point

## EV COMPETITIVENESS IS HEAVILY DEPENDENT ON BATTERY COST AND TECHNOLOGY IMPROVEMENTS

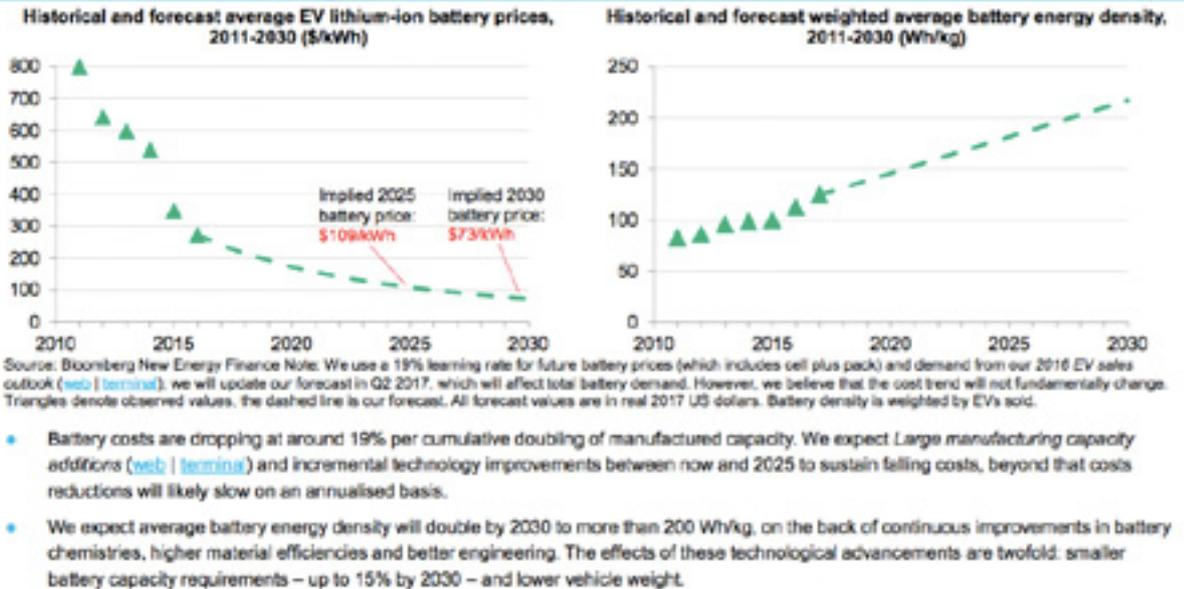


Figure 56: Projection of the development of the EV battery price (at pack level, PHEV and BEV included), source: Bloomberg New Energy Finance (April, 2017).

## BATTERY ELECTRIC VEHICLE SPECIFICATIONS

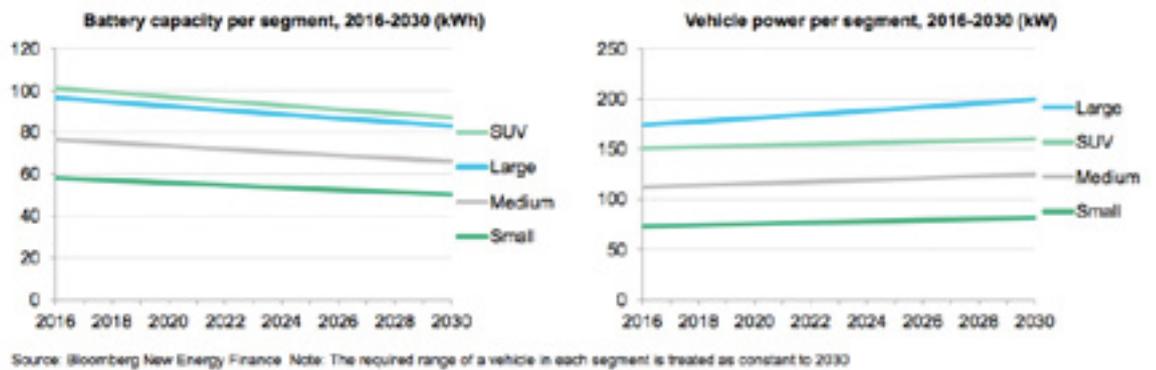


Figure 57: BNEF battery capacity and power forecast per vehicle segment (April 2017)

