ENDING THE ICE AGE

TECHNICAL ANNEX

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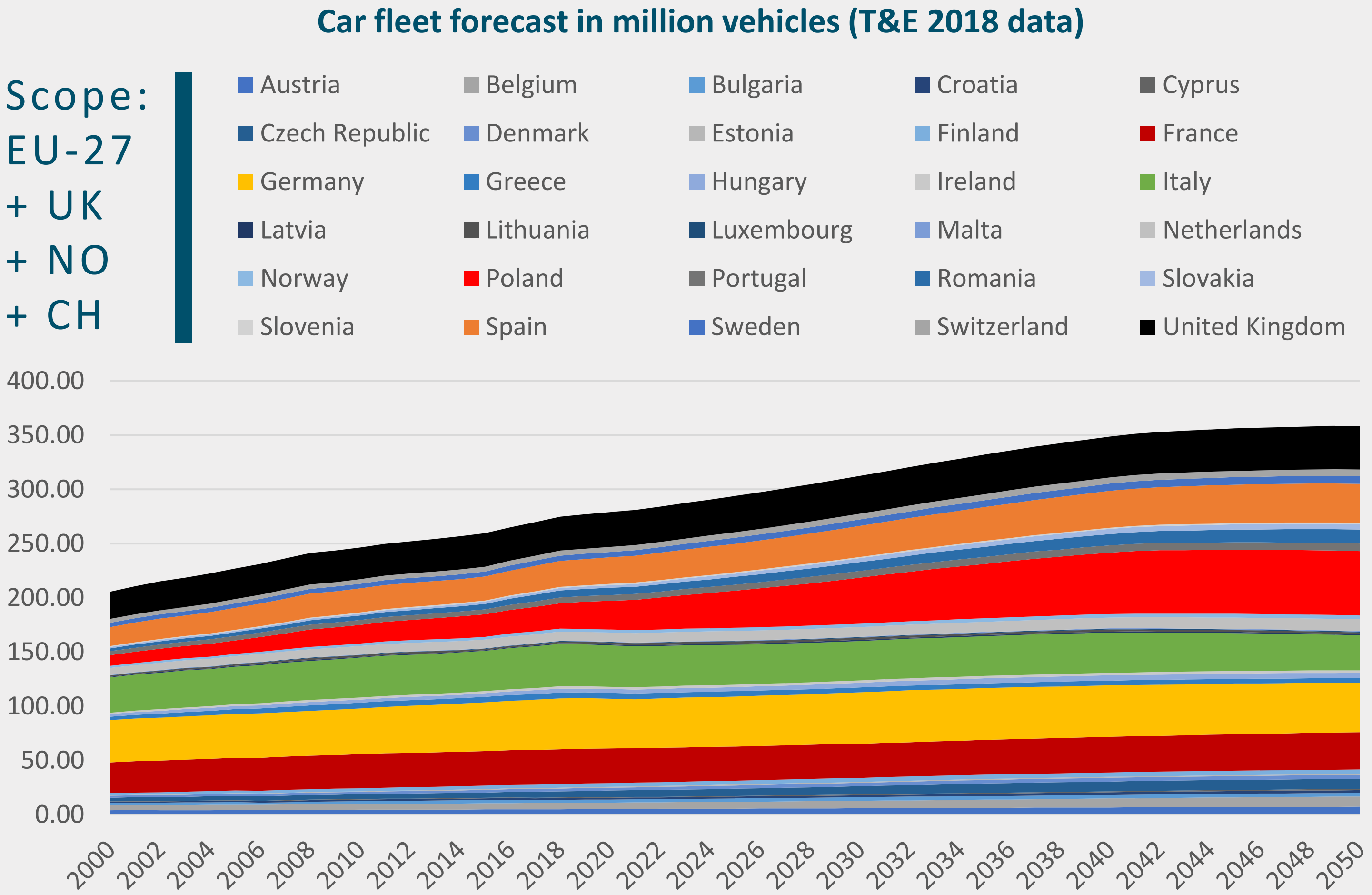
CHAPTER I EUROPEAN CAR FLEET TRANSITION

1. Sales & fleet size forecast
2. Fleet aging
3. Price of new & used cars
4. CO_2 emissions vs carbon budget
5. External cost
6. Affordable EV shortage
7. Exported used fossil cars

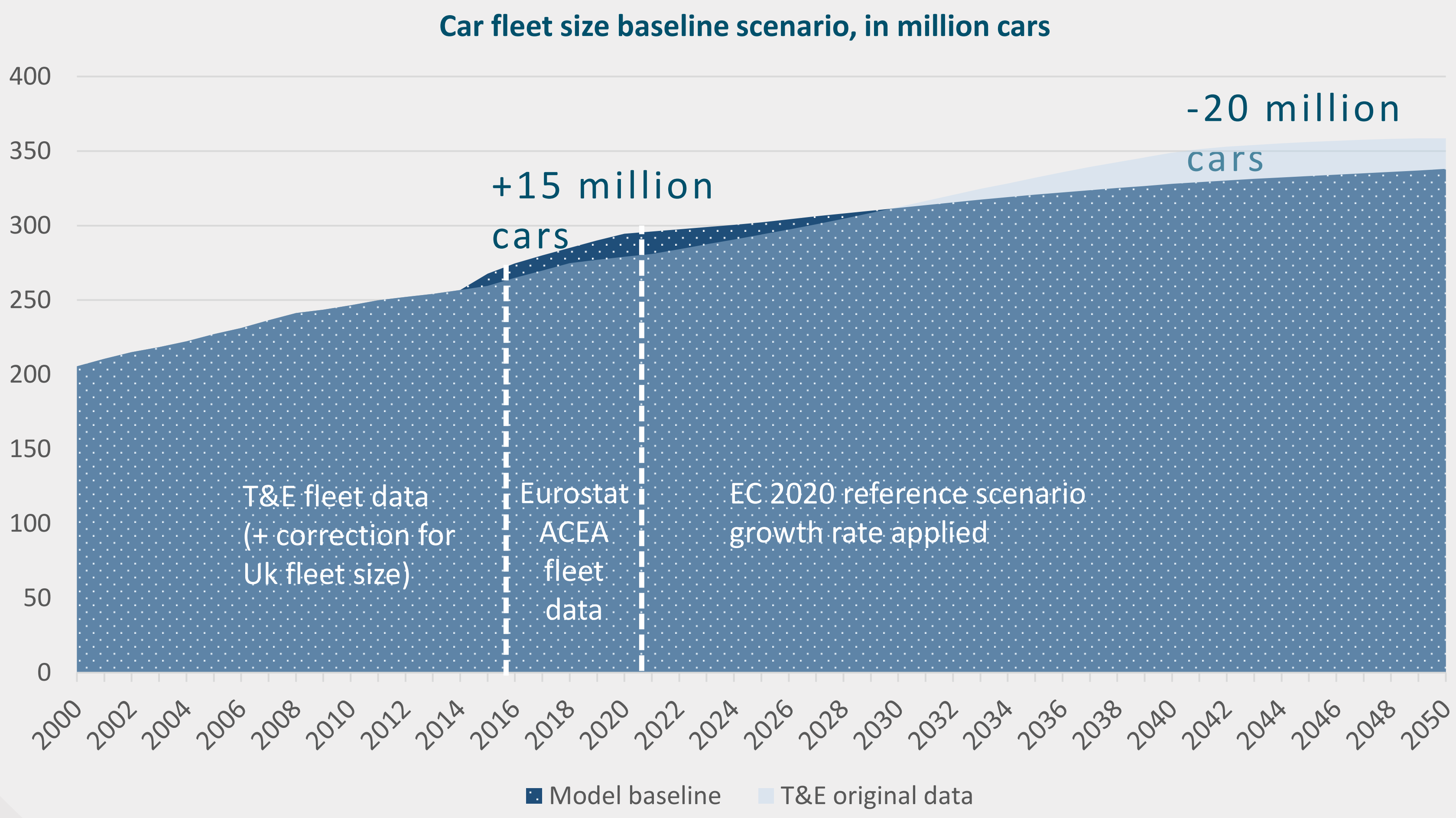
Starting point

Scope:
EU-27
+ UK
+ NO
+ CH



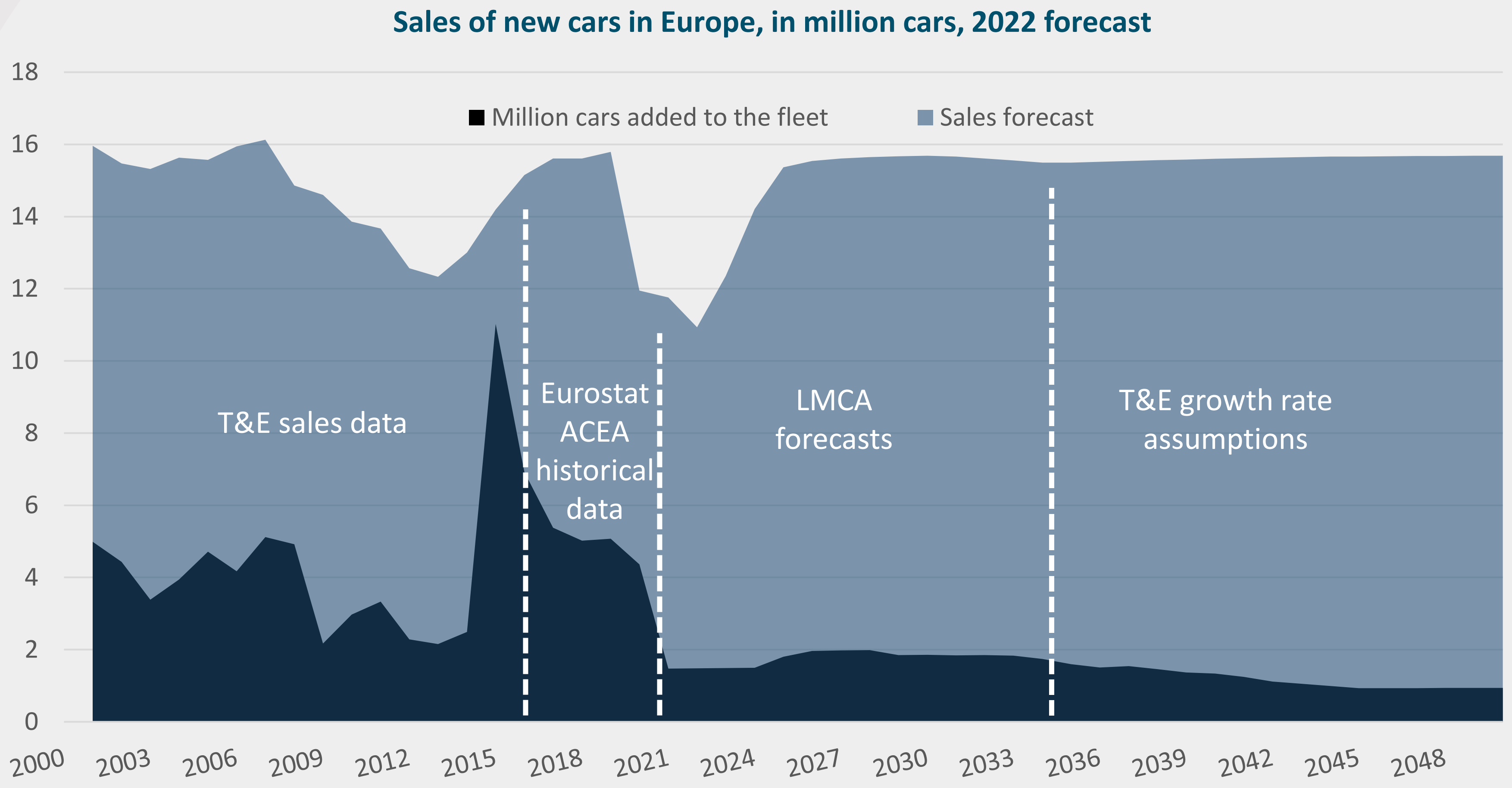
Source: Transport & Environment forecast (2018)

Step 1: Update fleet size



Sources: Eurostat (2022), ACEA (2022), EC 2020

Step 2: Update Sales

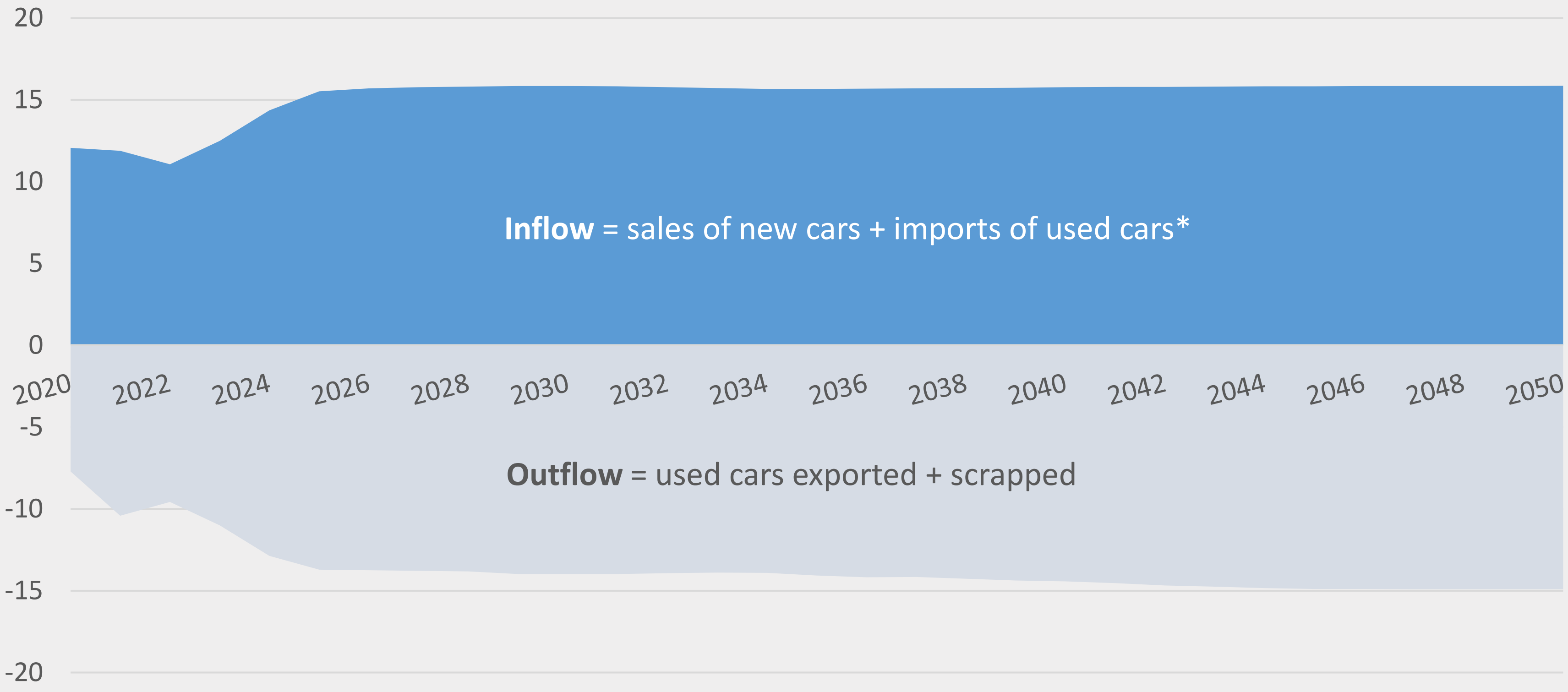


Cars added to the fleet = current fleet size – fleet size previous year

Sources: Eurostat (2022), ACEA (2022), LMCA (Q2 2022)

