element energy

Availability and Affordability of ZEVs

Final Report

for

BEUC and ECF

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List of Abbreviations

AV	Autonomous Vehicle
BEUC	The European Consumer Organisation
BEV	Battery Electric Vehicle
EC	European Commission
ECF	European Climate Foundation
EE	Element Energy
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
PCP	Personal Contract Plan
PHEV	Plug-in Hybrid Electric Vehicle
T&E	Transport and Environment
TCO	Total Cost of Ownership
ULEV	Ultra-Low Emissions Vehicle
ZEV	Zero-Emissions Vehicle

1 Introduction

In 2016, Element Energy carried out a detailed study for BEUC and ECF on the future ownership costs of low carbon cars and the implications for consumers and policy makers. The report, entitled *Low carbon cars in the 2020s: Consumer impacts and EU policy implications*, found that a transition to low and zero emission cars is likely to have strong and positive impacts on EU consumers. Technology cost projections showed that the total costs of ownership (TCO) of low emission models will become equivalent to conventional petrol and diesel cars in c.2025, before country-specific incentives are taken into account. The analysis also showed particular benefits for buyers of second- or third-hand low emission vehicles, as the fuel and maintenance cost savings for these vehicles are the dominant ownership costs for used cars.

The 2016 study considered TCOs in conventional ownership models, in other words the new car buyer and subsequent owners buying a car for personal use, and reselling it after a number of years (or scrapping it in the case of the final owner). Building on this work, ECF and BEUC wished to carry out a supplementary study with a particular focus on the following:

- Availability of ultra-low emission vehicles, in terms of the number of models on the market now and in the future but also true availability in dealerships across Europe
- Affordability of ZEVs, and whether lease offers for ZEVs are competitive with offers available for conventional vehicles
- The impact of new ownership models such as car sharing or the introduction of autonomous vehicles in the future, and how these influence costs of vehicle ownership or mobility

This supplementary study employs the same vehicle cost and performance model and TCO analysis carried out for the 2016 study, to ensure consistency with the original results. All core assumptions such as vehicle technology costs, fuel prices, insurance costs etc. are the same as in the previous study unless explicitly stated otherwise. Given the similarity in methodologies, detailed descriptions of the model and original assumptions are not repeated here, and the reader is referred to the public report of the 2016 study for further information. This is available at:

http://www.element-energy.co.uk/publications/

A non-technical summary of the report written by BEUC is accessible at:

http://www.element-energy.co.uk/wordpress/wp-content/uploads/2017/01/Low-carbon-cars-in-the-2020s-Consumer-impacts-and-EU-policy-implications-BEUC-Summary-Report.pdf

2 Availability of ZEVs and ULEVs

2.1 Methodology and data acquisition

Availability of zero emission vehicles in a wide range of models is an important prerequisite of widespread uptake. This is because customers are likely to have preferences for certain non-powertrain attributes of new vehicles, such as size, styling, boot space, entertainment features etc. If ZEVs are only available in a limited number of models, potential customers may not buy them if it requires compromises on the vehicle brand and these other attributes. It should be noted that some drivers are likely to prefer petrol/diesel cars for other reasons, for example the long driving range or torque, and for those customers availability of more ZEV models will have little or no effect on their buying patterns. However, for potential buyers open to choosing a ZEV, availability of a range of models maximises the chances of them finding a vehicle that meets all of their needs.

Previous studies have attempted to estimate the perceived value of brand or model choice for consumers. Greene et al. (2001) found that a very limited model choice (for example only 1 available model in a given segment) had the same impact on alternative fuel vehicle sales as increasing the sales price by €3,645[1]. A more recent study conducted by Element Energy for the UK Department for Transport using a survey of would-be car buyers found a perceived 'penalty' of €1,815 for powertrains in which only one model was available in a segment[2]. In the early years of ZEV deployments, these values are small compared with the additional purchase price of the vehicles (before incentives are taken into account). However, as other barriers to ZEV uptake improve in future (e.g. purchase prices, higher ranges, more widespread infrastructure), lack of model choice or real world access to ZEVs through dealerships becomes increasingly important.

The aim of this availability task was to quantify the number of ZEV (primarily BEV and PHEV) models currently on the market and examine how this is likely to change in the short and medium term. Element Energy's existing database of ZEV models was used as a starting point for this work, and this was updated to include all models on the market or announced up to mid-September 2017. Expected future model availabilities were then divided into announced models in the short term (c.2020) and medium term (c.2025). Models included in the short-term database are those that have been named and given a date for start of production or market release, as opposed to concept cars or press releases referring to un-named future models being electrified. Medium term projections are based on Original Equipment Manufacturer (OEM) projected sales volumes and expected market shares rather than specific model announcements. In some cases, OEMs publish statements about the numbers of new (but as-yet unnamed) models to be introduced in the future, for example the 12 new zero emission models expected from the Renault-Nissan-Mitsubishi group by 2022[3]. Where available, the following information for each model was compiled and added to our database:

- Manufacturer and model name
- Year of introduction (and European introduction year if different)
- Segment
- Powertrain (e.g. BEV, plug-in hybrid, fuel cell)
- New model / refresh of existing model

[1] Based on a $2,500 penalty in 2001 USD, converted to 2017 EUR. Study available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.199.2796&rep=rep1&type=pdf
[2] Element Energy (2017) - Survey of consumer attitudes to plug-in vehicles (in press)
[3] https://electrek.co/2017/09/15/renault-nissan-mitsubishi-alliance-12-new-all-electric-vehicles/

- Motor output power in kW
- Battery size / range (for BEVs/PHEVs)
- Expected selling price

Research on the current and future availabilities was initially conducted through a systematic review of OEM websites and press releases. The amount and quality of data available for each model depends strongly on the OEM (some OEMs release information early while others published limited official information until closer to introduction) as well as the actual introduction date (generally more information is available for models being introduced in the near future). Wherever possible, information which was lacking or unavailable was complemented with other sources such as published strategy documents, executive statements, employee interviews or news articles in the automotive press.

2.2 Results of the Market Review

2.2.1 Current and short-term availability

As mentioned previously, current availability refers to the number of models available for purchase in Europe today. Short-term availability is defined here as all future named models which have been named by the OEMs and have been given an expected production date. This excludes most concept cars or prototypes and generally limits the scope to approximately 3 years into the future.

Figure 1 below shows the cumulative availability of Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) in Europe, from 2010 to 2020. It shows how the number of models available to European customers has been rising steadily over recent years. This is in large part as a response to new car CO_2 standards in Europe (95 gCO_2/km by 2021[4] for average new car emissions) and equivalent measures in other international markets.

The market review showed that in 2017, there were 19 BEVs and 26 PHEVs available for purchase in Europe, representing a large increase compared to 2010 when only 3 BEVs and no PHEVs were available. For comparison, a study carried out by Transport and Environment (T&E) recently reported that there were over 417 vehicle models available to European customers with petrol and diesel internal combustion engines (ICE) [5]. This indicates that there is a significant lack of choice for customers looking to buy an EV powertrain vehicle from their preferred brand. For example, within the B-segment 'supermini' category there are BEVs offered by Renault (the Zoe) and BMW (the i3), but no BEV versions are available in most of the bestselling models in that segment such as the Ford Fiesta, VW Polo or Opel Corsa.

[4] European Commission Climate Action Website: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en

[5] T&E (Sept. 2017) - Carmakers failing to hit their own goals for sales of electric cars: Missed targets due to a lack of choice, availability and marketing

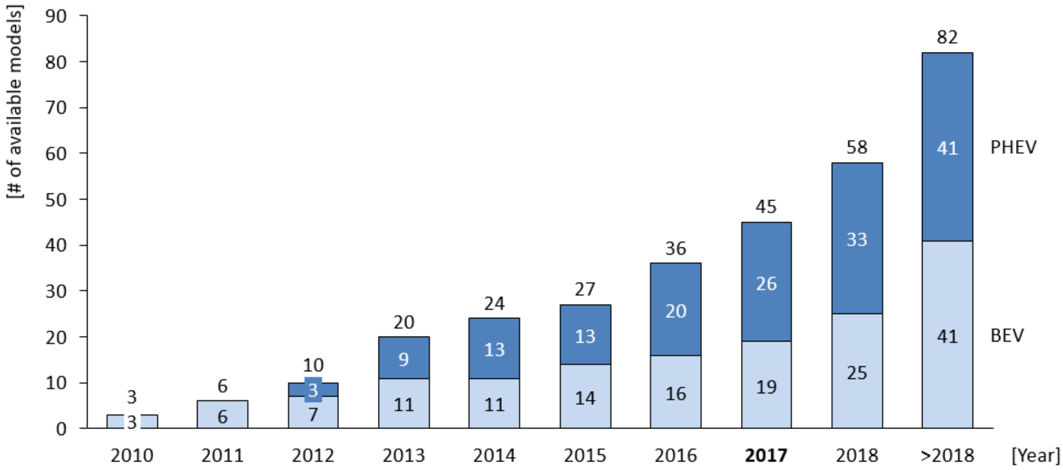

Figure 1 Current and short-term model availability in Europe

Figure 2 and Figure 3 show how BEV and PHEV models are distributed across the various car market segments, where segment E+ comprises segments E and above. The first thing to be noted when comparing the two figures is that PHEVs models are concentrated in the large and premium car segments with no models available in the A and B segments until 2017, while BEVs are spread out more evenly across the segments.

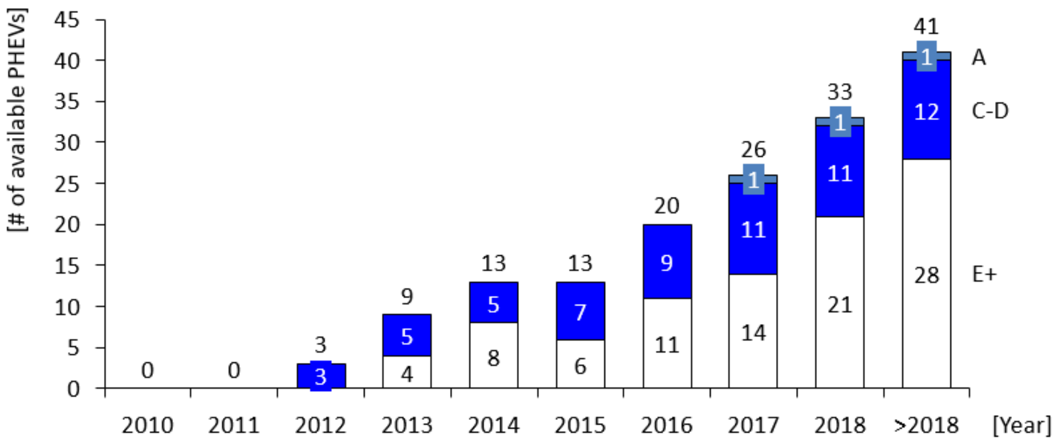

Figure 2 Availability of PHEVs in Europe by Segment

There are several reasons for OEMs' focus on the larger segments for PHEVs. The first is that larger vehicles have higher emissions than small ones on average, and so the CO_2 reductions from a PHEV powertrain are higher than for a small car. Secondly, larger cars tend to cover higher mileages (as they are used as company cars or primary cars for households), and have been less suitable for first generation BEV powertrains with limited driving ranges. Thirdly, PHEV powertrains require sufficient packaging space for an engine, traction battery and fuel tank which is more practical to integrate into large vehicles.

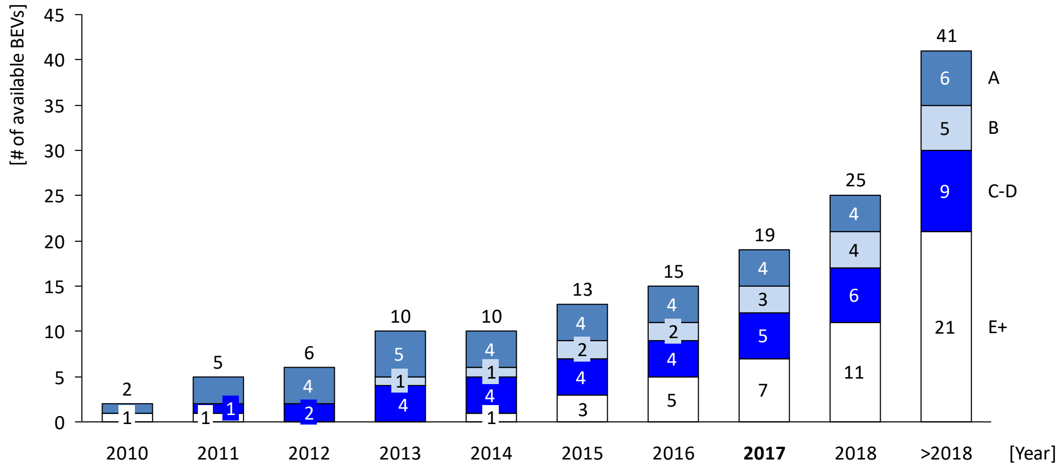

Figure 3 Availability of BEVs in Europe by Segment

In the BEV market, the opposite trend was prevalent until recently, with BEVs concentrated in smaller vehicles (with Tesla being the exception). This focus on smaller vehicles was consistent with minimising battery pack sizes while the cost per kilowatt-hour was high, and appealing to drivers in two-car households for whom low range vehicles could meet their mobility needs. In the coming years, BEVs are expected to be introduced into larger vehicle segments like large sedans and SUVs, with models including Jaguar I-Pace and Audi E-Tron.