**Figure 11: The Bolt has ~60% lower after-sales costs (\$)**

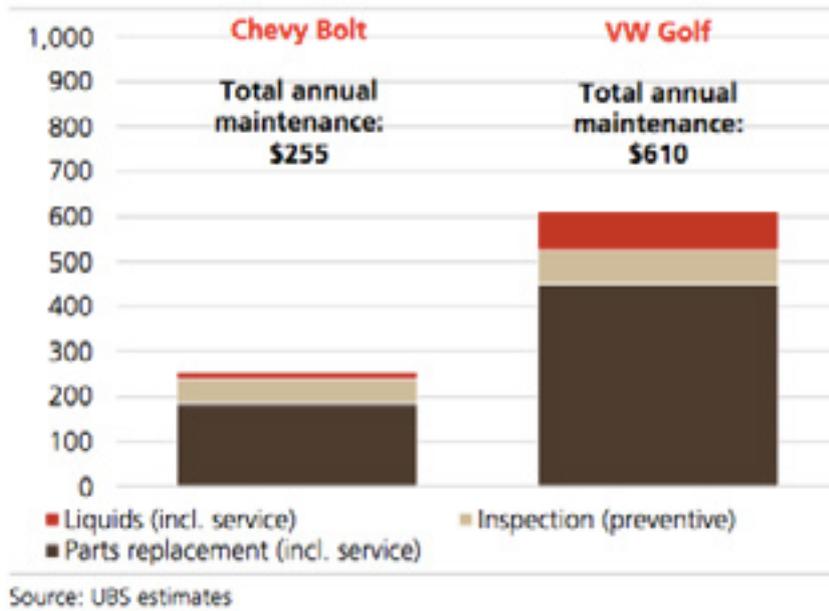


Figure 58: UBS Tear-down maintenance cost analyses Chevrolet Bolt versus VW Golf

**Figure 7: Number of parts in the powertrain**

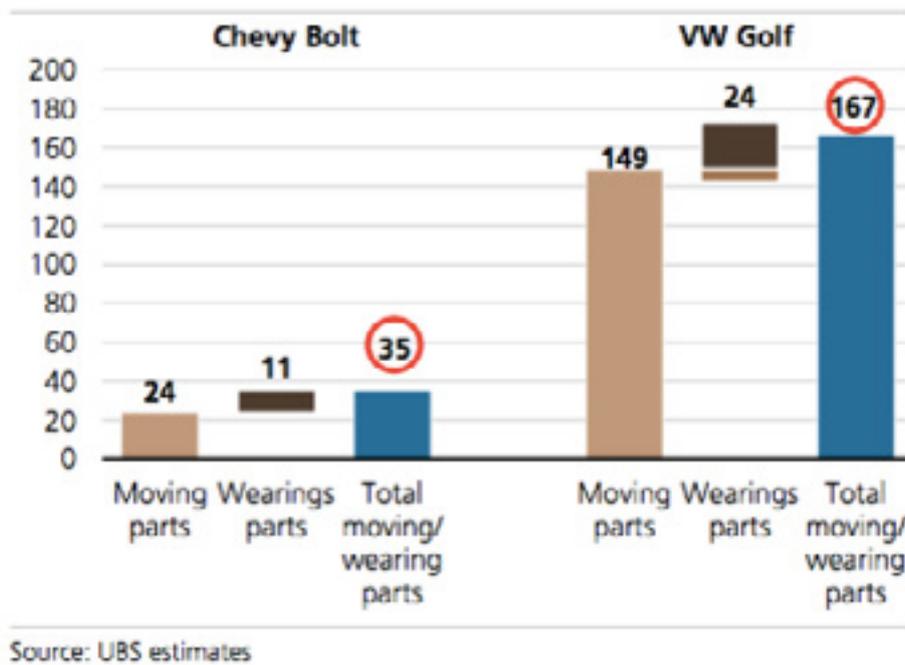


Figure 59: Comparison of moving and wearing parts in an EV compared to an ICEV

## 8.2

## Annex 2: Additional data from the study

## New car sales 2020 - 2050 (literature)

Scenario 1:  
LOW ZEV forecast (from literature)

	ICE	PHEV	ZEV
2015	99.28%	0.36%	0.36%
2020	<b>94.17%</b>	<b>5.47%</b>	<b>0.36%</b>
2025	<b>79.82%</b>	<b>15.41%</b>	<b>4.78%</b>
2030	<b>71.23%</b>	<b>20.77%</b>	<b>8.00%</b>
2035	56.50%	25.40%	18.10%
2040	43.12%	30.95%	25.93%
2050	34.66%	35.81%	29.53%

Scenario 2:  
Average EV uptake (Literature)

	ICE	PHEV	ZEV
2015	99.28%	0.36%	0.36%
2020	<b>91.04%</b>	<b>5.64%</b>	<b>3.32%</b>
2025	<b>74.82%</b>	<b>14.44%</b>	<b>10.74%</b>
2030	<b>62.05%</b>	<b>21.16%</b>	<b>16.78%</b>
2035	56.50%	25.40%	18.10%
2040	38.42%	27.58%	34.00%
2050	24.00%	24.80%	51.21%