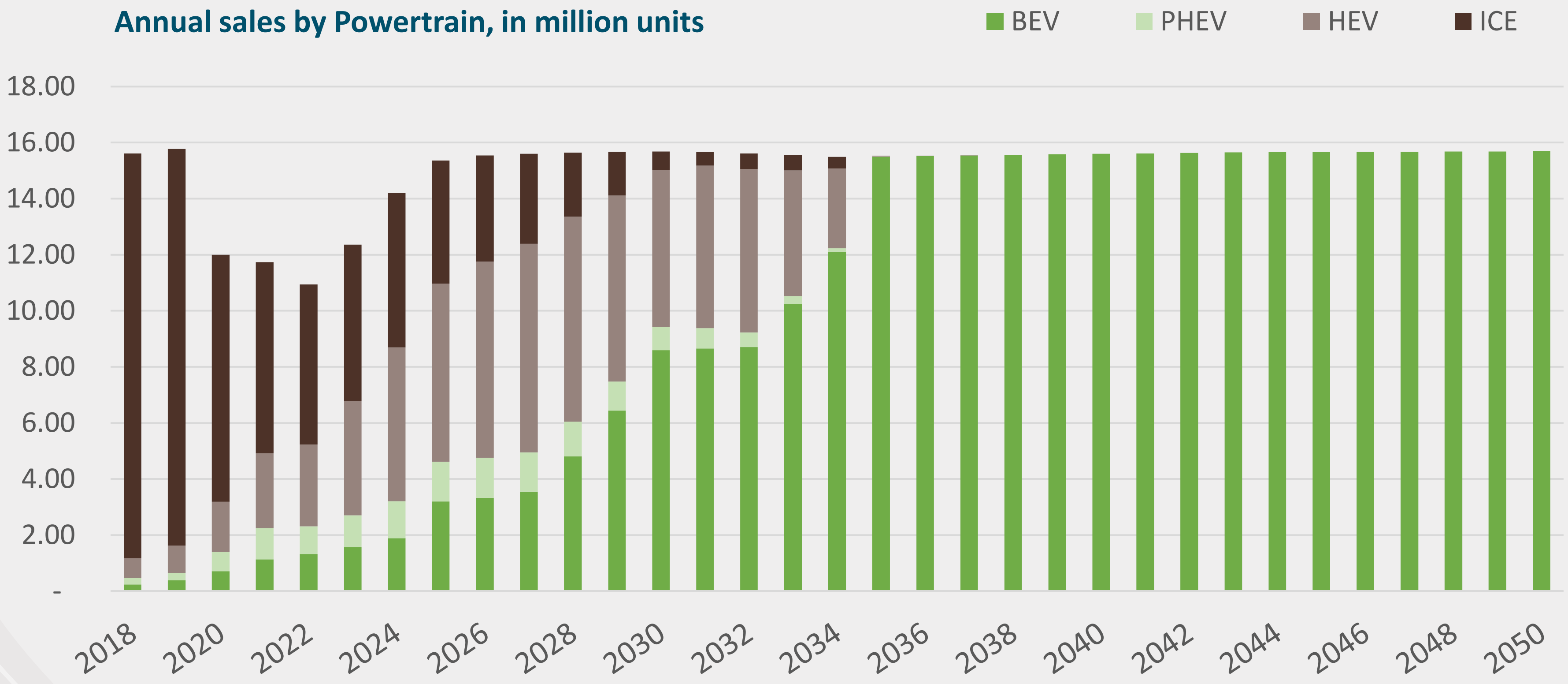
Step 3: Outflow Baseline (v1)

Inflows and outflows in million cars per year



Outflow formula: $$\sum_{Year=2021}^{2050} (\text{fleet previous year} + \text{new cars sold} + \text{used cars imported} - \text{current Fleet size})$$

*Ratio 1.1% of sales applied (source: Oko Institute EV)



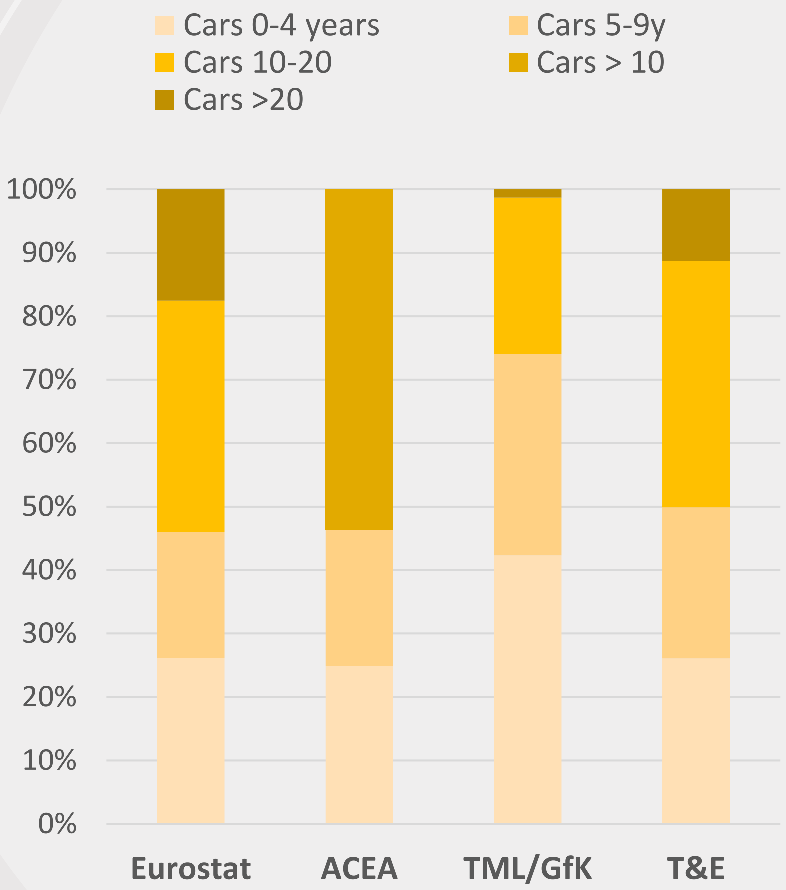
Sources: Eurostat (2022), ACEA (2022), LMCA (Q2 202

Step 4: Sales Breakdown by Powertrain

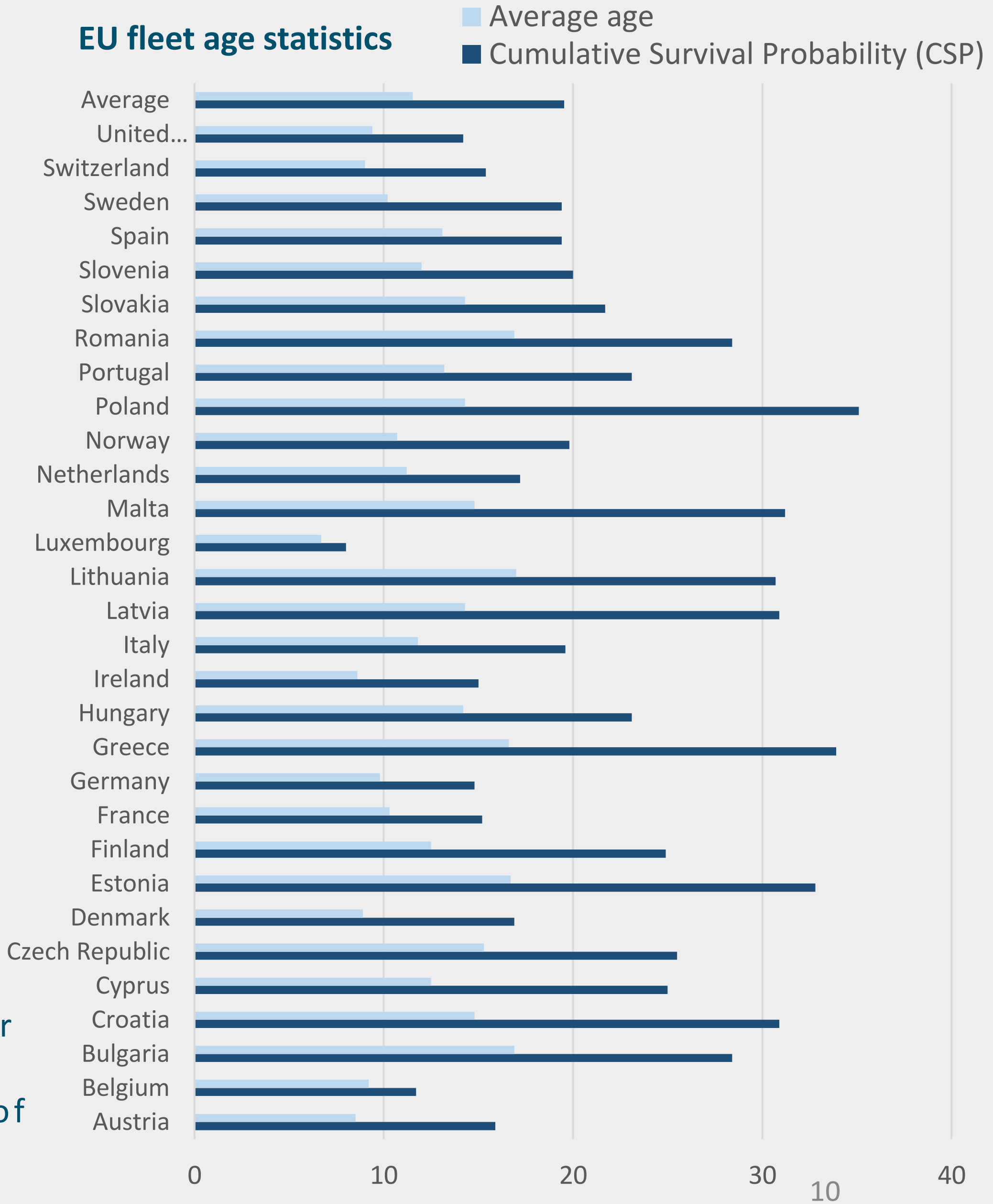
1. Sales & fleet size forecast
2. Fleet aging
3. Price of new & used cars
4. CO_2 emissions vs carbon budget
5. External cost
6. Affordable EV shortage
7. Exported used fossil ca