2.2.2 Medium-term availability

Medium-term availability data, defined here as the availability of BEVs and PHEVs up to 2025 as projected by OEMs, exist in the form of expected EV sales volumes, expected EV market shares and general announcements on the expected number of production models with electrified powertrains.

The prevalence of OEM announcements with a focus on electrified vehicles has been increasing; the majority of major OEMs have stated targets or expectations in terms of available models and EV sales. This suggests that they recognise both the need to electrify their portfolios to meet future CO_2 targets, as well as the potential customer demand from competitively priced, long range electric vehicles.

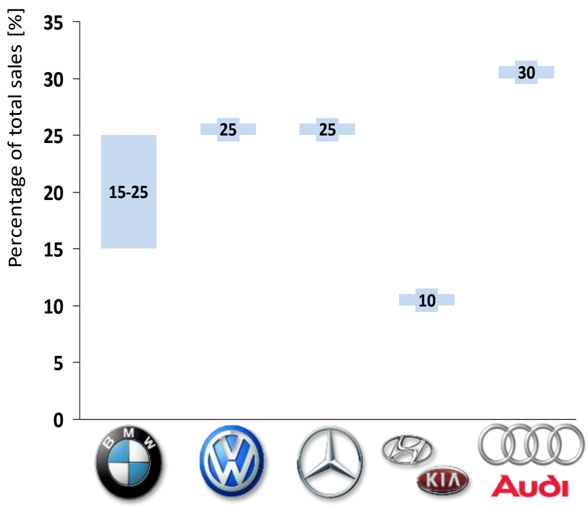

Figure 4 Sample of OEM electrified vehicle sales targets

Figure 4 gives a sample of OEM targets in terms of percentage of vehicle sales which they expect will be partially or fully electric by 2025.

Along the same lines, Mercedes-Benz intends to sell 100,000 EVs per year by 2020 (with 2015 global sales including all powertrains of c. 2 million units), Nissan expects that 20% of its EU sales will be electric by 2020 and Volvo announced that a goal to sell 1 million electrified cars by 2025.

With regards to model availability, VW Group has announced it will have 80 new BEVs by 2025 and that it wants to electrify its whole portfolio by bringing at least one electrified version of each of the 300 or so Group models across all brands and markets by 2030[6]. Jaguar has promised that 50% of its production vehicles will be available with EV or PHEV powertrains and Honda has announced that it aims to electrify two-thirds of its line-up by 2025.

Mazda, an OEM which has to date favoured improvements in internal combustion engine technology rather than electrification, has announced that it plans on electrifying all its offerings by 2030[7] as well as concluding a deal with Toyota which will partner them up to build an EV assembly plant in the U.S. with a value of $1.6 billion.

It should be noted that there is often some ambiguity in these medium-term OEM announcements, in terms of how 'electric' or 'electrified' vehicles are defined. For example, Volvo recently announced the following about its future electrification plans:

> *"Volvo Cars, the premium car maker, has announced that every Volvo it launches from 2019 will have an electric motor, marking the historic end of cars that only have an internal combustion engine (ICE) and placing electrification at the core of its future business."*

This was reported by many media outlets as Volvo producing only BEVs and PHEVs from 2019 and ceasing production of ICE vehicles. In fact, Volvo's commitment is to make all new models launched in 2019 or beyond electrified to some degree, from mild hybrid powertrains to PHEVs or BEVs. Models introduced before 2019 will presumably continue to be produced with standard internal combustion until their next refresh cycle. This underlines the need for caution when interpreting OEM statements to avoid misleading expectations of how many PHEVs and BEVs will be available in future model portfolios.

2.2.3 Anecdotal evidence and recommended further research

The data above considers availability in terms of the number of models offered to the market by OEMs. An additional dimension of availability is the extent to which electric vehicles can be found at dealerships or ordered without excessive waiting times.

For example, T&E showed that "available" models were not always available in showrooms and dealerships – notably the Opel/Vauxhall Ampera and Ampera-E (the European name for the Chevrolet Bolt). Indeed Opel dealers in Norway were recently instructed to stop taking new orders for the Ampera-E so it is not currently available for purchase[8]. Furthermore, it was found that others models which *were* available in showrooms may have long waiting times due to lack of manufacturing capacity, like the Hyundai Ioniq electric and BMW i3[9]. US studies have highlighted several other issues such as dealerships not making electric vehicles prominent in their showrooms, not knowing about available incentives or failing to have charged EVs ready for test drives[10].

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6 (VW Group 2017) "The Volkswagen Group launches the most comprehensive electrification initiative in the automotive industry with "Roadmap E"" https://www.volkswagenag.com/en/news/2017/09/Roadmap_E.html

7 http://autoweek.com/article/rumormill/mazda-electrify-all-its-models-2030-report-says

8 https://electrek.co/2017/10/20/chevy-bolt-ev-opel-norwegian-dealers-stop-taking-orders/

9 Transport & Environment (2017) - Slow electric car uptake due to lack of choice, availability and marketing spend – report

10 See for example https://www.sierraclub.org/sites/www.sierraclub.org/files/uploads-wysiwig/1371%20Rev%20Up%20EVs%20Report_09_web%20FINAL.pdf

These trends are likely due to several factors, such as lack of knowledge among dealership staff of electric models, lower margins on current generation EVs, and a longer sales process from would-be EV buyers who may have lots of questions about the technology, suitability for their needs, incentives etc. There may also be an additional concern over lost aftersales revenue from electric vehicles requiring less maintenance than conventional vehicles, which encourages dealers to prioritise selling the latter.

Traditionally, car sales teams are highly familiar with the features of internal combustion engine vehicles, and refuelling is already familiar to almost all customers. However, customers who want to buy an EV will tend to have more questions about the car, related to the technology itself (vehicle features or charging infrastructure) or tax benefits/incentives. Mystery shopper studies in the US suggest that a lack of knowledge on EV-specific features contributes to a negative customer experience, which in turn gives dealers an incentive to focus on selling petrol or diesel vehicles [11].

Another aspect which seems to hinder EV sales is that salespeople feel like they can sell ICEs faster and receive larger commissions[12], partly because customers know what they are buying and tend to ask fewer questions but also because of the larger margins they make on ICEs.

Finally, dealerships' largest source of revenue tends to be their service department. As EVs require less maintenance than their ICE counterparts, selling an EV potentially reduces profit margins on the initial sale but also on the future revenues from the after-sales department. This potentially creates a stronger incentive to sell conventional vehicles than ZEV models. It is not yet clear whether this will change in the longer term, as other EV-specific services or parts replacements (for example battery upgrades or replacements) provide revenues to compensate the lower annual maintenance income revenues. For example, the Renault connected car services for their battery electric vehicles (which allow remote activation of heating and cooling among other features) require a monthly subscription after the first year. Some of these revenues would go directly to the manufacturer rather than the dealer, so there remains an element of risk for dealers in terms of the certainty of revenues for petrol/diesel cars and the potential revenues for BEV servicing in the future.

Recommended further research

For a deeper understanding of influencing factors and their effects on the actual availability of current models, more real-world data for the EU is necessary for analysis. This could be achieved through surveying potential customers and EV owners about the sales experience, or through a 'mystery shopper' study where researchers visit dealerships directly to compare the sales process for conventional and electric cars. Finally, anonymous surveys of dealerships or sales teams by industry associations could highlight attitudes to EVs and the reasons for differing customer experiences from the dealers' perspective.

Such field work could be carried out across different OEMs and Member States, to highlight any systematic differences in customer experiences. Repeating this survey work at regular intervals would also be valuable, as it would highlight whether these issues persist in the future, or whether they disappear for next-generation ZEVs with sales margins closer to industry norms and as dealer knowledge improves.

Finally, this work would benefit from input from large fleet owners and lease companies, which buy large numbers of vehicles and would be able to provide useful data on model

[11] https://its.ucdavis.edu/blog-post/the-future-of-electric-vehicles-part-1-car-dealers-hold-the-key/

[12] https://cleantechnica.com/2015/12/03/car-dealers-dont-like-selling-evs-no-duh/

availability, waiting times and the relative competitiveness of offers for conventional and low emissions vehicles.

3 Affordability of ZEVs

The previous section assessed how the availability of ZEVs will increase in the short and medium term. This section considers the affordability of ZEVs relative to conventional petrol and diesel cars, building on the TCO analysis in the previous study. It approaches the affordability of BEVs/PHEVs from three different angles, namely:

1. How financing deals can affect a vehicle's TCO in comparison to outright ownership for a range of powertrains. This includes an analysis of available data to see if current leasing deals are systematically more or less favourable for ultra-low emission vehicles compared with petrol or diesel cars
2. How the recent diesel developments such as the 'Dieselgate' scandal and announcements on potential tax changes and city bans have affected residual values of diesel cars, which in turn affects the relative TCOs of other powertrains.
3. Investigate alternative, shared ownership models which are available to customers (and others currently under development) to see how they compare to traditional personal ownership models in terms of the costs of mobility per year or per kilometre.

Note that this study has not considered financial incentives for low emission vehicles that can be implemented at a Member State or local level. These incentives include exemptions from registration taxes, dedicated purchase incentives, free city parking or car ferry use (for example in Norway), or 'convenience' benefits such as permission to drive in bus lanes. These incentives have a very strong effect on the relative costs of different vehicle powertrains and have been covered in detail in numerous studies such as in the ICVUE (Incentives for Clean Vehicles in Urban Europe) project, the overview of incentives in different member states by ACEA[13], a 2017 study by the EU Joint Research Centre[14], and a report on the correlation between incentives and market share by the ICCT[15]. In addition, BEUC will publish a series of country-specific case studies examining how the TCOs of low emission vehicles are influenced by national incentives. Given this detailed prior work, incentives are not revisited here, and instead the focus is on other market factors that influence the affordability of EVs such as the financing costs and depreciation listed above.

3.1 Financing

3.1.1 Methodology and data acquisition

The type of financing which was analysed for this study is a lease with an option to purchase. In the UK these are known as Personal Contract Plans (PCP), while in French-speaking countries they are termed Location avec Option d'Achat (LOA, or rental with an option to purchase). These are contracts where the customer pays a deposit at the start of the first month, chosen here as c.10% of the purchase price of the car for consistency. Subsequently, the customer makes pre-defined, fixed monthly payments over a period of 2 to 4 years. At the end of the contract period, the customer is given 3 options:

1. **Purchase Option:** the customer pays a final payment, usually called a "balloon payment" and becomes the owner of the previously leased vehicle

[13] https://www.acea.be/uploads/publications/EV_incentives_overview_2018_v2.pdf
[14] https://ec.europa.eu/jrc/en/news/fiscal-incentives-how-do-they-impact-electric-vehicle-sales
[15] https://www.theicct.org/sites/default/files/publications/ICCT_EVpolicies-Europe-201605.pdf

2. **Renewal Option:** the customer can hand back the car (subject to fees for damage beyond 'fair wear and tear') and sign a new lease deal on another vehicle[16]
3. **Give the car back:** customer hands the car back, subject to damage and over-mileage penalties.

The option investigated for the purpose of this study is 3rd one. The customer hands the car back and it is assumed here that no penalties are incurred (since costs for minor paintwork/wheel damage are likely to be similar for different powertrains). Assuming a 4-year contract is chosen, this makes PCP/LOA contracts and previously modelled 4-year TCOs highly comparable. For all intents and purposes, the TCO for a leasing contract is simply the sum of the deposit, additional monthly payments and other running costs over the contract duration (insurance, maintenance and fuelling, with finance costs being included in the lease payments). The total paid by the end of the contract is a good indicator of the depreciation dealerships/ leasing companies believe the vehicles will experience over the contract period. This is in contrast to 'full service leasing' (available to private customers and fleets) where the monthly payments cover the depreciation of the vehicle plus the majority of the other costs of vehicle use such as maintenance, tyres, insurance, fuel management with fuel cards etc.

Most OEMs websites provide interactive PCP/LOA calculators which require a deposit, contract length and average annual mileage as inputs. As outputs, the calculator provides estimated monthly payments, optional final payments, interest rates, government grants

[16] In the UK, PCP monthly payments are based on an assumed 'Guaranteed Minimum Future Value'. At the end of the term, the residual value of the car is usually above this GMFV, and so the surplus paid by the customer through their monthly payments (known as equity) is available for use as the deposit for the next vehicle. This makes renewal of PCP deals with a new vehicle more favourable than purchasing the car or not renewing. Though this is specific to the UK, leasing with a purchase option is available across European Member States.