Scenario 3:  
HIGH ZEV forecast (from literature)

	ICE	PHEV	ZEV
2015	99.28%	0.36%	0.36%
2020	<b>85.98%</b>	<b>5.33%</b>	<b>8.69%</b>
2025	<b>66.48%</b>	<b>12.83%</b>	<b>20.69%</b>
2030	<b>53.34%</b>	<b>21.66%</b>	<b>25.00%</b>
2035	46.00%	22.00%	32.00%
2040	33.87%	24.31%	41.81%
2050	16.93%	17.50%	65.57%

Figure 60: New Car Sales 2020-2050 (literature)

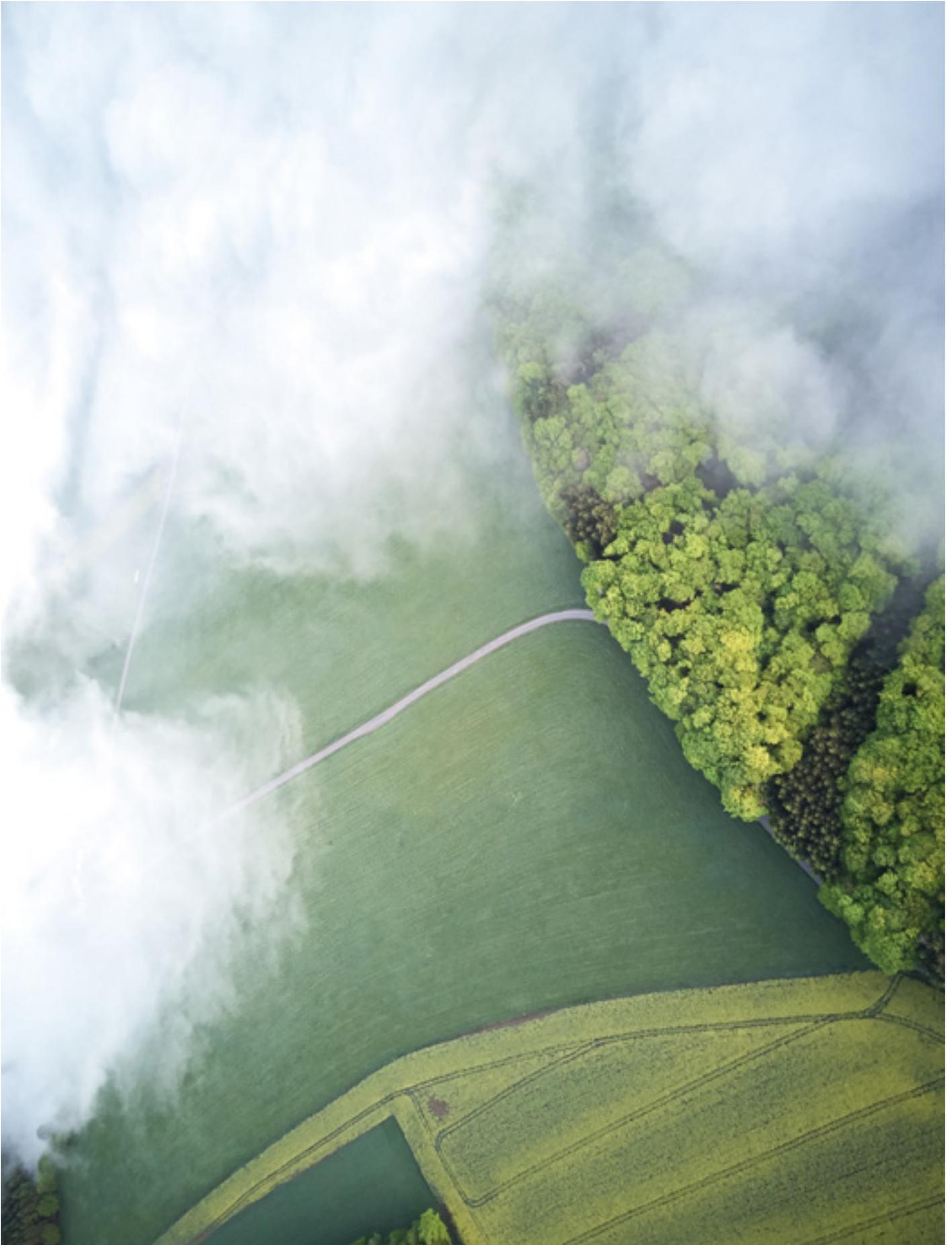
## Literature forecasts and EAFO scenarios: CO<sub>2</sub> yearly and cumulative emissions 2016 - 2050