Starting point: Historical data turned into assumptions

2020 car fleet broken down by age group



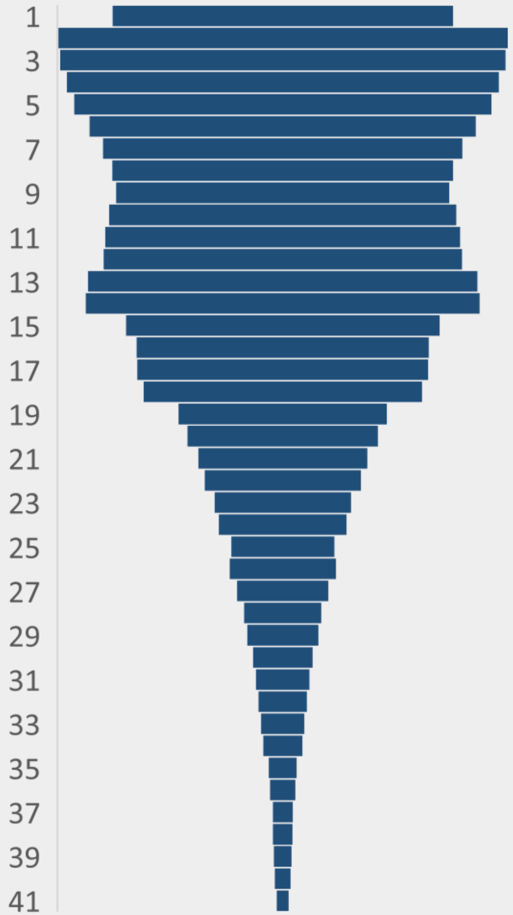
EU fleet age statistics



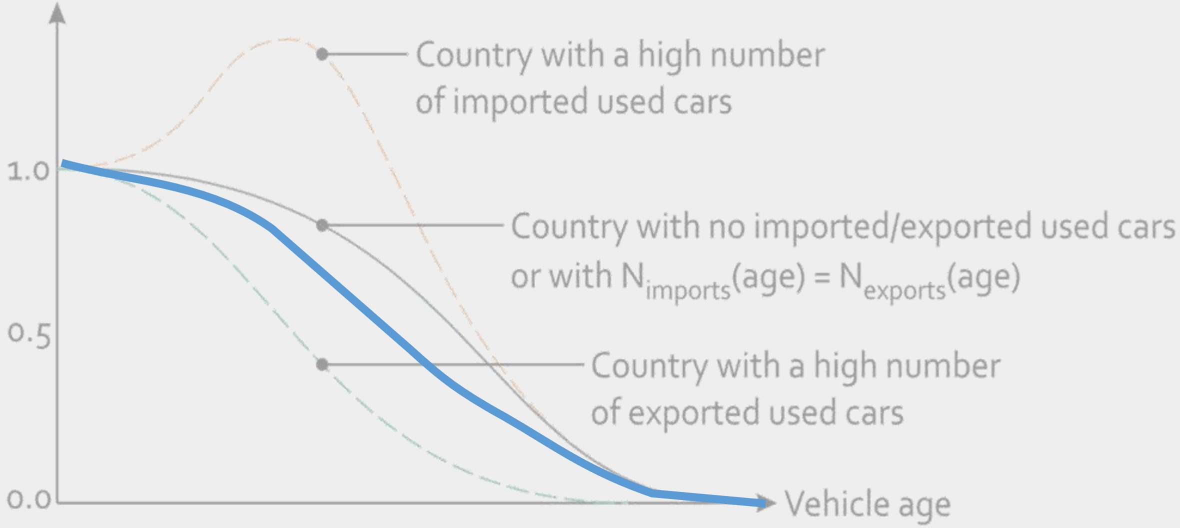
Source CSP: Lifespan of passenger cars in Europe: empirical modelling of fleet turnover dynamic (Held, 2021)

Starting point: Historical data turned into assumptions

2020 Fleet age distribution



Cumulated Survival Probability



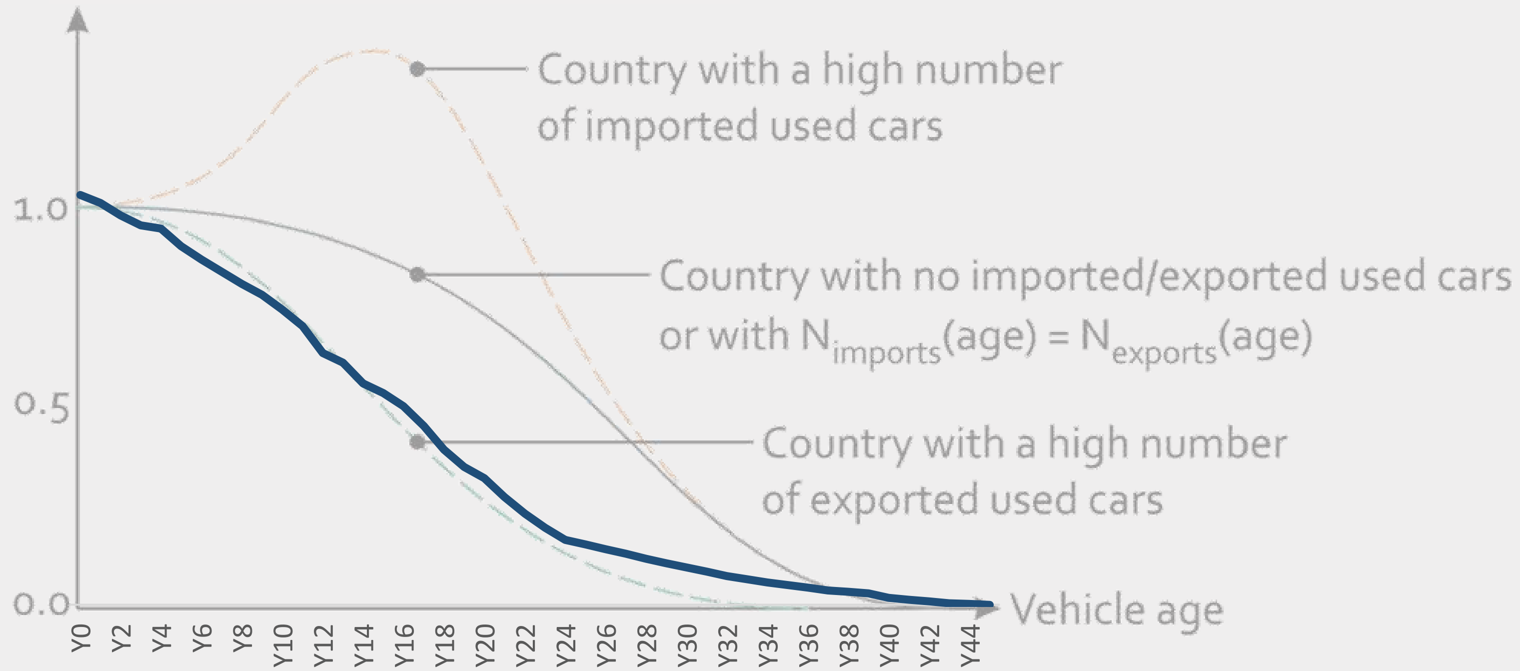
Based on the historical data from difference sources (previous slide) and the academic literature (Held, 2021), an assumption is built for the 2020 car fleet age distribution and the underlying survival probability curve

Input to the model:
- Survival Curve v1
- 2020 fleet distribution

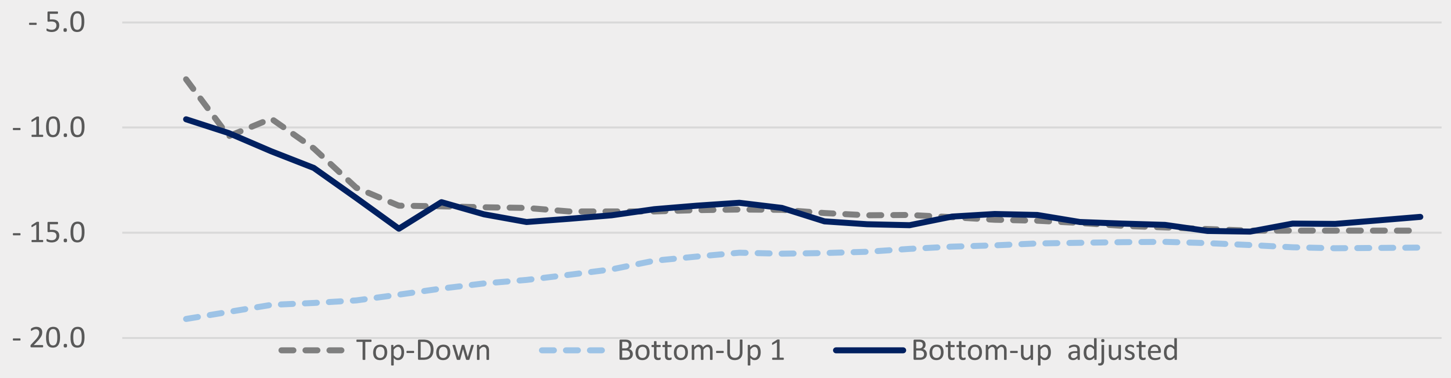
Step 1: Recalibrate the survival curve & Outflow

The survival curve and the outflow are manually adjusted to...

Cumulated Survival Probability curve (v2)

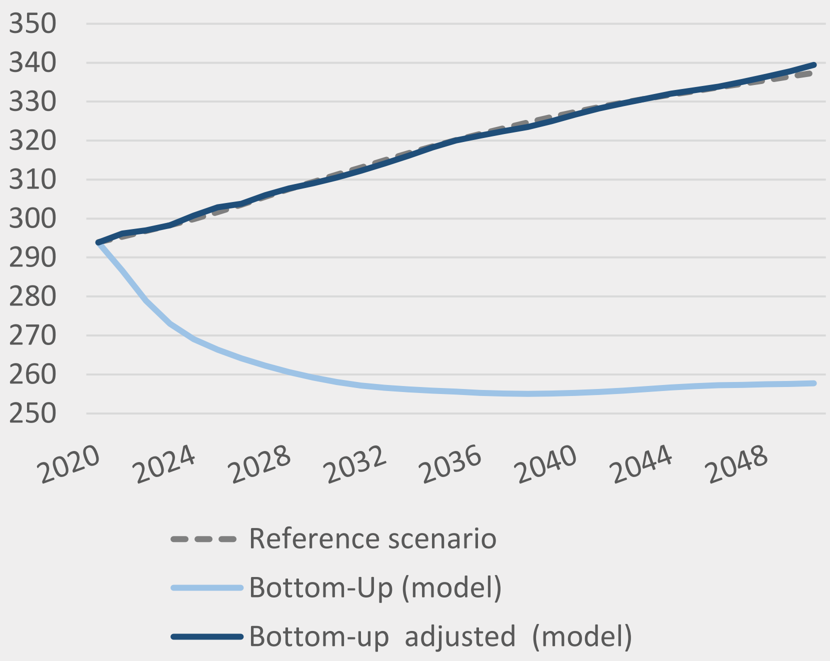


Outflow in million vehicles (v2)

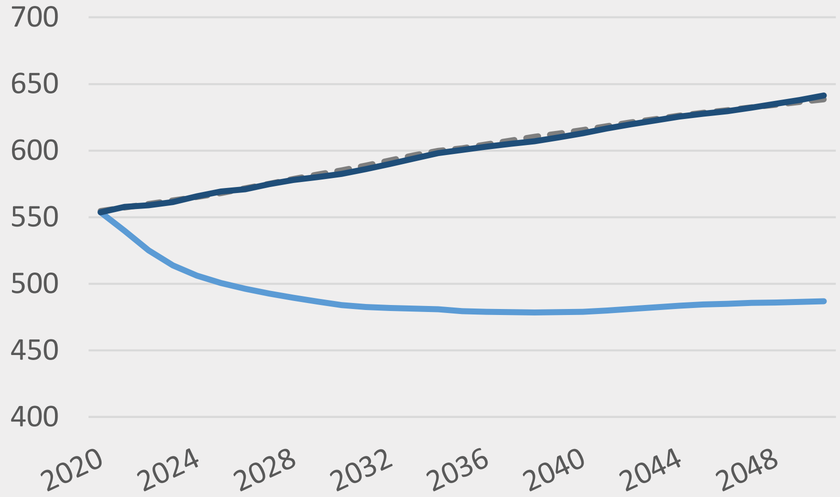


Step 1: Recalibrate the survival curve & outflow

Car fleet size in million vehicles



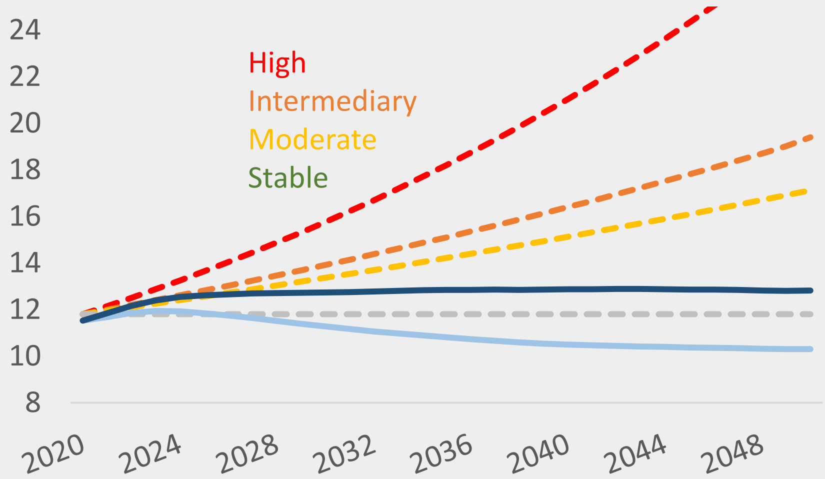
Motorization rate, car per 1000 habitants

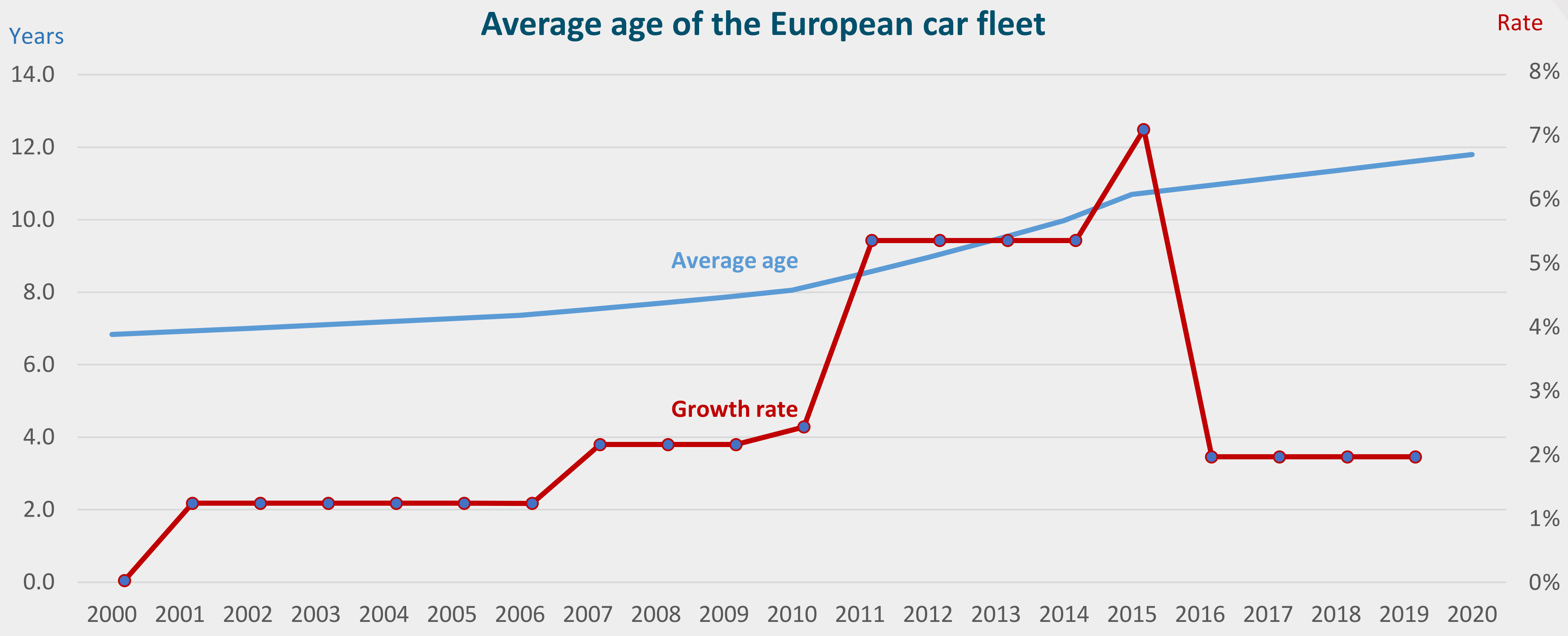


The survival curve and the outflow are manually adjusted (year by year) to...