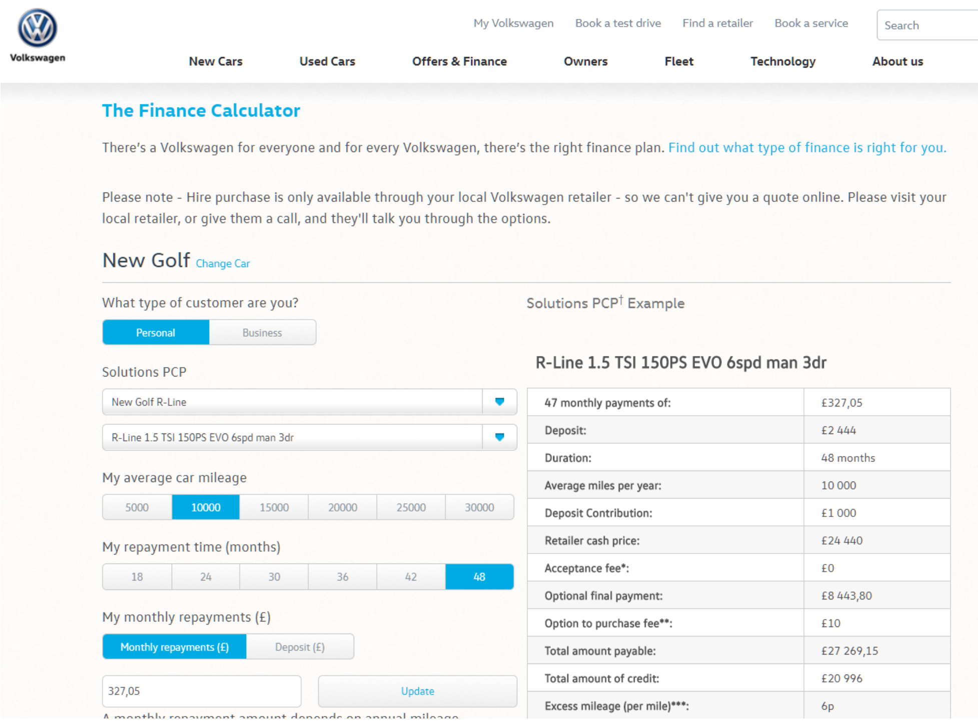

Figure 5 Screenshot of VW UK PCP finance calculator

(when available) and excess mileage penalties. An example of a calculator interface, taken directly from the VW UK website is shown in Figure 5.

Outputs from the finance deal calculators were compiled in an Excel database for a range of vehicles, OEMs and powertrains. The percentage of purchase price paid by the end of the contract was found for each vehicle before being categorised by powertrain (petrol ICE, diesel ICE, petrol PHEV and BEV). Then the average percentage paid over the leasing period was found by powertrain to allow for comparison between leased and purchased vehicle costs.

It should be noted that Personal Contract Plan products are highly popular in the UK, whereas lease products in other Member States tend to be a mixture of personal contract hire (long term car rental with no option to purchase the vehicle at the end of the term) or a traditional lease with purchase option. PCP/LOA offers were used for this exercise since finance offers are widely available on OEM websites (particularly in the UK and France) in contrast to different lease offers (PCH or full-service leasing) which are also widespread but usually require individual discussions with dealerships or lease companies to access detailed cost information. Since the purpose of the analysis was to compare the difference between powertrains rather than the absolute costs, the use of PCP/LOA data is likely to be relevant for markets where other lease products are available. As cross-check, where the data was available, data on PCH offers on manufacturer websites in France were collected. Although outright comparison is difficult due to many PCH contracts lasting three years rather than four, it was found that the relative differences between powertrains were broadly consistent with results using PCP/LOA offers.

3.1.2 TCOs compared for outright purchase and financing

The average leasing deal figures by powertrain for the purchase price, deposit and monthly payments were compiled form a sample of 47 different PCP leasing deals from both the UK and France (13 BEVs, 8 Petrol PHEVs, 14 Diesel ICEs and 12 Petrol ICEs) and are presented in Table 1 below. The final column of the table shows what percentage of a vehicle's cash purchase price - on average - has been covered by the initial deposit and monthly payments by the end of a 4-year leasing contract. Note that this does not include purchase grants included in markets like the UK and France, which have the effect of lowering the percentage of the purchase price paid over 4 years by lowering the starting price as seen by the customer.

Table 1 Average leasing deal characteristics by powertrain

Powertrain	Purchase Price [€]	Average Deposit [€]	Average Monthly Payments [€]	Average % of purchase price paid over 4 years
Petrol ICE	21 408	2180	318	70
Diesel ICE	28 011	2803	372	66
Petrol PHEV	33 691	3179	477	65
Electric	25 888	2996	371	63

Based on the previous study's findings, one would expect to see higher purchase prices for electric vehicles than diesel ICEs along with a smaller difference between BEVs and PHEVs. This apparent anomaly is explained by the tendency for diesel cars and PHEVs to be concentrated in larger vehicle segments, as shown in Figure 2 and Figure 3, while BEV models are more spread out across segments with many comparatively small models available for purchase. Although this pushes average PHEV prices up and BEV prices down, this study focuses on average quantities paid over four years as a percentage of the original purchase price. Assuming depreciation as a percentage of purchase price is uniform across segments, this method allows for direct comparisons to be made.

The comparison above is based on the average prices and lease costs of the PCP offers found. Direct comparisons within a segment or a particular model are challenging, since there are few models available with all four different powertrain options and relatively low numbers of models within each segment. An exception is the VW Golf, which is available in petrol, diesel, petrol PHEV and BEV variants. The proportion of the purchase price paid over a 4 year lease is 75%, 76%, 64% and 66% for the respective powertrains, which is in broad alignment with the results in Table 1.

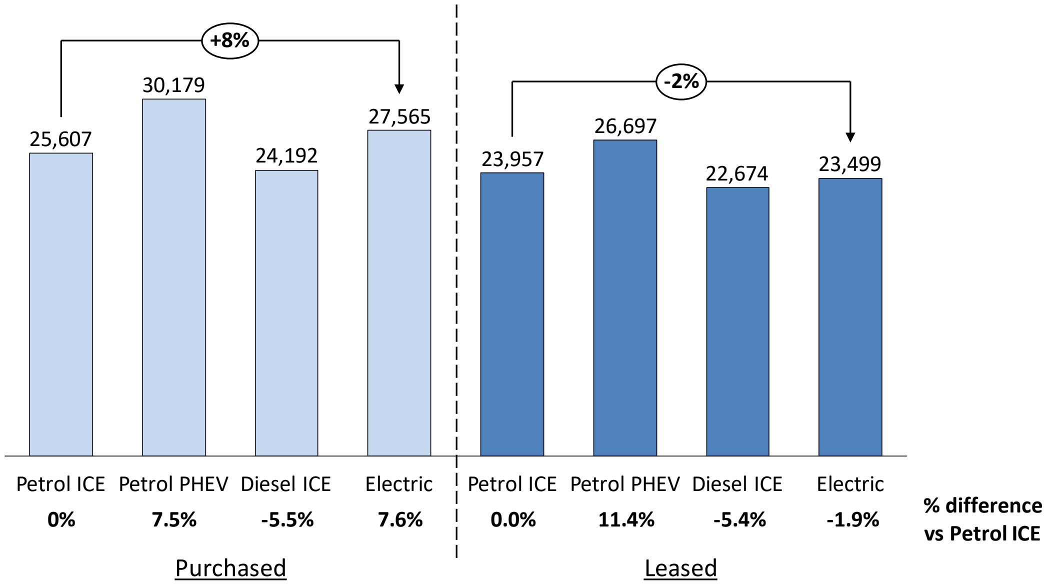

Figure 6 Outright ownership TCO from previous study compared to leasing TCO for a C-segment vehicle

Figure 6 gives the average TCOs for C-segment leasing deals alongside the previous study's findings for outright ownership. The numbers under each bar in the chart show the percentage difference in TCO between each powertrain and either a leased or owned petrol ICE. The results show that according to available data, leasing deals tend to be cheaper over the 4-year ownership period than outright purchase for all modelled powertrains. It also shows that leasing deals tend to reduce the TCO gap between ICEs and electrified cars, with C-segment BEVs being 1,958 EUR more expensive than equivalent petrol ICEs over the ownership period to costing 458 EUR less in the leasing case.

It might be expected that lease deals are systematically less competitive for ZEVs compared to petrol/diesel cars, due to lower margins on the vehicle itself or pessimistic assumptions made by finance companies on the residual values of ZEVs. In fact, the opposite was found to be true. Table 1 shows that by the end of the leasing deals, a smaller percentage of the total value of the car has been paid for BEVs than any other powertrain, suggesting a relatively optimistic assumption on future residual values for ZEVs. It should be noted that the sample size for this analysis was by definition limited by the number of ZEV models on the market. Repeating this analysis in future would allow other trends to be determined, for example whether increasing ranges or higher charging speeds of new ZEVs depresses residual values of older models (and hence makes lease deals less competitive), and whether battery upgrade programmes for older EVs (as announced by BMW and Renault) help to support prices of used cars.

3.2 Residual Values of Diesel ICEs

3.2.1 Methodology and Data Acquisition

Element Energy's previous study made several assumptions on the rate of depreciation of ICEs and ULEVs. Emerging evidence suggests that increasing awareness of diesel pollution (since the VW emissions scandal) and the potential for tax changes and urban access restrictions are beginning to affect values of used diesel cars. Compounding the issue, announcements have been made by countries such as the UK and France that diesel and petrol ICEs will be banned for sale by 2040[17]. A German federal court has ruled that cities that exceed air quality limits can ban older diesel cars without seeking authority from the national government and the Netherlands recently confirmed plans on an outright ban on new petrol and diesel sales by 2030[18]. In Norway, where as a percentage of all sales, BEVs made up 29.1% of the market in 2016 and a record-breaking 42% of all sales in June 2017, a ban on petrol and diesel sales is planned for as early as 2025.

Desk-based research was carried out by compiling anecdotal evidence from news outlets, automotive magazine websites and car forums as well as reviewing recent, but scarce, residual values data which is starting to emerge from companies that specialise in used car data aggregation and analysis such as Cap HPI and Motorway.co.uk.

Motorway.co.uk recently released data which show that the average value of diesel variants of the UK's top 10 most popular second-hand car models fell by 5.7% between the first and third quarters of 2017.[19] The data also showed that in some extreme cases, such as for the Vauxhall/Opel Corsa, diesel ICEs had lost up to 26% of their value. It should be noted that these large percentages are for relative changes in price for cars with relatively low purchase prices. A 26% drop in the value of a Vauxhall Corsa translates into an absolute loss of £568 on an initial value of £2,160.

Figure 7 below gives an overview of these findings and compares average differences in diesel ICE residual values with the differences in value perceived by their petrol counterparts. Interestingly, over the same period in 2017, petrol ICE vehicles increased in value by an average of 5%, with some vehicles such as the VW Polo increasing by as much as 19.3%.

The effect of uncertainty, resulting from expected diesel bans, on residual values is becoming apparent in Germany, where a diesel sales ban was approved for Stuttgart and Dusseldorf on the 27th of February 2018[20]. A study by Autovista Group estimates that there will be a 1% decline in diesel residual values in both 2018 and 2019 while the German Dealer Association claim that both new and used diesel car prices have dropped by 10-20%[21]. Similar trends have also been observed in other European markets, particularly those discussing diesel bans[22].