	Low ZEV Literature		Medium ZEV Literature		High ZEV Literature		ZEV Base Case		PHEV Bridging		ZEV Leader	
	Annual	Cumul.	Annual	Cumul.	Annual	Cumul.	Annual	Cumul.	Annual	Cumul.	Annual	Cumul.
<b>2001</b>	38	38	38	38	38	38	38	38	38	38	38	38
<b>2002</b>	37	76	37	76	37	76	37	76	37	76	37	76
<b>2003</b>	38	113	38	113	38	113	38	113	38	113	38	113
<b>2004</b>	39	152	39	152	39	152	39	152	39	152	39	152
<b>2005</b>	39	191	39	191	39	191	39	191	39	191	39	191
<b>2006</b>	40	230	40	230	40	230	40	230	40	230	40	230
<b>2007</b>	40	270	40	270	40	270	40	270	40	270	40	270
<b>2008</b>	36	306	36	306	36	306	36	306	36	306	36	306
<b>2009</b>	37	343	37	343	37	343	37	343	37	343	37	343
<b>2010</b>	35	378	35	378	35	378	35	378	35	378	35	378
<b>2011</b>	34	412	34	412	34	412	34	412	34	412	34	412
<b>2012</b>	31	442	31	442	31	442	31	442	31	442	31	442
<b>2013</b>	30	472	30	472	30	472	30	472	30	472	30	472
<b>2014</b>	32	504	32	504	32	504	32	504	32	504	32	504
<b>2015</b>	35	539	34	538	35	539	35	539	35	539	35	539
<b>2016</b>	34	573	33	571	34	573	34	573	34	573	34	573
<b>2017</b>	33	606	32	603	32	604	32	605	33	606	32	604
<b>2018</b>	31	637	30	633	30	634	30	635	31	637	30	634
<b>2019</b>	30	667	29	662	28	662	28	663	30	667	28	662
<b>2020</b>	28	695	28	690	26	688	26	689	28	695	26	688
<b>2021</b>	28	723	27	717	25	714	24	713	27	722	24	712
<b>2022</b>	28	751	26	743	24	738	23	736	26	748	22	734
<b>2023</b>	27	778	26	769	23	761	21	757	26	774	20	754
<b>2024</b>	27	804	25	794	23	784	19	775	25	798	18	773
<b>2025</b>	26	830	24	818	22	806	17	793	24	822	16	789
<b>2026</b>	26	856	24	842	21	827	15	808	22	845	14	803
<b>2027</b>	26	882	24	866	21	847	13	821	21	866	12	815
<b>2028</b>	26	908	23	889	20	868	11	832	20	886	9	824
<b>2029</b>	25	933	23	911	20	887	9	841	18	904	7	831
<b>2030</b>	25	958	22	933	20	907	7	848	17	921	5	835
<b>2031</b>	24	982	22	955	19	926	6	853	14	935	4	839
<b>2032</b>	24	1006	22	977	20	946	4	857	10	945	3	842
<b>2033</b>	23	1029	21	998	20	966	3	860	7	952	2	843
<b>2034</b>	22	1050	21	1020	21	987	1	862	3	955	1	844
<b>2035</b>	21	1071	21	1041	17	1004	0	862	0	955	0	844
<b>2036</b>	20	1092	20	1060	19	1024	0	862	0	955	0	844
<b>2037</b>	19	1111	19	1079	18	1042	0	862	0	955	0	844
<b>2038</b>	19	1130	18	1097	16	1058	0	862	0	955	0	844
<b>2039</b>	18	1148	16	1113	15	1073	0	862	0	955	0	844

<b>2040</b>	17	1165	15	1128	13	1086	0	862	0	955	0	844
<b>2041</b>	17	1182	15	1143	14	1100	0	862	0	955	0	844
<b>2042</b>	16	1198	14	1157	14	1114	0	862	0	955	0	844
<b>2043</b>	16	1214	14	1170	15	1129	0	862	0	955	0	844
<b>2044</b>	16	1230	13	1183	15	1144	0	862	0	955	0	844
<b>2045</b>	16	1246	12	1196	16	1160	0	862	0	955	0	844
<b>2046</b>	15	1261	12	1208	14	1174	0	862	0	955	0	844
<b>2047</b>	15	1276	11	1219	12	1186	0	862	0	955	0	844
<b>2048</b>	15	1291	11	1230	10	1196	0	862	0	955	0	844
<b>2049</b>	14	1305	10	1240	9	1205	0	862	0	955	0	844
<b>2050</b>	14	1319	10	1250	7	1212	0	862	0	955	0	844

Figure 61: Literature forecasts and EAFO Scenarios: CO<sub>2</sub> yearly and cumulative emissions 2016 - 2050





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Image, p5 by Håkan Dahlström.

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