... align the car fleet size and motorization rate with the EU reference scenario values, while controlling for the average age of the fleet (increased to 12.7 years)

Average age of the fleet: past trend projection vs model



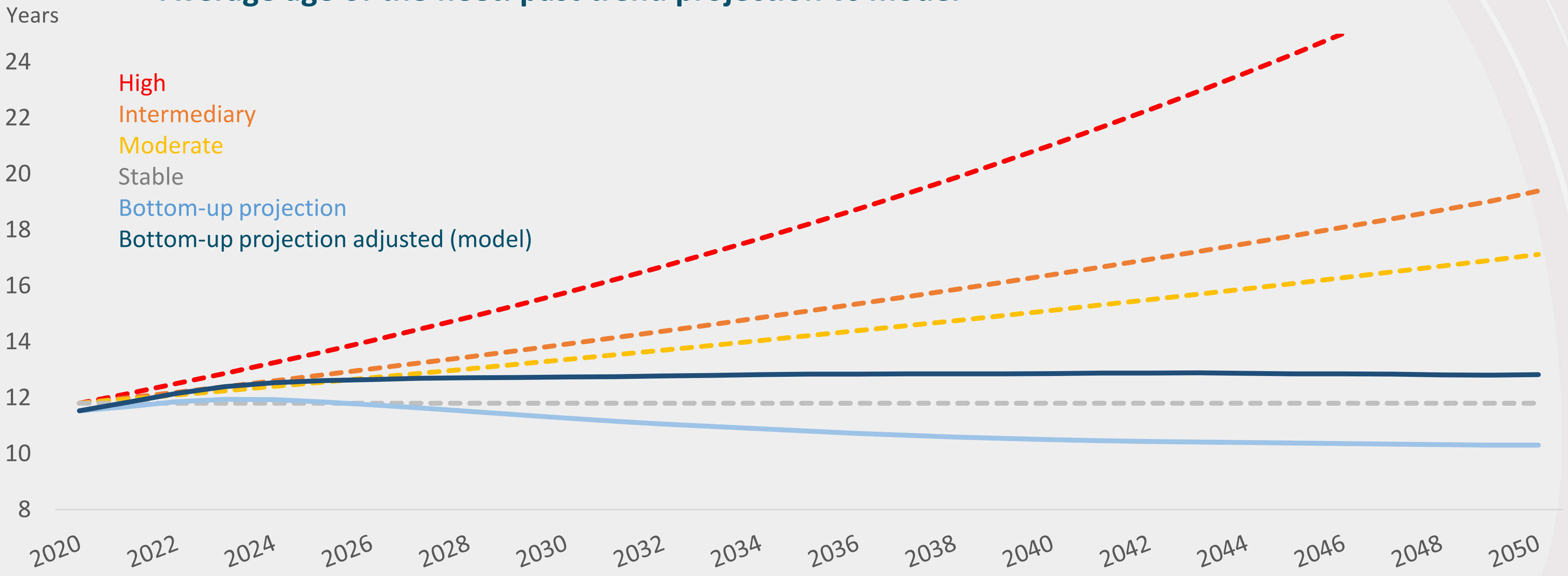


Sources: Eurostat

Factor of uncertainty

Over the past 20 years, the average age of the European fleet grew from 7 to 12 year-old, with an annual growth rate between 1.2% and 7.3%.

Average age of the fleet: past trend projection vs model



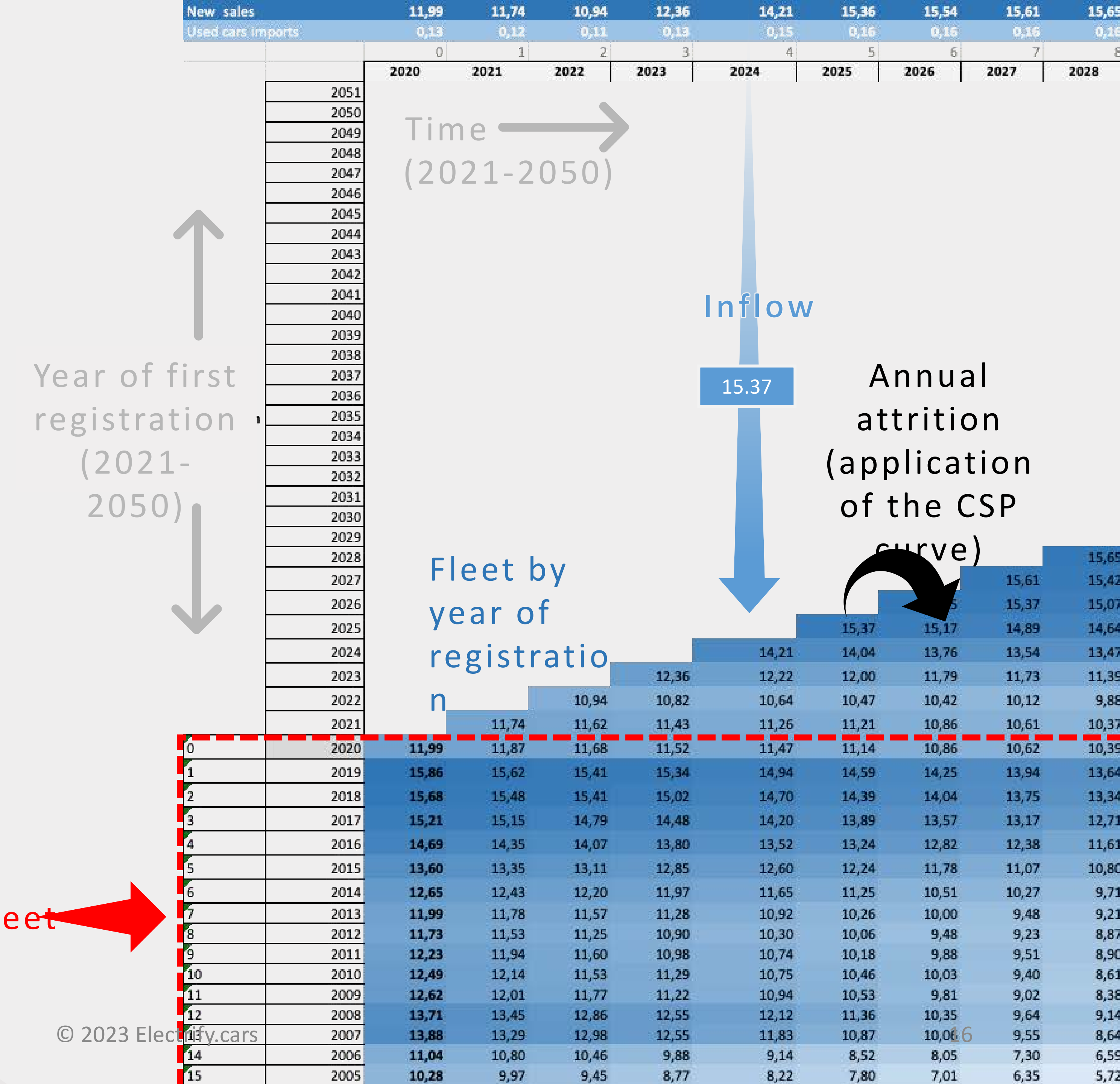
Factor of uncertainty

Extrapolating past aging trends (see high, intermediary, and moderate curves) would significantly increase the average age by 2050. Our model is based on a relatively stable average age (dark blue curve), consistent with the fleet size projection in the EU reference scenario and third-party sales forecast. The accelerated renewal due to electrification is expected to offset the general trend in aging observed over the past 20 years.

An aging curve aligned with past trends would dramatically change the results of the simulation.

Step 2: Aging Matrix

The annual inflow (new cars sold + imports) is added to the fleet, and the adjusted cumulated survival probability curve is applied each year to compute the attrition of the fleet.



		2020	2021	2022	2023	2024	2025	2026	2027	2028
New sales		11,99	11,74	10,94	12,36	14,21	15,36	15,54	15,61	15,65
Used cars imports		0,13	0,12	0,11	0,13	0,15	0,16	0,16	0,16	0,16
		0	1	2	3	4	5	6	7	8
	2051									
	2050									
	2049									
	2048									
	2047									
	2046									
	2045									
	2044									
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	2034									
	2033									
	2032									
	2031									
	2030									
	2029									
	2028									15,65
	2027								15,61	15,42
	2026							[illegible]	15,37	15,07
	2025						15,37	15,17	14,89	14,64
	2024					14,21	14,04	13,76	13,54	13,47
	2023				12,36	12,22	12,00	11,79	11,73	11,39
	2022			10,94	10,82	10,64	10,47	10,42	10,12	9,88
	2021		11,74	11,62	11,43	11,26	11,21	10,86	10,61	10,37
0	2020	**11,99**	11,87	11,68	11,52	11,47	11,14	10,86	10,62	10,39
1	2019	**15,86**	15,62	15,41	15,34	14,94	14,59	14,25	13,94	13,64
2	2018	**15,68**	15,48	15,41	15,02	14,70	14,39	14,04	13,75	13,34
3	2017	**15,21**	15,15	14,79	14,48	14,20	13,89	13,57	13,17	12,71
4	2016	**14,69**	14,35	14,07	13,80	13,52	13,24	12,82	12,38	11,61
5	2015	**13,60**	13,35	13,11	12,85	12,60	12,24	11,78	11,07	10,80
6	2014	**12,65**	12,43	12,20	11,97	11,65	11,25	10,51	10,27	9,71
7	2013	**11,99**	11,78	11,57	11,28	10,92	10,26	10,00	9,48	9,21
8	2012	**11,73**	11,53	11,25	10,90	10,30	10,06	9,48	9,23	8,87
9	2011	**12,23**	11,94	11,60	10,98	10,74	10,18	9,88	9,51	8,90
10	2010	**12,49**	12,14	11,53	11,29	10,75	10,46	10,03	9,40	8,61
11	2009	**12,62**	12,01	11,77	11,22	10,94	10,53	9,81	9,02	8,38
12	2008	**13,71**	13,45	12,86	12,55	12,12	11,36	10,35	9,64	9,14
13	2007	**13,88**	13,29	12,98	12,55	11,83	10,87	[illegible]	9,55	8,64
14	2006	**11,04**	10,80	10,46	9,88	9,14	8,52	8,05	7,30	6,59
15	2005	**10,28**	9,97	9,45	8,77	8,22	7,80	7,01	6,35	5,72

Step 2:
Aging Matrix

The matrix is reorganized by car age (one row per year) to calculate the age distribution of the fleet.