17 https://www.theguardian.com/business/2017/jul/06/france-ban-petrol-diesel-cars-2040-emmanuel-macron-volvo

18 https://electrek.co/2017/10/10/netherlands-dutch-ban-petrol-diesel-cars-2030-electric-cars/

19 https://motorway.co.uk/blog/2017/9/11/press-release-used-diesel-car-values-drop-6-toxin-tax-diesel-scrappage-scheme-announcements-begin-bite

20 https://www.thelocal.de/20180227/federal-court-gives-green-light-for-diesel-ban-in-german-cities

21 https://rmsautomotive.eu/german-dealer-lobby-warns-of-10-20-used-and-new-diesel-price-declines/

22 https://www.fleeteurope.com/en/remarketing/europe/analysis/when-will-diesel-residual-values-stabilise

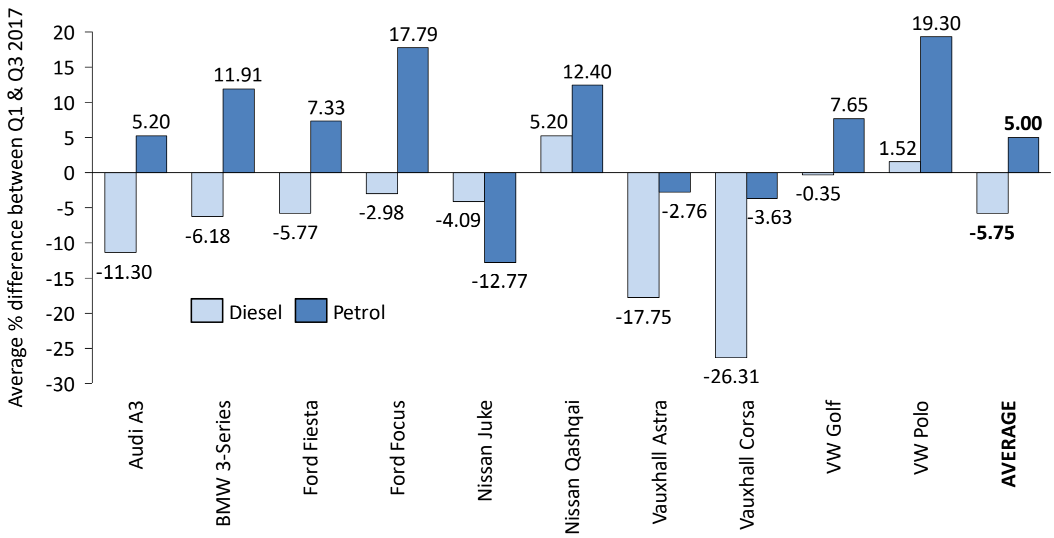

Figure 7 Percentage difference in average residual value between Q1 & Q3 2017 of 10 most popular models in UK (Source: Press release on Motorway.co.uk)

Cap HPI has refuted this claim, saying that more detailed information on the vehicles was necessary on top of a wider view of the market, as Motorway.co.uk only compiles online valuations from dealer websites. Results from Cap HPI's year-on-year deflation analysis of black book values showed that, while there is variation by sector, overall diesel depreciation between January and September 2017 was only c.2% worse than historical averages when accounting for seasonal changes and other factors linked to the age and condition of the vehicles[23].

In light of the available evidence, three modelling scenarios were chosen:

1. **2% drop:** A base case where residual values are 2% lower than assumed in the previous model. This value includes seasonal variations and compares vehicles of similar age, mileage and condition at the time of sale.
2. **5% drop:** This represents the average value for a fleet composed of all the second-hand diesel ICEs in the UK which were included in the motorway.co.uk analysis (10 most popular models).
3. **25% drop:** An extreme case because if diesel bans materialise and become more pervasive (and are applied even to the latest diesel vehicles in the medium to long term), large reductions in residual value such as this could be seen, which are in-line with the depreciation for the worst-performing vehicles in the motorway.co.uk analysis.

The third scenario is deliberately extreme, in order to simulate the impact of a large fall in residual values on TCOs and assess the degree of financial risk carried by owners of current diesel cars. Recent evidence from some of the latest diesel models suggests that vehicle manufacturers are reaching very low emissions of particulates and NOx based on the Real Driving Emissions test. For example, Mercedes engines have achieved NOx emission values of between 40 and 60 mg/km[24] in real world conditions while engines equipped with Bosch's new diesel technology have achieved values as low as 13mg/km[25], approximately

23 http://www.am-online.com/news/used-cars/2017/09/15/cap-hpi-responds-to-diesel-depreciation-scaremongering.
24 https://www.daimler.com/innovation/diesel/diesel-debate.html
25 https://www.bosch-presse.de/pressportal/de/en/breakthrough-new-bosch-diesel-technology-provides-solution-to-nox-problem-155524.html

1/10th of the prescribed limit of 120 mg/km that will apply from 2020 on a European level. Average emissions for the tested vehicles were around 40mg/km.

If these results are replicated across all new diesel vehicles receiving type approval in the future, these vehicles are likely to be exempt from diesel restrictions and city bans for the foreseeable future, since their emissions are similar to modern petrol engines. This means that the residual value risk is a more significant issue for vehicles currently on the road (e.g. Euro 4, 5 and early Euro 6 models), than for buyers choosing the best new models on sale today.

3.2.2 Effect of residual value assumptions on Diesel ICE TCOs

The three new depreciation scenarios are presented graphically in Figure 8 and compared to the base case from our original study. It shows how the decrease in residual values increases the difference between the vehicle's initial purchase price and its selling price at the end of the 4-year ownership period.

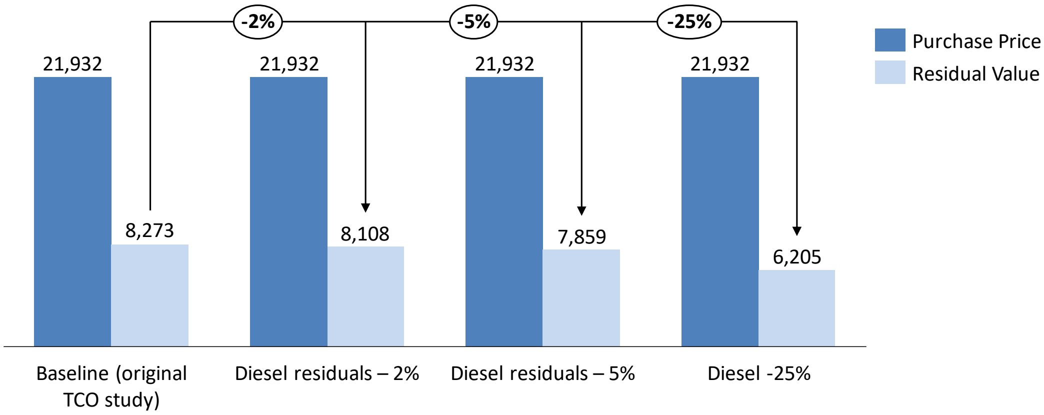

Figure 8 Purchase price and residual value of diesel ICEs for the baseline case and three modelled scenarios

The residual values calculated for each of the three scenarios were used to calculate the TCOs of a new diesel car, presented in Figure 9 below. Each TCO has been divided into its constituent cost components where depreciation is defined as the difference between purchase price and residual value at the end of the ownership period. Also indicated is the percentage difference between each modelled diesel ICE scenarios and the baseline petrol ICE case. As is well known, diesel vehicles make up for their higher purchase prices, when compared to equivalent gasoline counterparts, with lower fuel and maintenance costs over the whole ownership period when yearly mileage is sufficiently high.

What can be seen here is that for the smaller effects being modelled, diesel vehicles' TCO advantage is reduced from 5.5% to 4.9% and 3.9% for Scenarios 1 and 2 respectively. For the extreme case of Scenario 3, the diesel vehicle's TCO is higher than that of the baseline petrol vehicle by 2.6%. This means that the diesel vehicle's lower running costs no longer make up for the additional depreciation cost it incurs over the ownership period.

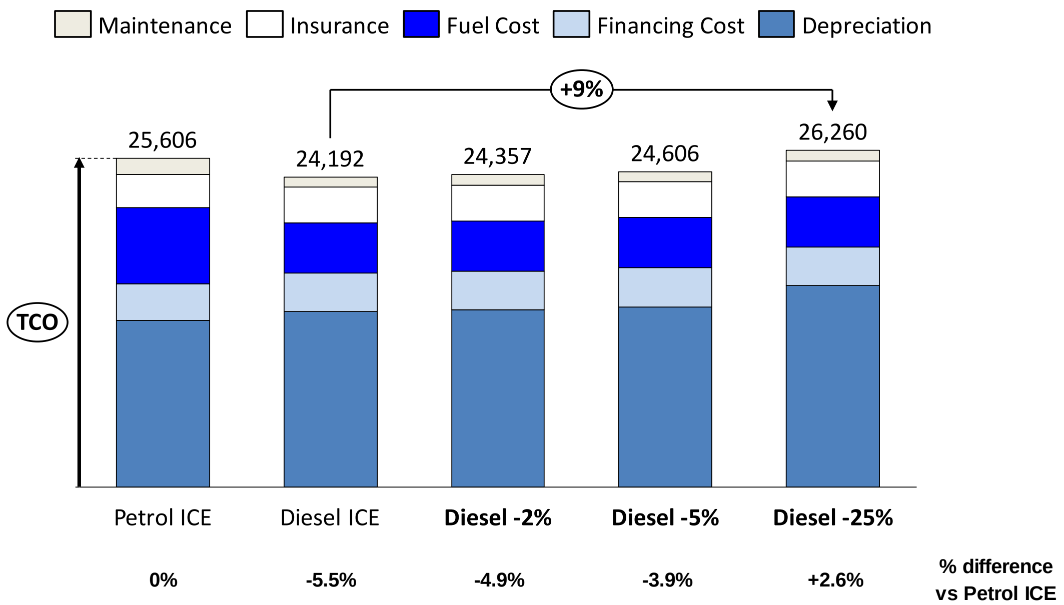

Figure 9 Comparison of TCOs for three modelled scenarios vs gasoline and diesel ICE baseline cases

It should be noted that these impacts on diesel TCOs are relatively minor and in the order of €100s per vehicle, except for Scenario 3. In reality, uncertainty about diesel bans and residual values could have greater impacts on consumer choice than a strict financial analysis suggests, should consumers begin to move away from diesel to avoid the risk of higher than expected depreciation. As discussed above, cleanest new diesel models are easily meeting the Euro 6d limits for NOx and particulates and should not be affected by air quality policies in the near future. However, it is often unclear to customers whether the vehicle they are about to buy meets the Euro6d limits, since this standard does not apply to all new cars sold until 2019. This lack of clarity may cause a perceived risk among diesel car owners until the real-world performance of all diesels (not only the best in class) and the resulting policy positions become clear. However, our analysis suggests that in the most plausible residual values scenarios, the impact of the TCO of BEVs versus diesel cars is limited (in the order of several hundred Euro), and is unlikely to be a key factor driving buyers towards low emission vehicles.

3.3 Shared Ownership Models

3.3.1 Introduction and scenario methodologies

The original TCO study and the lease scenarios in the previous sections are based on private usage of a vehicle by a person or a household. For these private users, the annual mileage of the vehicles is relatively limited (usually less than 15 000km per year), and the vehicles are parked for their majority of their lives. Given the relatively high ownership costs for private cars, there is increasing interest in shared ownership models, where users pay for access to a vehicle or 'mobility' rather than for exclusive use of their own car. This includes mobility as a service (MAAS) type models such as the car2go and Drivenow car-sharing services by Daimler and BMW respectively (the two car-sharing services have recently merged into a single joint venture) and independent providers like Zipcar and Bollore. Existing lease companies are starting offer MAAS packages as a logical extension of full service leasing, for example providing vehicles on a 'pay as you go' basis, or 'lease downsizing', allowing companies to select smaller cars for their employees and making larger vehicles available when required[26].

In addition to MAAS packages, modern ride-hailing services like Uber or Lyft offer app-based reservations and lower costs than traditional taxi companies and can be an alternative to car ownership, particularly in urban area. In this study, modern ride-hailing services were chosen for comparison over traditional taxis as data were widely available on fare structures and driver salaries. In addition, the fare structure for traditional taxis often includes high costs operating licences, such as the c. 200 000€ cost of taxi licence plates in Paris, which makes it difficult to calculate the fundamental vehicle and personnel costs which are the subject of this analysis. Modern ride-hailing services, on the other hand, tend to have a much more transparent cost structure and allow the costs of the vehicle and driver to be distinguished.

Finally, the majority of OEMs such as Daimler, Audi, Tesla and General Motors[27] and new entrants such as Waymo are already exploring the potential of autonomous vehicle (AV) technologies, which could offer the convenience of taxis but without the associated driver costs. This could have significant effects on the economics of taxi and car sharing services relative to personal car ownership.

In this section, the costs of mobility are investigated for four different ownership models to determine how competitive they are with traditional car ownership for different annual driving distances. The models investigated are the following:

1. Ride hailing/taxi with a human driver
2. Mobility as a service (for example one-way car sharing services)
3. Owning an autonomous vehicle and making it available for autonomous taxi
4. Autonomous vehicle ride-hailing as a user

The main characteristics of each ownership model are summarised in Table 2.

[26] See for example: https://corporate.sixt.com/en-gb/mobility-service-maas/
[27] https://www.navigantresearch.com/newsroom/daimler-audi-bmw-and-general-motors-score-highest-in-assessment-of-autonomous-vehicle-original-equipment-manufacturers

Table 2 Shared ownership models: description and characteristics

Type	Description	Payment Structure	Professional Driver?	Self-driving (SAE L5?)
Ride-Hailing	Service is ordered via a mobile application	- No fixed costs - Pay per km or per minute	✓	✗
Mobility as a service	Members of a club can pay to drive cars from a fleet	- No fixed costs - Pay by the minute	✗	✗
Autonomous car (owner)	Owner can allow car to act as taxi when not in use	- Buy autonomous vehicle - Rent as taxi when unused	✗	✓
Autonomous car (User)	User can use autonomous taxi similarly to Uber, Lyft, etc.	- No fixed costs - Pay by the minute	✗	✓

In this section, several assumptions on vehicle operating costs were adapted to account for different duty cycles of cars in taxi and car sharing applications, in particular the higher annual driving distances compared with personal cars. All new assumptions and changes to previous assumptions are described in their respective sections below.