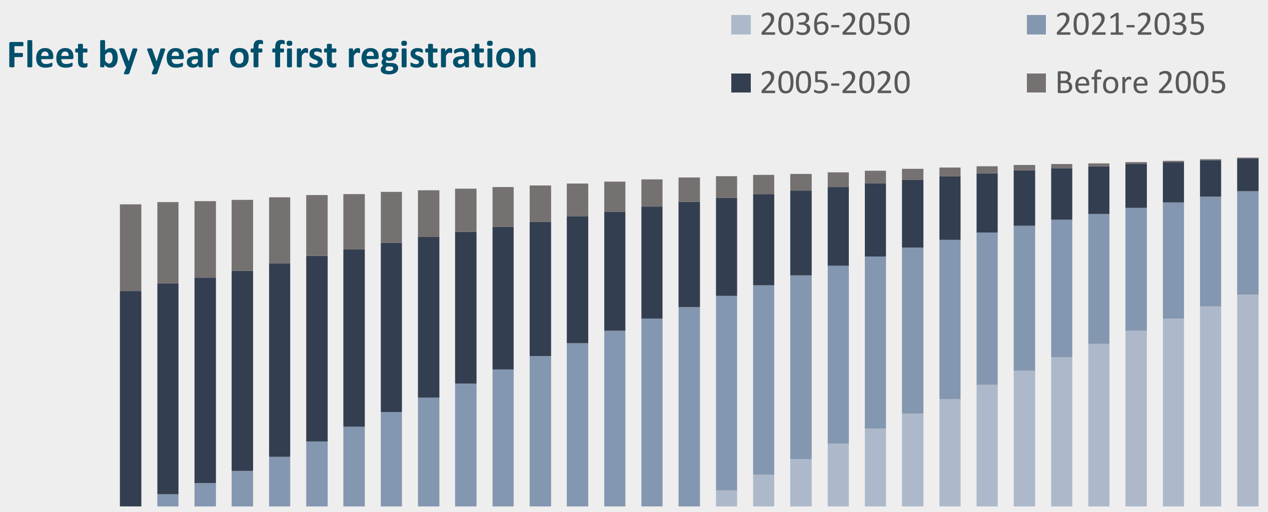
Fleet by age

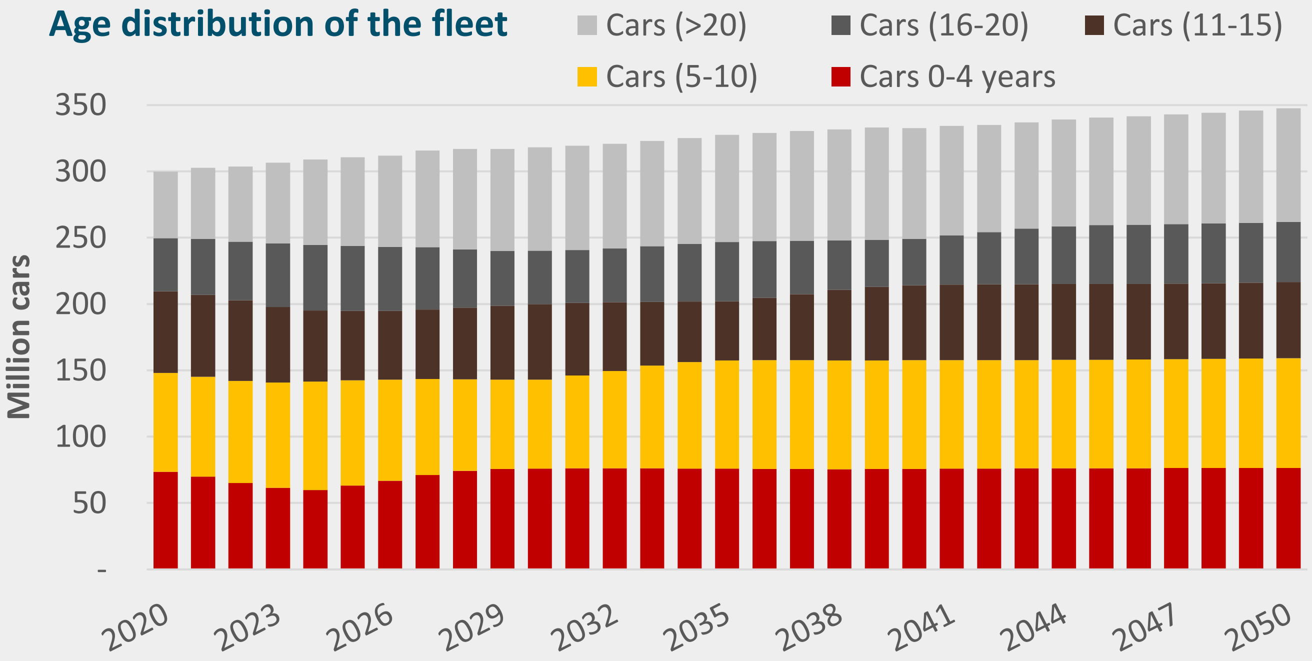
Age (New to 60 years old)

	2020	2021	2022	2023	2024	2025	2026
Top down	294	295	297	298	300	302	304
Sum table	293,90	296,15	296,94	298,31	300,74	302,91	303,80
0	11,99	11,74	10,94	12,36	14,21	15,37	15,55
1	15,86	11,87	11,62	10,82	12,22	14,04	15,17
2	15,68	15,62	11,68	11,43	10,64	12,00	13,76
3	15,21	15,48	15,41	11,52	11,26	10,47	11,79
4	14,69	15,15	15,41	15,34	11,47	11,21	10,42
5	13,60	14,35	14,79	15,02	14,94	11,14	10,86
6	12,65	13,35	14,07	14,48	14,70	14,59	10,86
7	11,99	12,43	13,11	13,80	14,20	14,39	14,25
8	11,73	11,78	12,20	12,85	13,52	13,89	14,04
9	12,23	11,53	11,57	11,97	12,60	13,24	13,57
10	12,49	11,94	11,25	11,28	11,65	12,24	12,82
11	12,62	12,14	11,60	10,90	10,92	11,25	11,78
12	13,71	12,01	11,53	10,98	10,30	10,26	10,51
13	13,88	13,45	11,77	11,29	10,74	10,06	10,00
14	11,04	13,29	12,86	11,22	10,75	10,18	9,48
15	10,28	10,80	12,98	12,55	10,94	10,46	9,88
16	10,24	9,97	10,46	12,55	12,12	10,53	10,03
17	9,80	9,72	9,45	9,88	11,83	11,36	9,81
18	7,34	9,16	9,06	8,77	9,14	10,87	10,35
19	6,71	6,94	8,63	8,51	8,22	8,52	10,06
20	5,95	6,44	6,64	8,25	8,12	7,80	8,05
21	5,50	5,51	5,94	6,10	7,54	7,36	7,01
22	4,81	5,08	5,07	5,44	5,57	6,83	6,60
23	4,51	4,43	4,67	4,64	4,96	5,03	6,11
24	3,63	4,15	4,07	4,27	4,22	4,47	4,49
25	3,75	3,51	4,01	3,92	4,10	4,04	4,27
26	3,22	3,60	3,37	3,83	3,74	3,90	3,83
27	2,72	3,09	3,45	3,22	3,66	3,56	3,69
28	2,51	2,58	2,93	3,26	3,03	3,42	3,31
29	2,11	2,40	2,46	2,78	3,09	2,86	3,21
30	1,90	2,00	2,27	2,32	2,62	2,89	2,66
31	1,71	1,79	1,88	2,13	2,17	2,43	2,67
32	1,54	1,59	1,66	1,74	1,96	1,99	2,21
33	1,38	1,45	1,50	1,56	1,63	1,83	1,84
34	1,00	1,30	1,36	1,40	1,45	1,51	1,68
35	0,90	0,93	1,22	1,27	1,30	1,34	1,39
36	0,71	0,84	0,88	1,14	1,18	1,20	1,23
37	0,70	0,65	0,77	0,80	1,03	1,06	1,07
38	0,63	0,67	0,61	0,72	0,75	0,96	0,98
39	0,56	0,59	0,62	0,57	0,67	0,69	0,88

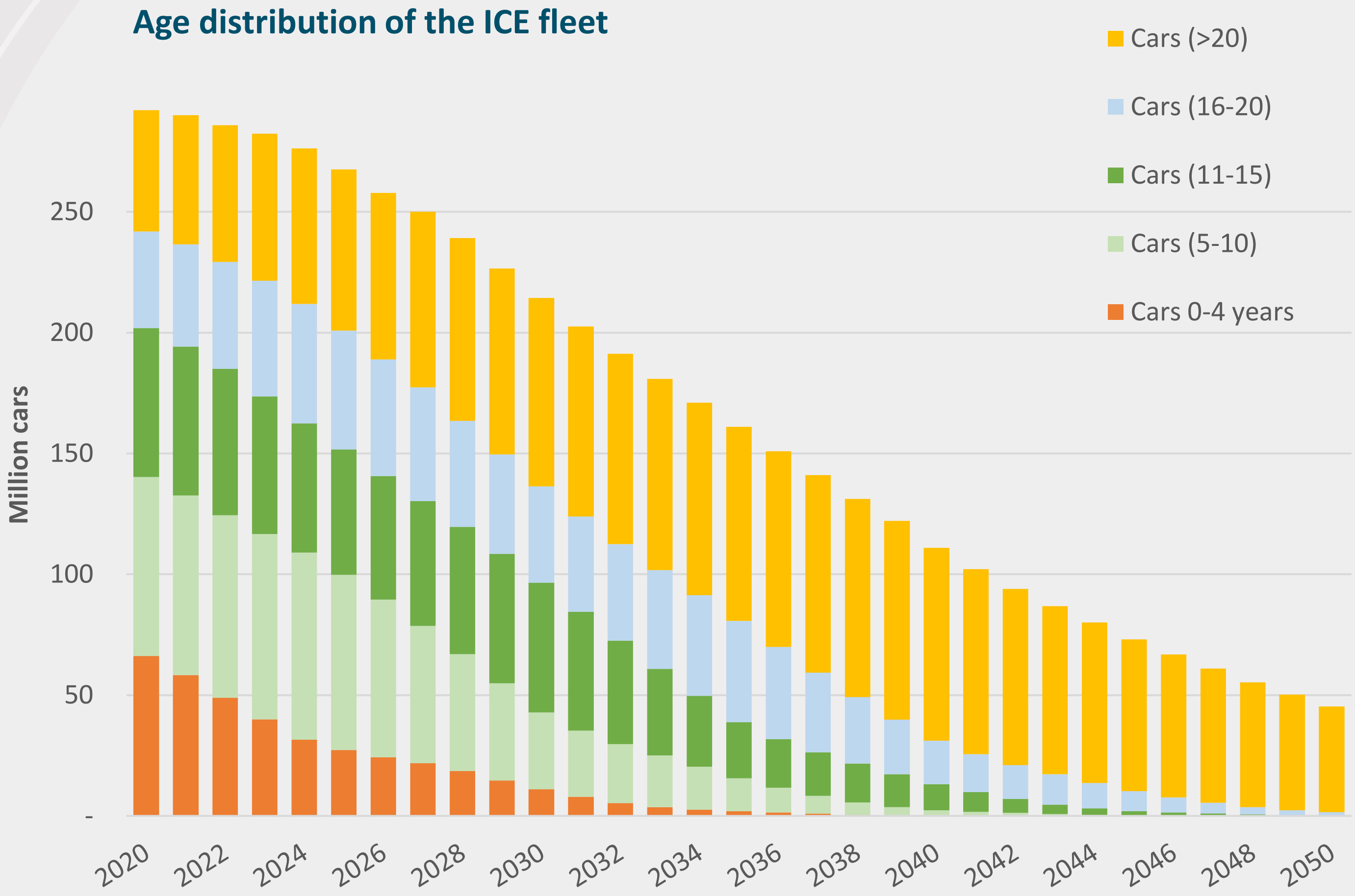
Step 2:
Aging Matrix

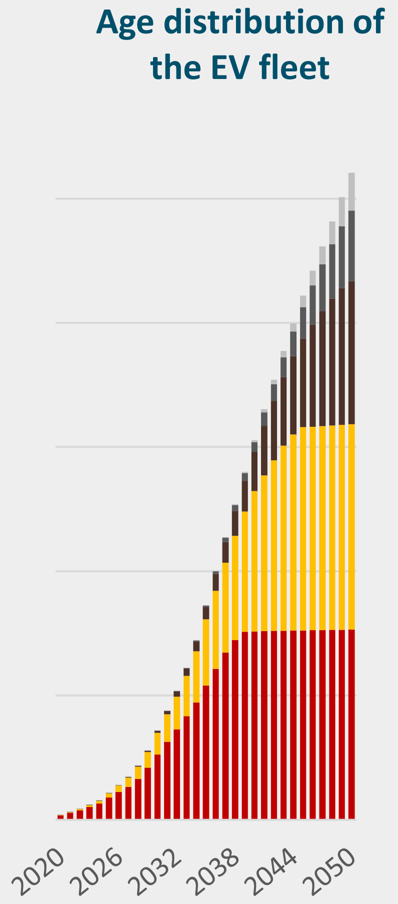
Output:
Fleet distribution by year of first, registration, by age





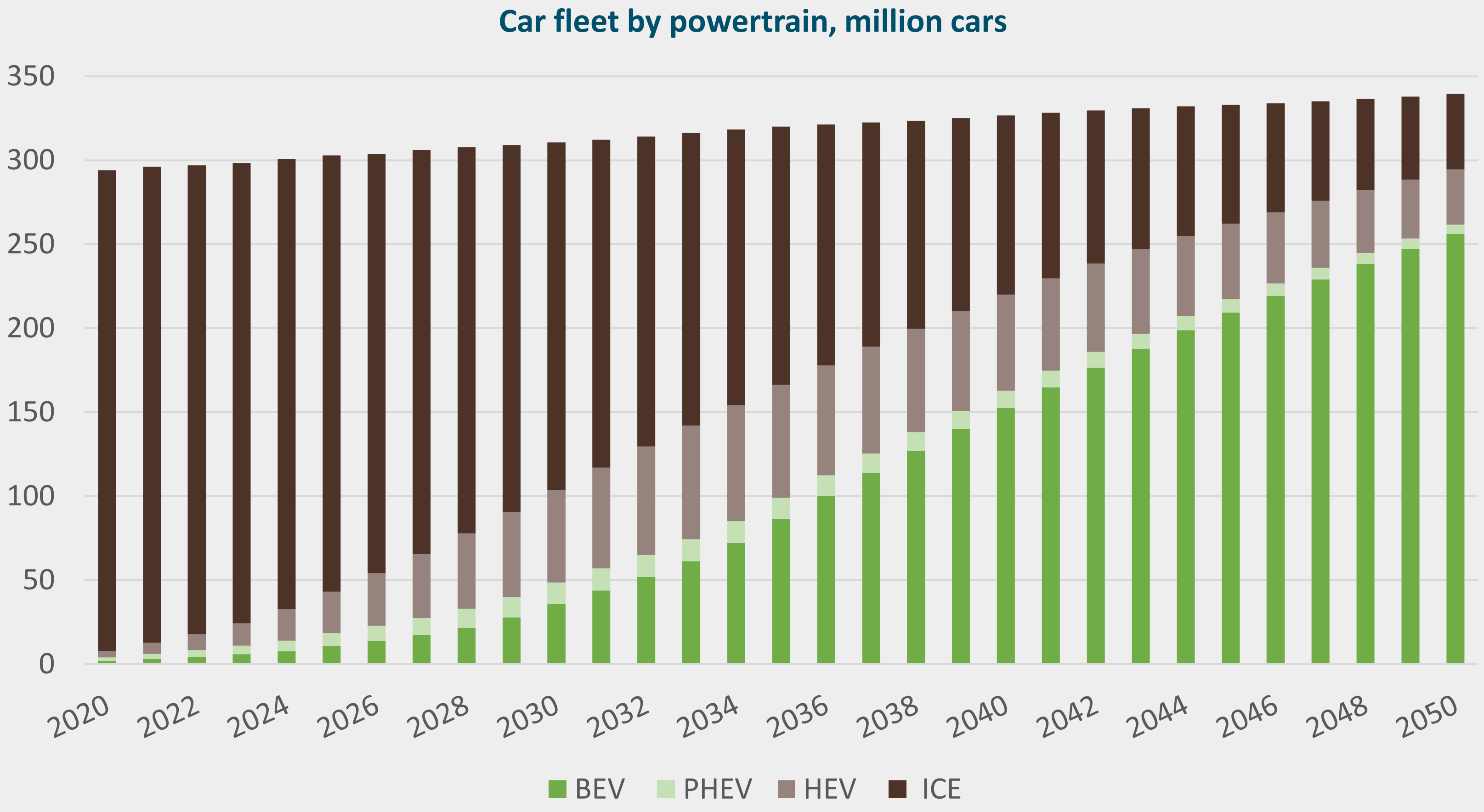
Step 2: Aging Matrix





The aging calculation is applied to the fleet for each powertrain:
BEV and ICE (diesel and petrol), as well as PHEV and Hybrid (not on the chart)