Ride-Hailing – Uber / Lyft

Modern ride-hailing services have been increasing in popularity in recent years due to the ease with which these services are called upon and paid for, in addition to the transparency of the service: up-front pricing information, GPS tracking over the whole journey and full receipts sent to the customer directly by email at the end of the trip.

There is a large amount of publicly available data on the costs of an average fare for services like Uber in different parts of the world. Although the fare is highly dependent on location, average values were found on the website priceoftravel.com[28] which shows the price of a 5km journey for a range of cities around the world. This information was collated for a range of European cities and is presented in Table 3.

[28] "Price of a 5-kilometer Uber ride in 67 cities around the world" (2015) - https://www.priceoftravel.com/6536/price-of-a-5-kilometer-uber-ride-around-the-world/

Table 3 Average Uber fares for a range of European cities[29]

City	€ per 5km journey	€/km
Brussels	6.46	1.29
London	13.50	2.69
Stockholm	7.36	1.47
Paris	10.62	2.12
Milan	5.39	1.08
Lisbon	4.84	0.97
Amsterdam	7.69	1.34
AVERAGE	7.82	**1.57**

A breakdown of the total fare into different components was carried out to separate the running costs of the vehicle from other costs such as driver salaries, cleaning etc. The following assumptions were used to adjust the existing TCO model for to reflect the costs of vehicles used in ride hailing/taxi services:

- Running costs (i.e. fuel and maintenance) increase linearly with distance travelled and the car travels an average of 75,000km per year instead of 15,000 km. The running costs were adjusted by applying a correction factor of 75/15.
- The vehicle's purchase price is fully depreciated over the first 4 years. In reality, vehicles will have a small resale value at the end of this period, but for simplicity we have assumed no residual value after 300,000km of driving.
- "Dead mileage" of 50% where the vehicle is travelling without passengers. These extra running costs and depreciation are fully recovered by being added to the passenger's fare.
- The operating/dispatching company takes 25% of the fare and the drivers keep the remainder, out of which they pay for all other operating costs and personal taxes.
- Cleaning costs for the vehicle are taken as 0.02 EUR/km[30]

Taxi mileages vary considerably, depending on factors such as the length of drivers' average shift and the city in which they operate. Several newspaper sources have given estimates of about 120 miles per day for London taxis which gives 42,000 miles per year (c. 67,600 km)[31,32] and a website for the ECFT ('*Ecole de Conduite et de Formation Taxis*'/Taxi driving school and training) in Paris uses 78,000 km per year as a basis for calculating taxi rental costs[33]. From the above figures and anecdotal evidence found on various French and British

[29] Exchange rates taken on the 10th of October 2017 from www.exchange-rates.org
[30] P.M.Bosch (Aug. 2017) – Cost-based analysis of Autonomous Mobility Services
[31] http://thechargingpoint.azurewebsites.net/news/electric-black-cabs-could-change-londoners-lives-says-ecovelocity.html
[32] http://www.autoexpress.co.uk/car-news/98450/new-tx-electric-london-taxi-priced-at-55599
[33] http://www.ecft.fr/location-taxi-et-autorisation-stationnement-paris.php

taxi forum, an average mileage per year of 75,000km was chosen for investigating ride-hailing models.

Dead mileage assumptions were made on the basis of qualitative and anecdotal evidence from taxi drivers on forums[34,35,36]. Most of the evidence points towards dead mileage of c.50-60% for taxi drivers. A dead-mileage value of 50% is used here.

Another component which must be included in the fare is the driver's wage. Driver wage data was compiled from several sources and therefore was often presented in different units. These figures were converted into units of €/km, based on the assumptions made above, and are presented in Table 4. The €/km values in the final column are gross income values, before taxes and expenses and after Uber's 25% service fee has been removed. For the final fare breakdown – presented in Figure 11 of the results section – the driver's net salary before taxes was found by removing the expenses calculated with the TCO model as well as vehicle cleaning costs. The costs calculated by the TCO model matched those calculated from Uber driver survey data very closely. The survey data (which has been made freely available online) calculated Uber driver expenses to be about 0.29 €/km while the TCO model output estimated them to be just over 0.36 €/km. This difference can be accounted for by higher fuel prices in Europe. For example, on the 9th of October 2017, average prices in the USA were c. $0.72[37] per litre whereas in the EU, prices were closer to c.$1.30-$1.40 per litre[38]. This suggests that the assumptions listed above correctly capture the cost structure of taxi operations.

[34] 53% dead mileage: https://www.accountingweb.co.uk/any-answers/dead-mileage-percentage

[35] 56% from two accounts: https://uberpeople.net/threads/crazy-dead-miles.141783/

[36] 50-60% dead mileage: http://www.taxi-driver.co.uk/phpBB2/viewtopic.php?t=2079

[37] http://www.globalpetrolprices.com/diesel_prices/

[38] http://www.globalpetrolprices.com/diesel_prices/Europe/

Table 4 Data on Uber driver gross income from several sources[39]

Source	€/week (Upper)	€/week (Lower)	€/week (Average)	€/year	€/week	€/km
Gazettereview.com[40]	c.508	c.1016	c.762		765	1.14
Alvia.com (Dublin)[41]				38 100	733	1.09
Alvia.com (London)				64 186	1234	1.83
Alvia.com (Edinburgh)				46 062	886	1.32
London TCI[42]						1.01
US Survey Data[43]						1.14
AVERAGE						**1.25**

The above data on vehicle purchase and operating costs and driver earnings were used to calculate the 4-year TCO for a ride-hailing vehicle travelling 75,000km per year. This TCO was then divided over the "occupied" kilometres, i.e. 37,500km using the 50% dead mileage assumption.

To find the final estimated fare, the drivers' wage was added to the model's vehicle operating costs with an additional 25% margin for the ride-hailing service company. The figure of 25% was taken directly from the Uber and Lyft websites[44, 45].

The values found for the total fare (calculated costs + calculated salary found in Table 4) were validated by comparison with average Uber fares collated in Table 3 as well as figures taken from a newspaper article (The Economist[46]).

Mobility as a service

Mobility as a service-type models like car-sharing services Car2go and ZipCar (or services provided by existing lease companies) are quickly rising in popularity in urban areas all around the world. Car2go has been taken as an example in this case due to the simple and

39 All currency conversions taken from www.exchange-rates.org on 10th October 2017
40 http://gazettereview.com/2017/01/average-uber-salary-income-wages/
41 http://www.alvia.com/uber-driver-pay-by-city/
42 Transport for London – Taxi Fare and Tariff Review 2016
43 https://www.ridesharingdriver.com/survey-data-how-much-uber-drivers-really-make-share/
44 https://www.uber.com/en-MY/drive/resources/getting-your-fares/
45 https://help.lyft.com/hc/en-us/articles/213815618-Lyft-s-commission-structure
46 "From zero to seventy (billion)" (The Economist 2017) - https://www.economist.com/news/briefing/21706249-accelerated-life-and-times-worlds-most-valuable-startup-zero-seventy

transparent EUR/min pricing structure which can be found on the main website. An example of the Car2go pricing webpage is shown in Figure 10.

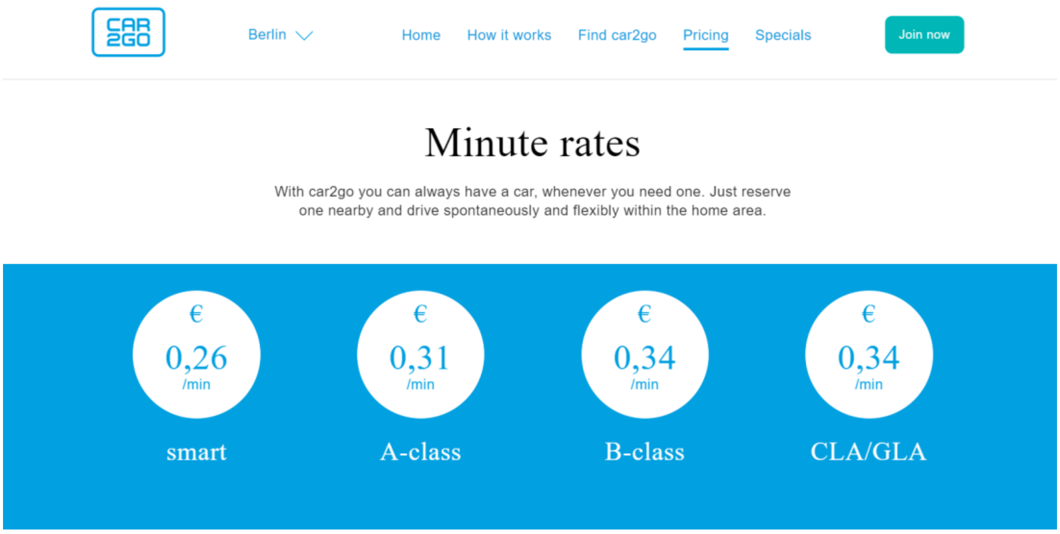

Figure 10 Car2go pricing webpage for Berlin

Prices from the website were compiled for Berlin, Amsterdam, Rome and Munich. From this data, an average cost per hour was calculated. In order to convert this figure into a cost per kilometre, data was collected on average traffic speeds in the centre of major cities. Average speeds vary widely from city to city and from year to year. A study on average speeds in Paris found that they had dropped from 26 km/h in 2000 to 17 km/h in 2013[47]. Average speed in central London in 2017 was above 13km/h (8.3 mph[48]) another website which collated average speeds for 15 congested European cities in 2008, gave a wide range of estimates ranging from 19 km/h to 35 km/h[49]. This shows how inconsistent various estimates are but also shows there has been a general trend for average speeds to drop year by year. From this data, an average speed of 22km/h was used for calculating car sharing costs per kilometre.

As a sense check, using the average speed to calculate the number of hours a driver must work to complete 37,500 occupied km in a year gives c. 9h45min per day for 350 days of work, considering he or she travels 75,000km in total and assuming all of the travel is done in cities. Accounting for time spent outside the centre of the city, for example taking passengers to airports or between cities, will increase average speeds and reduce the calculated working hours). Taking the same speed and multiplying it by a driver's wage per kilometre after expenses (c.0.89€/km) gives an annual salary before taxes of €33,750. These figures agree closely with all the data collected and described in the previous sections, so the value of 22km/h has been used in the analysis below.

Autonomous taxi – powertrain and cost assumptions

Firstly, research was carried out on the additional cost of reaching full SAE Level 5 autonomy, a vehicle in which passengers can travel without a human driver even for back up purposes. A recent study on the costs of automated mobility services used a figure of 20% to add to the purchase price of the car, with the underlying assumption that the

[47] http://www.gescop.fr/uploads/tx_gescopnews/GESCOPmunicipales2014.pdf - "Contribution de GESCOP (Paris 2014)

[48] Financial Times (Aug. 2016) - Traffic congestion: is London running out of road?

[49] https://www.statista.com/statistics/264703/average-speed-in-europes-15-most-congested-cities/

technology has reached maturity[50]. The assumption being that by the time the software is licensed for widespread adoption, the technology going in to the hardware will have reached maturity and the costs will have dropped significantly. An Australian study on the subject calculated that the cost of ownership would increase by $1000-$3000 per year [51] (c.670€ – 2000€ per year[52]) while an Element Energy study for the Centre for Connected and Autonomous Vehicles published a report in 2017 which estimated these additional costs at 4,300 £ (4838€) per vehicle[53] in the long term.

Taking the higher figure of 2000€ per year over four years (8000€) as a conservative assumption sets the cost of automation at c.25% of the purchase price of an electric vehicle for an average BEV price of c.30,000€. In this study, 25% was added to the cost of purchase (and financing) for all calculations involving an autonomous vehicle.

In 2015, KPMG estimated that the cost of insurance for automated vehicles would be a minimum of 40% lower than current insurance policies by 2040 in their baseline scenario due to lower accident rates[54]. Additionally, an NREL study from 2016 estimated that full automation could reduce insurance premiums by 40-80% while a report by McKinsey in 2015 projected reductions of up to 80-90%[55]. For this study, a conservative estimate of 50% reduction on insurance premiums was chosen as a baseline.

It is assumed here that the AV travels 100,000 km per year and that the assumption on residual values falling to zero remains valid. This assumption is made on the basis that AV’s are not limited to working hours, possibly only needing to stop for charging and cleaning. Hence, increasing mileage by 33% from 75,000 km (for ride-hailing vehicles) to 100,000 km for the AV scenario is likely to be a lower-bound (according to the New York City Taxi and Limousine Company, taxis already achieve mileages of 70,000 mi per year – over 112,000 km - without automation[56]). Discussions with a Paris taxi operator using double-shifted vehicles suggest that annual driving distances of 120,000km are possible in 24-hour operation, broadly in-line with a 100,000km assumption for a driverless vehicle. The maintenance costs in the TCO model were increased to account for this higher driving distance. As for the calculations made in the “mobility as a service” section, the assumption is that the AV’s residual value drops to zero after 4 years of ownership and 400,000 km. Hence, the vehicle’s full purchase price is depreciated over 400,000 km, where “dead-mileage” accounts for 50% of the kilometres travelled. Similarly, depreciation and other expenses are charged to customers over the remaining 200,000 km while the operator’s service fee is kept at 25% of the total fare. Dead mileage of autonomous vehicles is highly uncertain, since factors that might reduce it (such as a large user base reducing the average distance to pick up the next passenger) may be outweighed by factors that increase it (such as the low cost per km leading to passengers making one-way trips to remote destinations). Given this uncertainty, the dead mileage assumption of 50% for conventional taxis is retained.

[50] P.M.Bosch (Aug. 2017) – Cost-based analysis of Autonomous Mobility Services

[51] Todd Litman - Victoria Transport Policy Institute (2017) - Autonomous Vehicle Implementation Predictions: Implications for Transport Planning

[52] AUD – EUR exchange rate taken from Google Finance on 25th September 2017

[53] Element Energy, Cambridge Econometrics (Oct. 2017) Market Forecast for Connected and Autonomous Vehicles – Centre for connected and Automated Vehicles

[54] KPMG (Oct. 2015) – Marketplace of change: Automobile Insurance in the era of Autonomous Vehicles

[55] NREL (Nov, 2016) – Estimated bounds and important factors for fuel use and consumer costs of connected and automated vehicles

[56] 2014 Taxicab Factbook – New York City Taxi & Limousine Company

For simplicity, the assumption was made that fully-functional Level 5 vehicle automation for taxis is applied to BEVs only. From a cost point of view, this is logical since the higher purchase cost of a BEV is outweighed by fuel savings over the high mileages expected in autonomous use. However, this is dependent on sufficient battery longevity and access to rapid charging infrastructure to ensure sufficient availability for use by customers. This autonomous BEV powertrain was then compared on a TCO basis to equivalent high-mileage scenarios for other powertrains. For 4 different powertrains (petrol/diesel ICE, petrol PHEV and BEV), costs were split into fixed and variable yearly costs which were then plotted against yearly distance travelled. The most economical powertrain is the one with the lowest yearly costs for the expected travel distance. This is presented with the rest of the shared ownership results below.

Peer to peer car sharing with an autonomous vehicle

For the final ownership model, we consider the potential for owners of autonomous vehicles to make them available for use as an autonomous taxi when not needed for personal journeys. This is similar to existing services for non-autonomous cars such as Ouicar, which allows car owners to rent out their vehicles to cover some of their ownership costs. An equivalent service using autonomous vehicles is the principle of the rumoured Tesla Network, allowing Tesla owners to make their cars available for autonomous taxi use through an app. It is assumed here that the AV owner only seeks to recover some of his or her costs, rather than trying to reduce their net ownership costs to zero over 4 years (which would require higher passenger fees. Assumptions made previously on residual values and total distance travelled apply (residual value falls to 0 after 4 years, 100,000 km per year and dead-mileage of 50%). The same 25% service fee is taken by the service operator and assumptions made on average traffic speed in previous sections hold true.

3.3.2 Results of shared ownership cost analysis

Full Cost structure of modern ride-hailing services

As mentioned above, the data used for calculating driver wages came from a range of sources. These came in different units but were converted into €/km values as described in the previous section.

An average fare per km for a modern ride-hailing service was calculated as described previously, the result of the analysis is shown graphically in Figure 11. As this figure shows, the study's analysis of all the costs resulted in an estimate of 1.67 €/km for the price of an Uber fare. This matches calculated values from Table 3 very closely with a difference of only c. 6% between the two estimates.

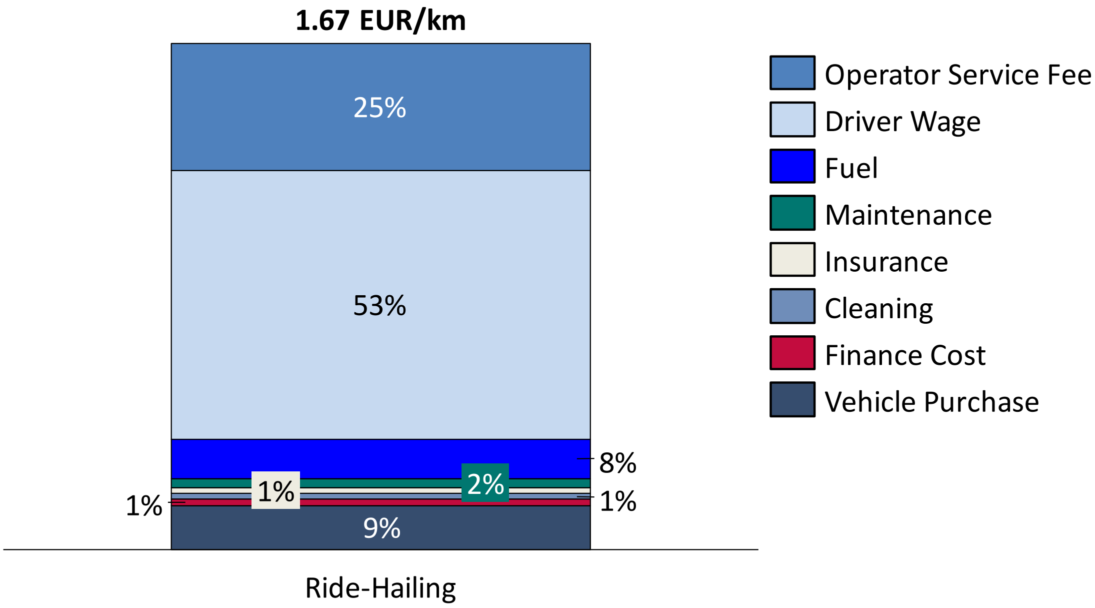

Figure 11 Breakdown of costs covered by an average ride-hailing fare

The analysis shows that the driver salary is the single biggest component of taxi costs, making up 53% of the fare paid by the passenger. For the high driving distances covered by taxis, vehicle depreciation is a relatively minor part of the total cost (at 9%), in contrast to private car ownership where depreciation is the largest component. Understanding taxi cost structures in this way allows the costs of mobility with future driverless vehicles to be simulated.

Autonomous taxis with electric powertrains

Before comparing the various shared ownership models, TCOs for the different drivetrains were compared for the high-use, high-mileage, autonomous case to assess whether BEVs are competitive with conventional vehicles in this role.

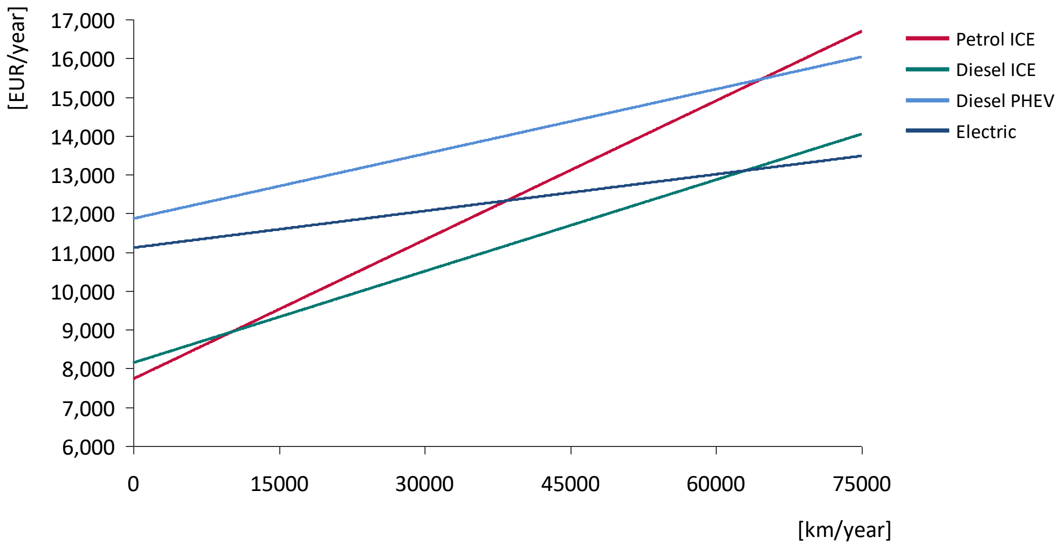

Figure 12 Yearly cost of ownership dependent on distance travelled for four different powertrains

Figure 12 shows that although EVs are more expensive to purchase, they become more and more competitive with petrol and diesel cars as the mileage increases. A BEV becomes cheaper per year than a petrol car at a threshold of 40,000km per year and is more economical than diesel when travelling over c.60,000 km per annum. The results demonstrate that high-use and high-mileage scenarios work in favour of the lower operating costs linked to EVs even at current battery prices, and this advantage will grow as technology costs fall in the future. A driving distance of 60,000km per year is 165km per day, which is achievable for the next generation of BEVs with real-world ranges above 300km. A remaining challenge for BEV taxis is access to charging infrastructure in cities, since a large fleet of autonomous vehicles would require significant numbers of charging points to supply their energy needs. Part of this is mitigated by the fact that demand for transport varies throughout the day (and night), allowing downtime for vehicles to charge outside peak periods. In cities where strong space or network constraints limit the operational feasibility of BEVs at large scales, other zero emission solutions such as fuel cell electric vehicles may be required alongside BEVs.

Comparison and discussion of shared ownership models

The results of the analysis and ownership model comparison are presented in Figure 13. The results show that modern ride-hailing services are significantly more expensive per kilometre than other mobility services such as car sharing, primarily due to the costs of the professional driver. For users who travel under c.3000km per year, ride-hailing is still a viable option in comparison to outright ownership of a car. The figure shows that today, mobility services such as car sharing/car clubs are the cheapest method of transport for users travelling under c.8,000 km per year. These findings show that for a large proportion of the population, car-sharing (mobility as a service) is currently the cheapest mobility solution, explaining its growing popularity and the increasing number of companies entering this market in European cities. Alternative mobility options are compared to outright ownership below. Lease arrangements such as full service leasing (where the customer pays monthly for an integrated package covering all costs of running a car), may in some cases be slightly more favourable than ownership although the costs are broadly similar since it is still fundamentally a vehicle used exclusively by one person and hence without any sharing of the asset cost between users.

After integrating future AV cost assumptions and adjusting for high-mileage scenarios, Figure 13 shows what the cost of using an autonomous taxi could look like as a function of the distance travelled per year. Again, these figures assume that the autonomous taxi is empty for 50% of the travelled distance and the standard service fee is included for the operator. It is very likely that dead mileage will be reduced when a fleet of AVs, under a single operator's control, can be dispatched as efficiently as possible, in a way that minimises operating costs and maximises profits. Additionally, reduced purchase prices for fleet operators as well as insurance and maintenance packages could potentially reduce the costs of autonomous vehicles further.

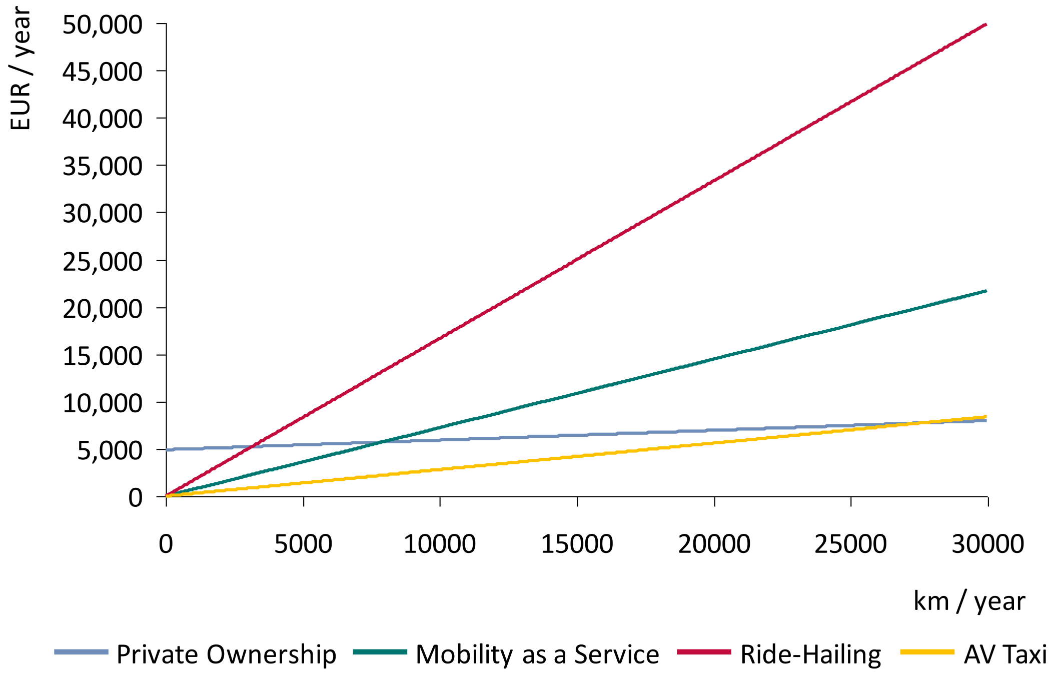

Figure 13 Cost of mobility for different ownership models depending on yearly distance travelled

This suggests that the actual AV CAPEX and OPEX could be significantly lower than Figure 13 suggests. According to this study, even with the inflated prices necessary to cover costs and produce a profit, autonomous taxis are cheaper than outright ownership up to just under 30,000km per year.