Step 3: Consolidation

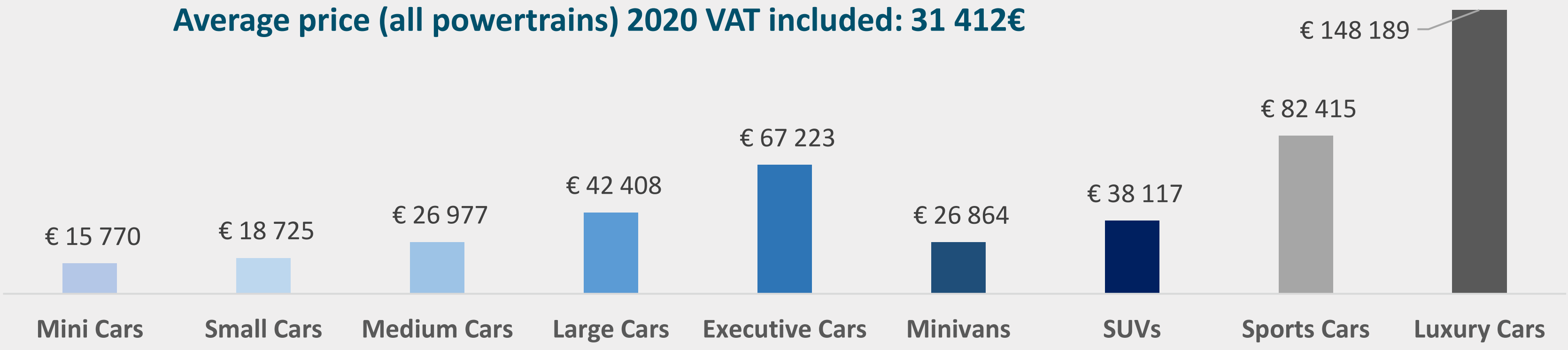


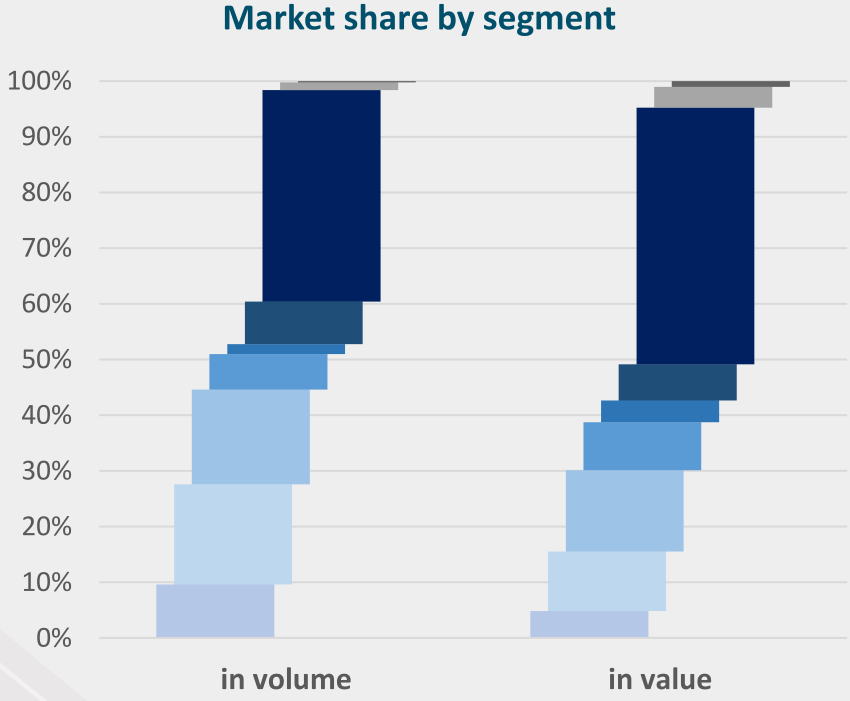
For each powertrain, the corresponding fleet is added up to get the breakdown of the overall car fleet by powertrain.

Without policy intervention, based on the survival curve, the last fossil car will be retired around 2070.

1. Sales & fleet size forecast
2. Fleet aging
3. **Price of new & used cars**
4. CO_2 emissions vs carbon budget
5. External cost
6. Affordable EV shortage
7. Exported used fossil cars

Starting point: Price of new cars





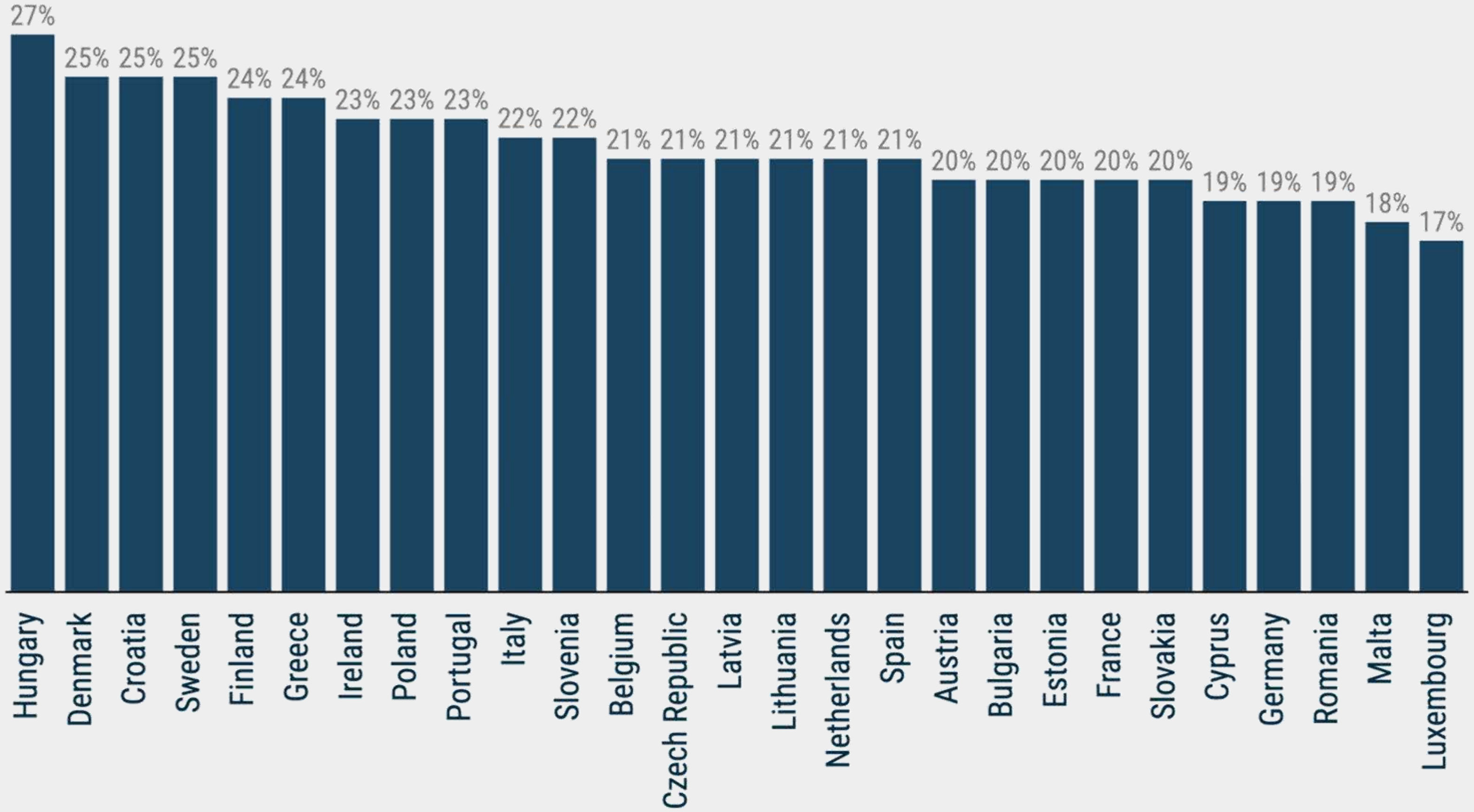
The analysis for Step 3 starts with calculating the average price of a new car based on market data (Statista 2022) for the EU-27+UK+NO+CH market.

We assume:

- VAT rate of 20% (see next slide)
- Constant price of a new ICE car over the forecast period (in €2020)

Sources: Statista (2022)

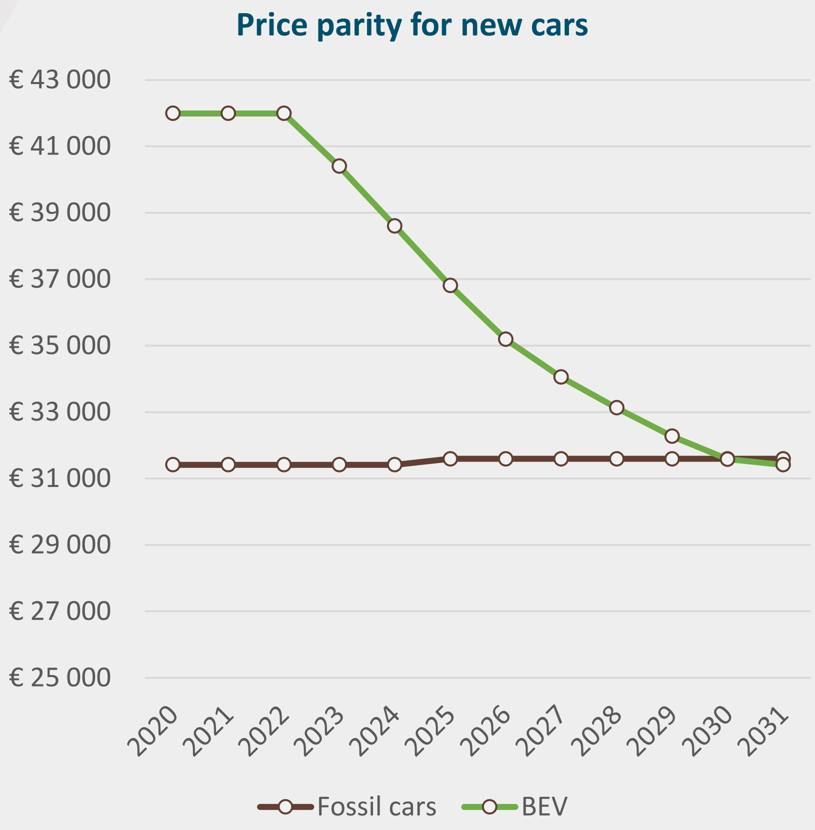
Share of VAT in the net price of cars



We assume an average VAT rate of 20%, given the share of Germany and France in the car market.

Sources: ACEA 2022

Step1: Premium on EVs



Key observations:

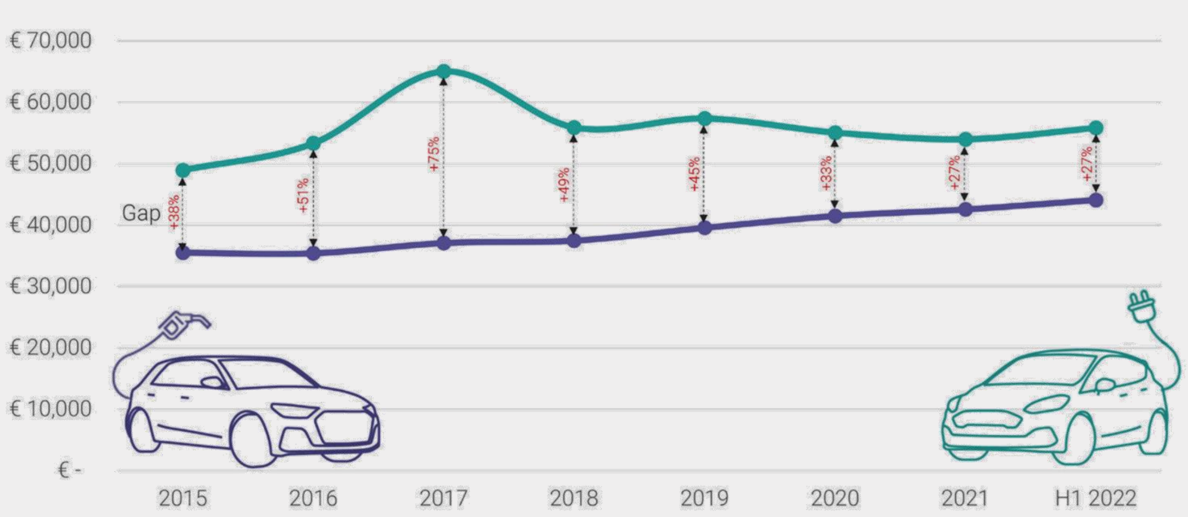
- Consumers currently pay a premium for EVs (vs similar ICEs.), estimated between €10k and €16k, (or 30-55%) depending on sources.
- The breakdown by category tends to be skewed towards higher-hand and larger cars, which increases the average price of EVs.
- Before 2022, depreciation was higher for EVs. 2022 market data for Tesla cars suggest slower depreciation than average ICEs, partly visible for other EV brands.

Key assumptions for the model

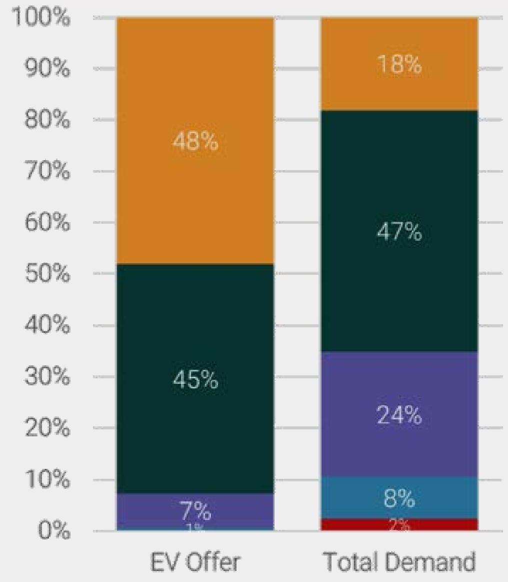
- Premium of €10.5k (34%) in 2022.
- Convergence of average retail prices with ICE cars in 2030 (source BNEF 2022);
- Increase of the average ICE car price by €180 in 2025 due to Euro 7 standards (Source: EC)

Sources: IEA EV outlook (2022), Jato (2022), various used cars online markets

Average price of EVs in Europe today (vs ICE cars)



H1 2022 EV offer vs demand



Today

On average, EVs are more expensive than comparable ICEVs, but more critically for the average price across the fleet, the manufacturers tend to be focus on SUVs and high-hand cars, for which sales are less sensitive to pricing and margins are higher. The second chart illustrates this trend with the retail price of electric cars by price range as percentage of total EV offer, compared to with the sales distribution by retail price range (data for H1 2022). Today, an EV in Europe is on average 27% more expensive than a gasoline car.

Sources: JATO 2022

Background data

Price of city electric cars today (vs ICE) in key European markets

Today

JATO data for small vehicles in the largest European markets suggests that retail price parity is a challenge on this segment. The average retail price of an electric city car in Europe has increased by 15% since 2015 to €28,319, whereas a gasoline city car can be purchased for just €17,527.

Price parity EV vs ICE tomorrow

"There is no consensus among analysts and researchers with respect to the future price path of EVs.

Some believe that Evs will become cheaper soon as a consequence of economies of scale and efficiency gains. Others argue that purchase prices may remain high or even increase because car manufacturers want to recover investment costs or demand surpasses supply."

Sources: JATO 2022, BNEF 2022

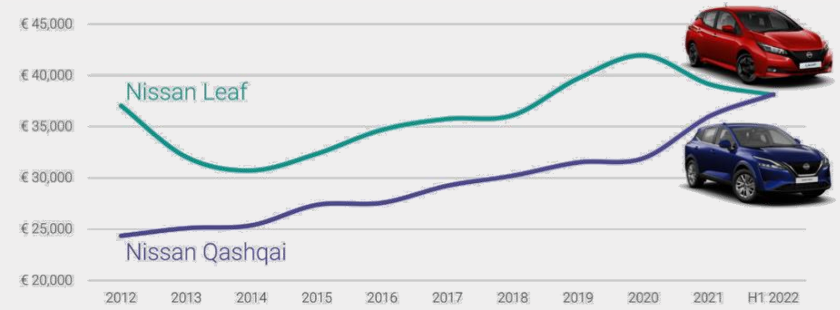
Affordable EVs Mass Adoption: The Industry Challenge

EV Outlook

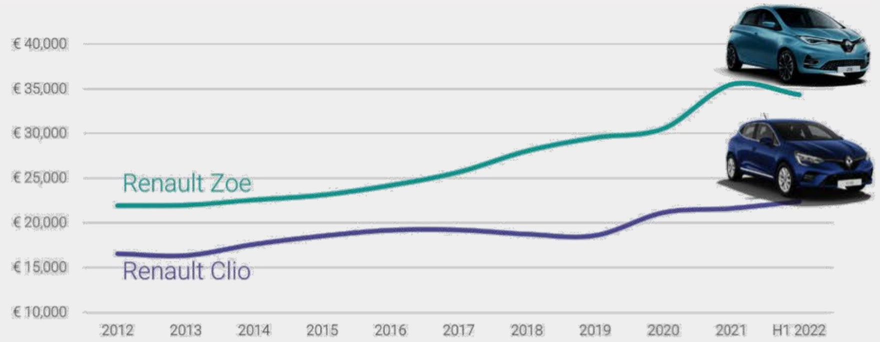
Transport & Mobility Leuven

Study on the implications of EU policies for the affordability of car use in the future

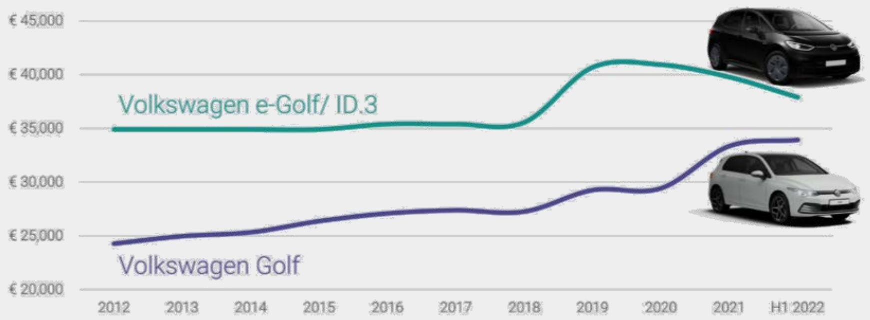
Average retail price (EV vs Petrol car) in the UK



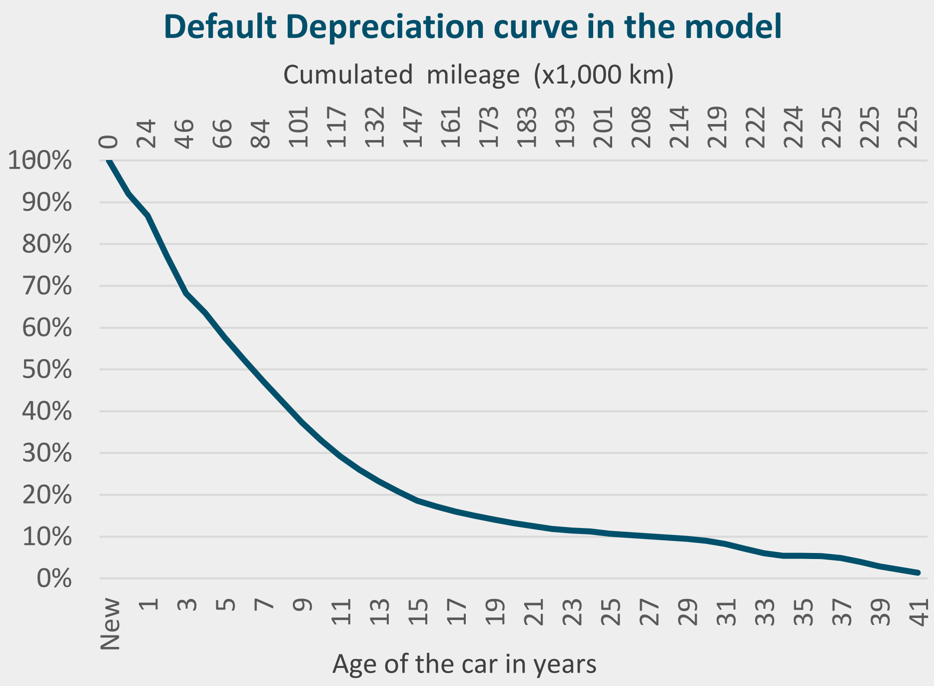
Average retail price (EV vs Petrol car) in France



Average retail price (EV vs Petrol car) in Germany



Step 2: Default depreciation curve (all vehicles)



Most studies conclude that the residual value is primarily based on total mileage.

For our default curve, we have assumed a total cumulated mileage of **225,000 km** over the lifetime of the car. To ensure consistency of the results across the study, we have applied the assumption used by T&E in the life cycle analysis and in the calculation of average annual CO_2 emission per car (based on Ricardo, 2013).

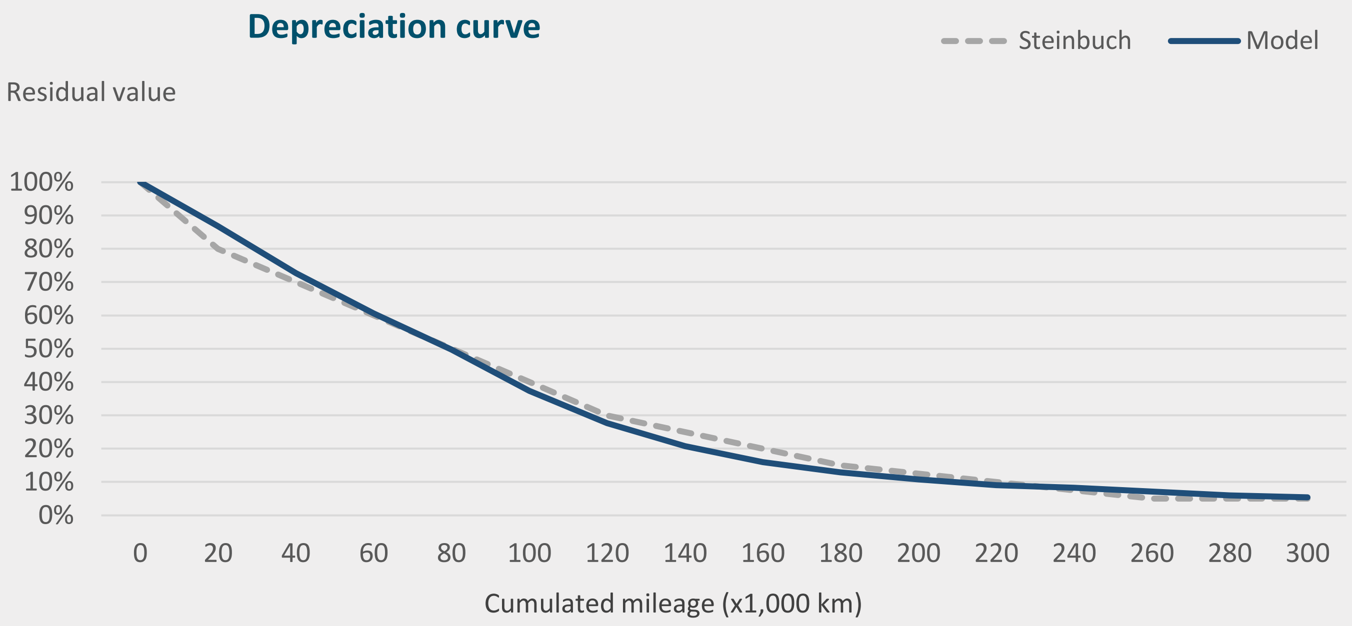
For the first 220,000 km the annual depreciation rate is roughly aligned with the assumptions used in *"Study on the implications of EU policies for the affordability of car use in the future"* page 34 (Transport & Mobility Leuven Nov. 2022), which are based on the Steinbuch (2014) formula.
The assumption is also informed by the results of the study *"Electric Cars: Calculating the Total Cost of Ownership for Consumers*" (BEUC, April 2021). We have slightly adjusted the curve based on a review of depreciation per category on French (La Central) and German (ADAC) car websites, and recent studies of absolute residual values (Car Vertical).

Main sources: Transport & Mobility Leuven (2016), BEUC (2021)

Steinbuch (2014) formula

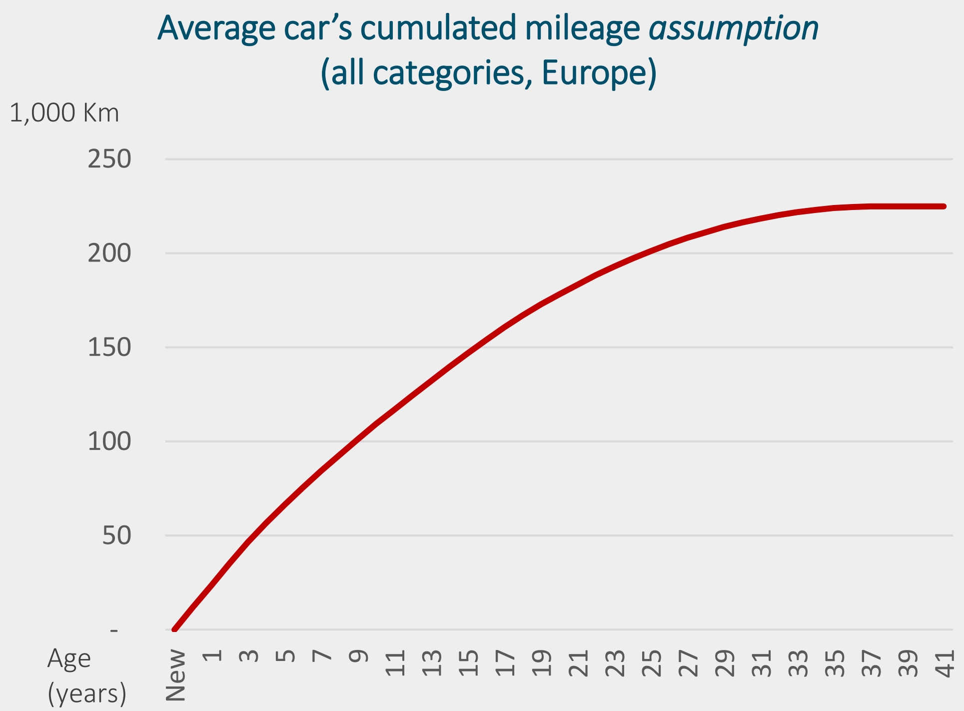
The resale value is X% of the vehicle's purchase price, with X equal to:

- 80%(up to 20, 000 km) to 30%(12,0000 km) with a step size of 10% per 20, 000km,
- 30% (120, 000km) to 15% (180,000 km) with a step size of 5% per 20,000 km,
- 15% (180 000 km) to 5% (260 000 km) with a step size of 2.5% per 20 000 km,
- 5% for a mileage above 260 000 km.