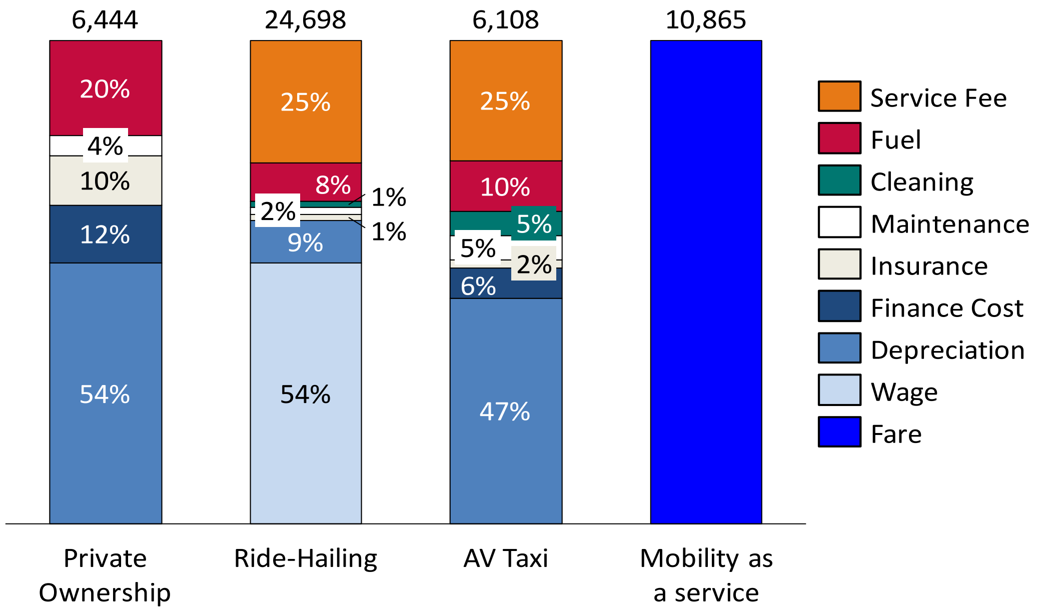

Figure 14 Relative cost structures for various mobility models at 15,000 km per year

The original study, which these models are based on, focussed on TCOs for an average distance travelled of 15,000 km per year. For ease of comparison with previous results, presented in Figure 14 and Figure 15 are the breakdowns of mobility costs at 15,000 km for each of the studied ownership models. Figure 14 does so in relative terms, showing the proportion of costs belonging to each category while Figure 15 simply shows the absolute cost breakdown at 15,000 km. Note that the costs in both figures are from the point of view of the user rather than the service provider (for example in the case of ride hailing or an autonomous taxi).

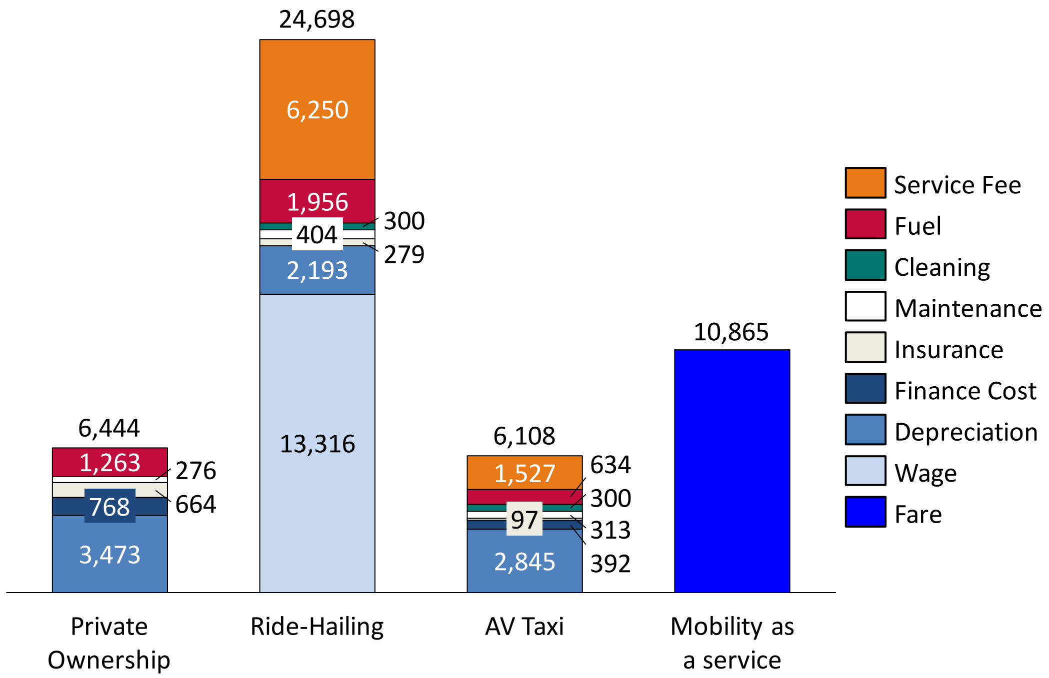

Figure 15 Absolute cost structure of various mobility models at 15,000 km per year for a vehicle/service user

Figure 15 highlights the substantially lower costs of autonomous electric taxi compared to a diesel vehicle with a professional driver. By removing the driver and lowering fuel and insurance costs, costs to the end user are reduced by approximately 75% per km. The future service fees for autonomous taxis are not yet clear. They are assumed here to be a fixed percentage of the other operating costs, which has the effect of lowering service fees for the lower cost autonomous taxi option. In reality service fees may not fall by the same proportion and in that case would make up a higher percentage of the total operating costs. This would mean that autonomous taxi fares for passengers would fall somewhere between private ownership and conventional taxis.

Sensitivity analysis for depreciation and dead mileage assumptions

The analysis so far has assumed that the car is fully depreciated after 4 years, by which time the autonomous taxi has travelled 400,000km. Firstly, this is likely to be a conservative estimate, resulting in a relatively high depreciation cost per km which must be included in the customer's fare. Secondly, the main component of a BEV that determines a vehicle's lifetime is the battery, which is normally replaced when c.70-80% of the original capacity remains (for example, this is usually the threshold for replacement given in OEM vehicle warranties). A study published in 2015 looked at driving patterns and battery degradation and found that EV batteries could meet driver needs well beyond this arbitrary 70-80% threshold,[57] concluding that battery retirement should not be determined by its remaining capacity but by whether it satisfies drivers' daily travel needs. In recent years, the amount of data available regarding the effect of travelled distance (which is itself roughly proportional to the number of charging cycles) on a BEV's battery capacity has been increasing steadily. Several databases have been created by Tesla model S and X owners, as well as companies that have fleets of EVs, in order to track battery capacities at different mileages.

[57] S. Saxena et al. (May 2015) - Quantifying EV battery end-of-life through analysis of travel needs with vehicle powertrain models

This can give an indication of the kind of battery degradation that is to be expected. A plot of one of these databases is presented Figure 16.

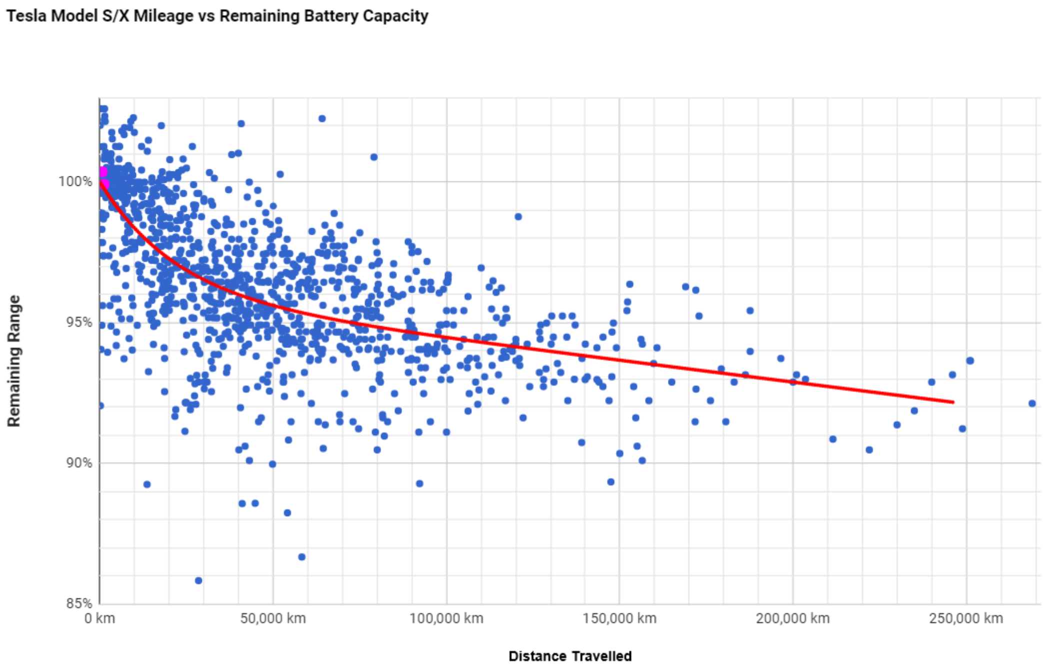

Figure 16 Battery Capacities for Tesla Model S/X against mileage

The graph above shows a steep drop in capacity over the first 50,000km, with a slow, steady decrease from c.100,000km onwards. A stable region appears as a straight line from c. 100,000km where over a distance of c.150,000km (between 100,000 km and 250,000 km) the battery capacities have only reduced by an average of just over 2%. Based on these data, significantly higher driving distances than 400,000km should be possible before battery replacement. Tesla itself has previously stated an ambition to manufacturer powertrains with design lifetimes of 1 million miles (1.6 million kilometres).

For the reasons outlined above, two additional scenarios were modelled where the purchase price of the autonomous taxi is depreciated over 1,000,000 km instead of the original 400,000 km. In the first scenario, it is assumed that the original battery remains unchanged for the full 1 million kilometres while the second scenario includes a replacement of the battery pack after 500,000 km. In the second scenario, it is also assumed that the car's interior needs refurbishing due to high usage.

The battery pack price selected here is 202€/kWh for a battery with a capacity of 80kWh, adding a total of 8000€ to the vehicle's original purchase price of €30,350. The value of 202€/kWh was taken directly from the previous study as the baseline predicted battery costs in 2020[58], this is because AV taxis are unlikely to need refurbishing before then and using today's battery pricing adds an unnecessarily high cost for the batteries which are becoming cheaper to produce year by year. A breakdown of the fare for the two new scenarios is shown in Figure 17 of this section, where they are compared to the original AV taxi scenario. Refurbishment costs can range between $5,000 and $10,000 depending on the quality of materials used[59]. Using the assumption that high quality materials are used sets

[58] Low carbon cars in the 2020s: Consumer impacts and EU policy implications (Nov. 2016) – The European Consumer Organisation (BEUC)
[59] http://cars.costhelper.com/car-upholstery-repair-cost.html

refurbishment costs at c. €8479 and includes complete professional reupholstering of the seats, side-panels, sail panels, headliner, carpets, etc.

So far in these calculations, it has been assumed that an autonomous taxi will experience the same kind of dead-mileage as a normal taxi today (i.e. dead-mileage of c.50%). This means that for every kilometre travelled by a passenger, he or she is paying for twice the operating costs actually incurred by the vehicle over the occupied distance. It is relatively safe to say that when service providers own large, automated fleets they will be able to optimise dispatching methods to minimise dead-mileage and other costs wherever possible. For this reason, an additional scenario is modelled where dead-mileage has been reduced from 50% to 25% by the service provider.

Effects of sensitivities on autonomous taxi TCO

Results for the scenarios discussed above are presented in Figure 17. The left-hand side of the figure shows that depreciating the fixed vehicle costs over 1,000,000 km rather than 400,000 km greatly reduces the overall TCO (by c.37%). Adding a cost of refurbishment and battery replacement - at a driving distance of 500,000 km - to the cost of the fare does significantly increase the total cost of travelling 15,000km in a year. This increases yearly costs 3,832€ by c. 986€ (i.e. c.26% increase) but still leads to an overall cost reduction of c.21% when compared to the baseline. The additional cost of battery replacement can be considered an upper bound because the price per kilowatt-hour chosen is conservatively high at 202 €/kWh and future replacements are likely to be closer to the cost of batteries at the time of replacement. Dead-mileage has been kept constant at 50% on the left-hand side with only the depreciation distance being altered.

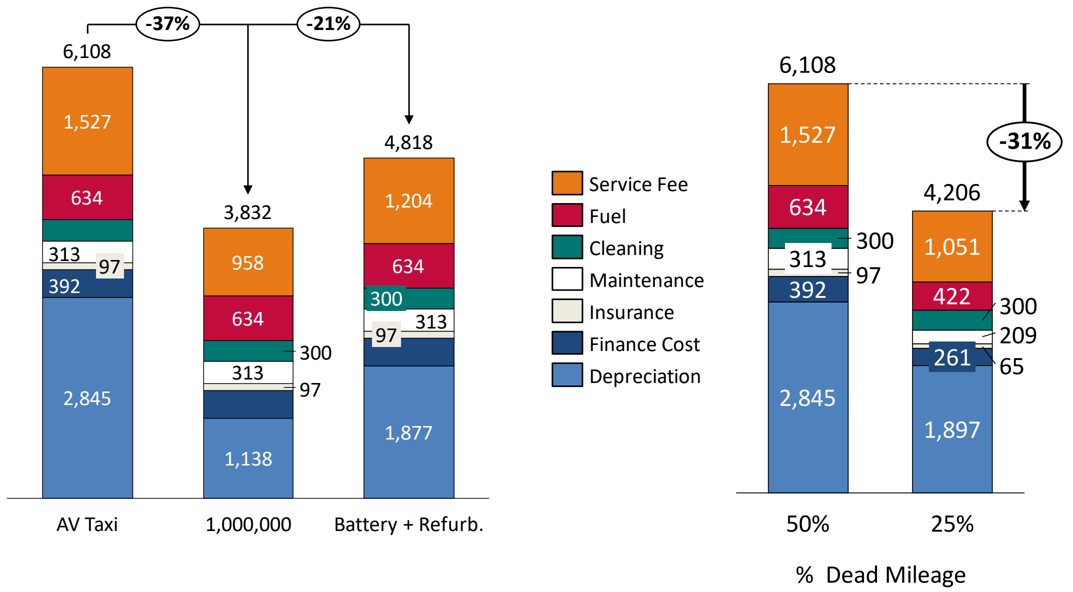

Figure 17 Effect of depreciation, refurbishment and dead mileage assumptions on autonomous taxi costs for a user travelling 15,000km per year

The figure on the right-hand side shows the effect of reducing dead mileage on the yearly cost of travel by an autonomous taxi for 15,000 km. The figure shows how efficient vehicle dispatching can significantly lower passenger fares (or increase margins for operators), where halving the number of dead miles (from 50% to 25%) causes a TCO reduction of 31%. Throughout the study, an effort has been made to choose conservative assumptions.

This, along with the sensitivity analysis shows that the autonomous taxi cost of €6,108 per year presented in Figure 15 should be taken as an upper bound rather than a baseline.

Additionally, this study assumes one passenger per vehicle per trip while data from a set of Western European countries from 2007 shows that on an average trip, there are 1.57 passengers per vehicle. This is equivalent to sharing one-in-two trips with another passenger, i.e. reducing overall costs by 25%. Again, this is an indication real world costs of autonomous taxi use could be lower than the conservative assumptions in this study suggest..

Autonomous car ownership with peer-to-peer sharing

Figure 18 shows the 4-year TCO of owning an electric autonomous car, for an annual driving distance of 15,000 km. The first column on the left-hand side shows the cost for traditional ownership, where the vehicle is for personal use alone and remains parked when unused. The other columns show how the owner's TCO when the vehicle spends an increasing number of hours per week (from left to right) as an autonomous taxi while not in use by the owner. The owner only covers operational expenses – cleaning, fuel and maintenance – and some depreciation. This peer-to-peer usage reduces total costs of ownership, because the revenue received offsets some of the depreciation that would otherwise be borne by the private owner.

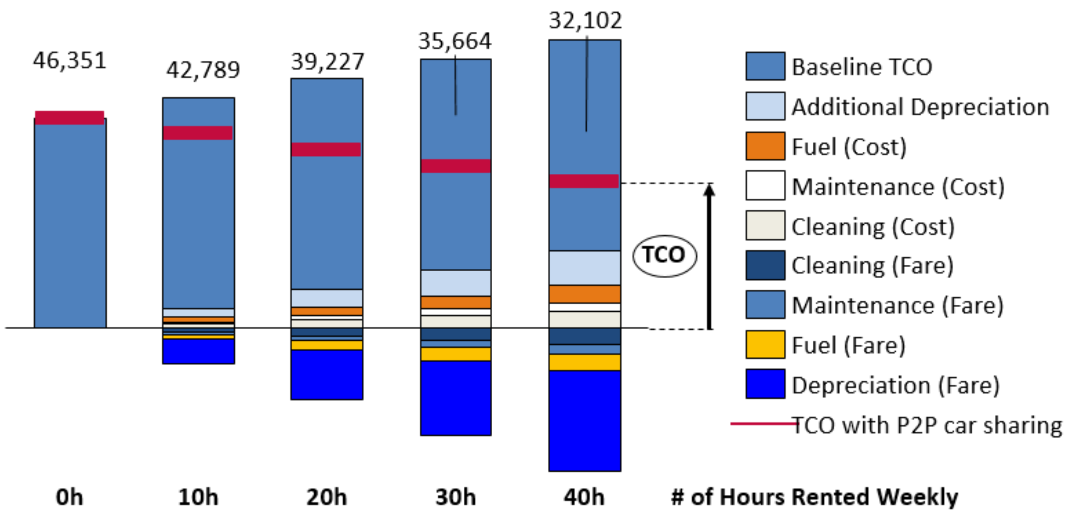

Figure 18 Costs, revenue and TCO of owning and renting an AV vehicle for a certain number of hours a week

The figure shows that by renting the vehicle out as an autonomous taxi for forty hours a week on average over a year, the owners TCO can be reduced by €14,249 over the 4-year period or c.31%. This system effectively reduces the TCO of an electric autonomous to the slightly above the original purchase price of the electric vehicle (€30,350 from the original study), in other words offsetting the majority of the vehicle's running costs beyond the original purchase. This shows how shared ownership models can be beneficial to several different actors, including vehicle owners, service providers/dispatchers and passengers. It remains to be seen whether customers are willing to offer their vehicles for use by other people in this way, and whether such systems can be competitive with dedicated companies running optimised fleets of autonomous vehicles. Our analysis suggests that the two systems can potentially coexist much like dedicated car sharing companies coexist with peer-to-peer models like Ouicar, while helping to lower net ownership costs of autonomous vehicle owners.

4 Conclusions and implications

This study has focused on various aspects affecting the availability and affordability of ZEVs in comparison with traditional powertrains, as well as the effect of modern mobility models on the costs of travelling by passenger car. The results suggest an increasing set of options for would-be car buyers, as the choice of powertrains expands at the same time as the ownership models themselves. The main findings of the analysis are set out below.

1. Availability of BEVs/PHEVs is rising but supply chain bottlenecks remain

The market review conducted in this study showed that the number of BEV/PHEV models available for purchase has increased substantially in recent years and will continue to do so. The number of available models is still relatively small compared to those available with ICE powertrains but strong increases in model availability and sales volumes are being projected by the majority of OEMs in the short- and medium-term.

On the other hand, anecdotal evidence suggests that official data on model availability for BEVs/PHEVs does not account for other bottlenecks in the supply chain which are hampering EV uptake and sales around the world. These bottlenecks are caused both by the inability (or unwillingness) of some OEMs to scale production volumes sufficiently to meet demand, and gaps in knowledge among the dealers selling them. The second issue results from the dealership's business structure and economic model, whereby selling current generation BEVs and PHEVs have lower profit margins and are therefore less interesting in a commission-driven business. It remains to be seen whether this 'real world' availability improves as future vehicle models offer similar margins to petrol vehicles and dealer knowledge improves.

It should be noted that incentives (both financial and 'convenience measures') currently play an important role in making low emission vehicles attractive to consumers. Ongoing incentives for using low emission vehicles, such as annual parking charges or circulation taxes, also have strong effects as they influence the costs of second hand vehicles and hence residual values. Hence simply increasing the availability of models will not be sufficient to drive substantial increases in market share in the absence of incentives and continued developments in charging infrastructure. However, the presence of long wait times for models currently on the market, and large pre-orders for new models (over 400,000 reservations for the Tesla Model 3, and 7000 pre-orders for the Hyundai Kona in Norway alone) suggests that there is latent demand not being met. Meeting this demand in the short term would have wider impacts on the development of the EV market, by improving the business cases for infrastructure through increased customer numbers, and by raising awareness of EVs among mass-market consumers through higher 'road presence' and word of mouth experience from neighbours and colleagues who own these vehicles.

2. Leasing deals available today help close the TCO gap between ZEVs and petrol/diesel cars relative to outright ownership

Our analysis shows that on average, leasing deals were not less competitive for ZEVs than for petrol or diesel cars, which might have been expected if OEMs were making cautious assumptions about second hand values of ZEVs. In fact, it was found that leasing deals tend to reduce the four-year TCO gap between conventional and low-emission powertrains by since customers pay a slightly lower proportion of the purchase price for a ZEV than a petrol or diesel car. Further work is required to see if this trend holds as next generation, high volume models enter the market. The lease offers shown in this study are based on Personal Contract Plan or Hire Purchase. Full service leasing, where the lease company covers all costs of servicing, insurance, fuel management (for example access to charging networks in the case of BEVs), could also play a valuable role in improving the ownership experience of BEVs by eliminating residual value risk, and potentially through the provision of conventional vehicles for long distance trips where necessary).

3. **The availability of low-cost convenient alternatives to private car ownership provide consumers with a range of options depending on their mobility needs**

The cost analysis in this study has shown that traditional car ownership can often be more expensive than alternative models depending on the distances travelled over a year. For annual mileages under c. 8,000 km, the study found that "mobility as a service"- type models were cheaper for the customer than either traditional ownership or ride-hailing services (such as Uber or Lyft). For infrequent users who like the practicality of reserving a car and being dropped off directly at the desired destination, ride-hailing services are cheaper than private ownership under 3,500 km per year, even for current (non-autonomous) services using professional drivers. These findings indicate that for many city inhabitants in Europe, who would rarely travel over 8,000 km in a year, cheaper mobility solutions exist which are capable of satisfying their needs. The rapid growth of the car sharing market[60] and falling car ownership levels in major cities[61], suggest that the benefits of alternative mobility offers are being recognised by increasing numbers of European consumers.

4. **Autonomous vehicle technology has the potential to significantly reduce the cost of mobility services by eliminating driver costs and lowering fuel costs when combined with electric powertrains**

Even with the additional purchase price incurred from adding full SAE Level 5 automation to an electric vehicle (enabling it to act as an autonomous taxi) and the addition of service operator fees, autonomous taxis should offer a lower cost alternative to private car ownership for the majority of current vehicle users (those travelling up to c.30,000km per year. This is without accounting for other factors that could further reduce costs such as reductions in dead-mileage in a highly optimised dispatching system, and powertrains with long design lifetimes reducing per-kilometre depreciation. These dramatic changes in the cost of mobility are likely to widespread impacts on the ways consumers buy cars and access to mobility. While many of these effects are likely to be positive (such as increased safety and less urban space occupied by idle private cars), there may be secondary effects such as modal shifts away from public transport towards more convenient passenger cars. These secondary effects are beyond the scope of this study but should be considered by policymakers when projecting future impacts of autonomous vehicle technology as if they are not managed carefully, substantial increases in congestion and diversion of money away from public transport would have negative effects for society that offset some of the large safety and convenience benefits promised.

5. **Autonomous vehicle technology could also benefit owners of private cars by allowing convenient peer-to-peer sharing of unused vehicles**

Based on conservative assumptions on depreciation and residual values, it was found that an autonomous car owner's 4-year TCO could be reduced by 31% if used as a taxi when not needed by the owner, relative to a vehicle used exclusively for personal use. This is achievable by renting the vehicle as a taxi for about 40 hours a week, which is a small proportion of the time an average vehicle is parked and not in use. This peer-to-peer model

[60] http://www.circularchange.com/circular-mobility-megatrend-14-million-europeans-will-use-car-sharing-2021/

[61] https://www.csmonitor.com/Business/In-Gear/2014/0925/Why-is-car-ownership-plunging-in-Europe-s-cities

could help to cover the increased capital cost of autonomous vehicles, encouraging their adoption and the associated safety benefits. The use of peer-to-peer sharing could also complement dedicated autonomous taxi companies by providing additional vehicles to the taxi parc when they are needed.

6. The analysis confirms the increasing range of cost-effective powertrains and mobility models and the widening choices facing would-be car owners

The original study conducted in 2016 showed a positive outlook for zero emission vehicles, which are expected to reach TCO parity with petrol and diesel cars by the mid-2020s and at that time will offer significant consumer benefits to new and second-hand buyers, in addition to CO_2 reductions and air quality improvements. This follow-up work reinforces those conclusions while showing that future consumers will need choose not only between different powertrains, but between car ownership and other mobility models. This choice is a complex one, and consumers will need access to clear, independent information on the costs and benefits of different options to make optimal choices, both from a financial and environmental point of view.

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