Source: Steinbuch (2014)

Annual milleage assumptions

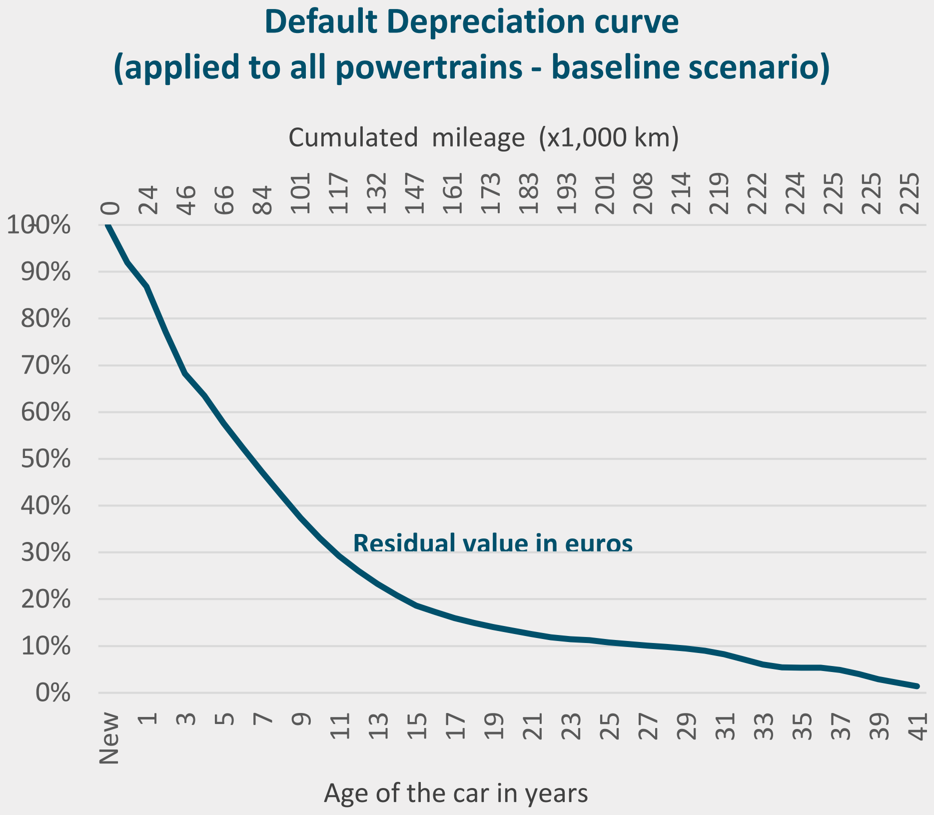


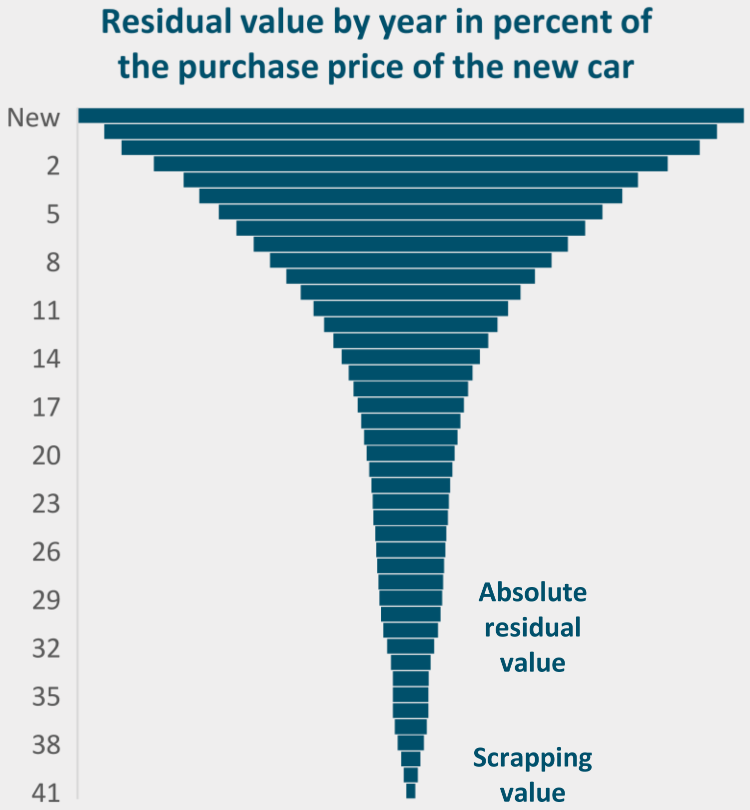
Most studies conclude that the residual value is primarily based on total mileage, while professional calculators factor mileage and age.

For our default curve, we assume **225,000 km over 40 years**, with a decreasing annual mileage (illustrated by the flattening of the curve on the cumulated mileage chart).

The maximum age is derived from the cumulated survival probability from Held et al (2021), and the annual mileage is derived from Transport & Mobility Leuven 2022. It is to be noted that Transport & Mobility Leuven assumes an average 265,000 km cumulated mileage over a lifetime in their study of the used car market. However, studying old cars involves a "survival bias", a percentage of the cars being exported before the end of their lifetime and therefore reducing the average mileage of the fleet.

Source CSP: Lifespan of passenger cars in Europe: empirical modelling of fleet turnover dynamic (Held, 2021)





Based on the two figures above (depreciation based on mileage and mileage per age), the depreciation curve has been applied by age – which is the main unit used in our overall model.

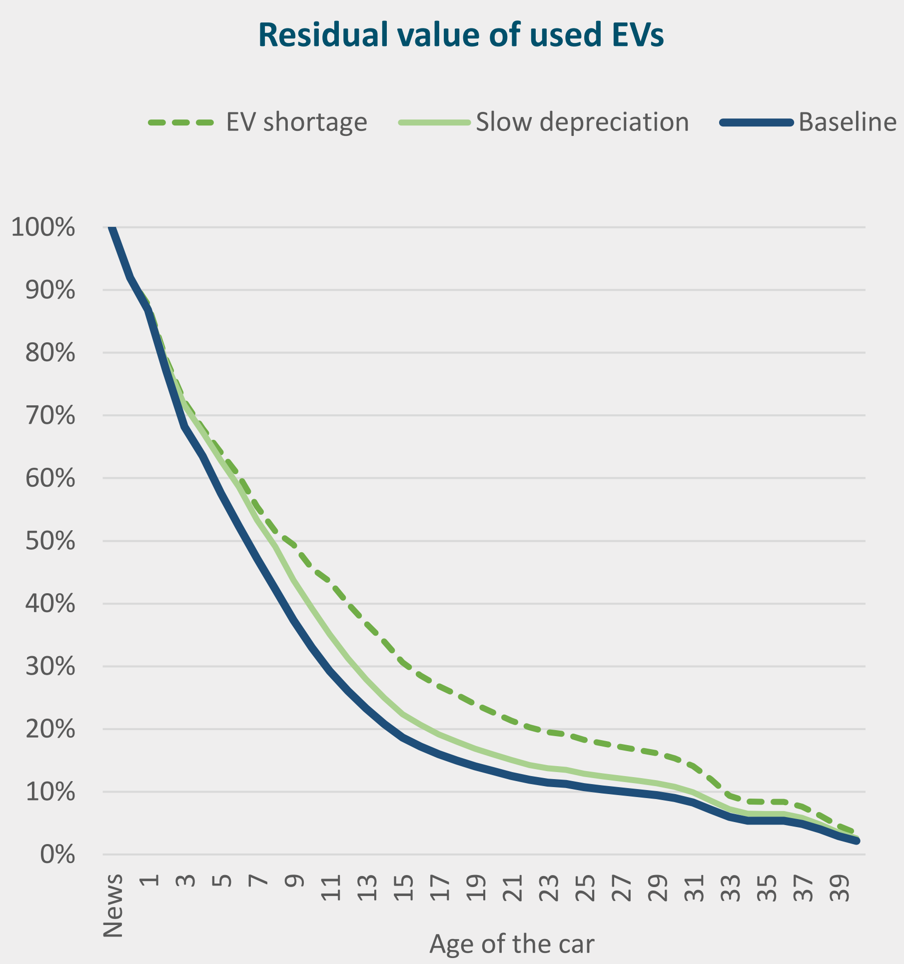
After 22 years, we assume that the average annual mileage declines and the car reaches its absolute residual value (between 5 and *33%* of the original price depending on the brand and category, according to CarVertical. The average is 10% in our model). After 40 years, we assume that the car reaches its "scrapping" value which is 1.5% of the original price on average, or 50€ to 500€ depending on the car category. The exception is sport and luxury cars, which keep their absolute residual value indefinitely in the model

Step 3: Depreciation curve for EVs

Experts consider that the depreciation rate of EVs is impossible to forecast.

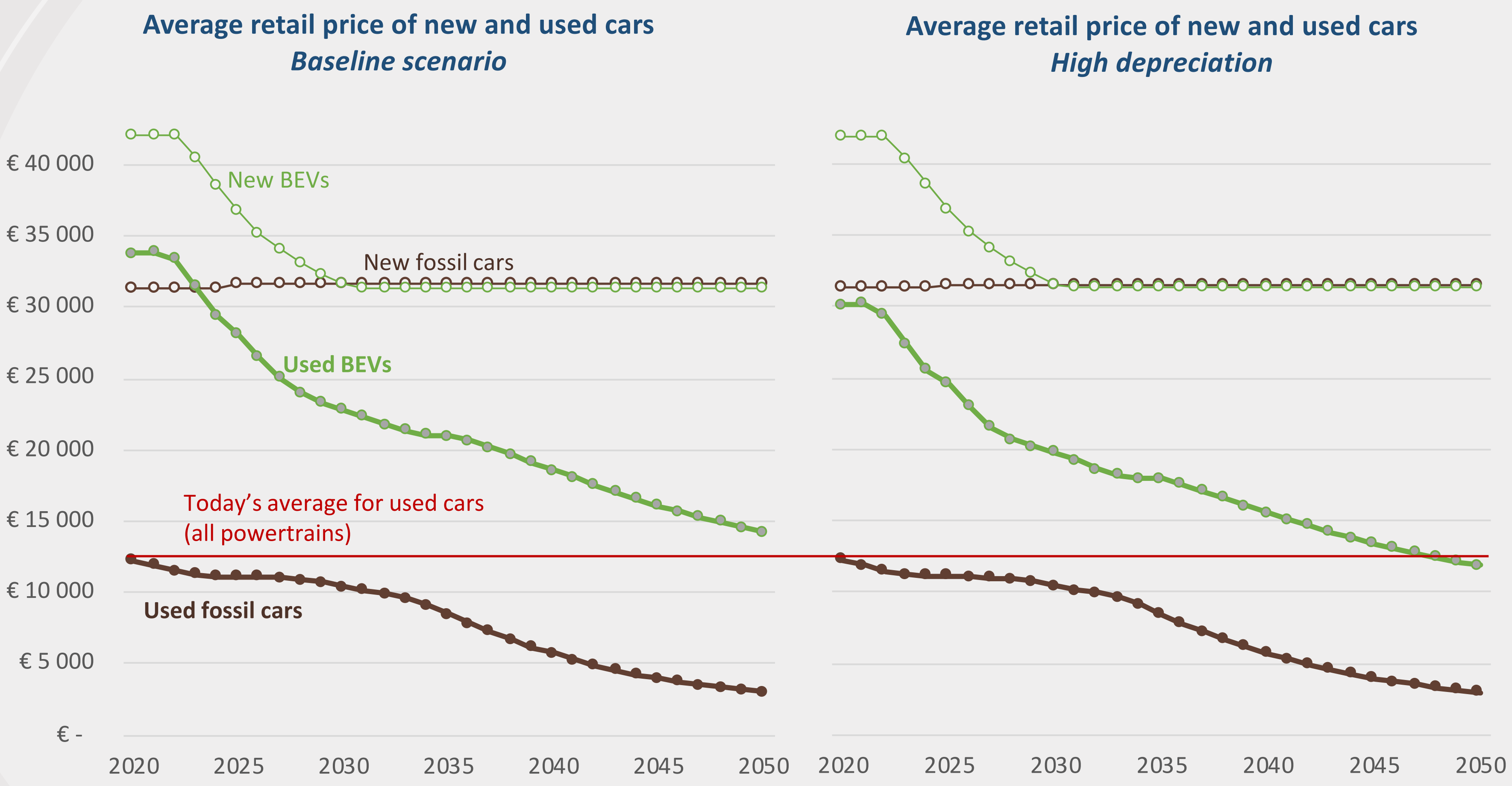
For the purpose of modelling, we have built 3 scenarios:

- The baseline scenario is aligned with the default curve for all cars;
- The slow depreciation scenario - 20% compared to the baseline;
- The last scenario “EV shortage) mimics the inflationary effect of used cars shortage on Tesla prices during the COVID crisis.



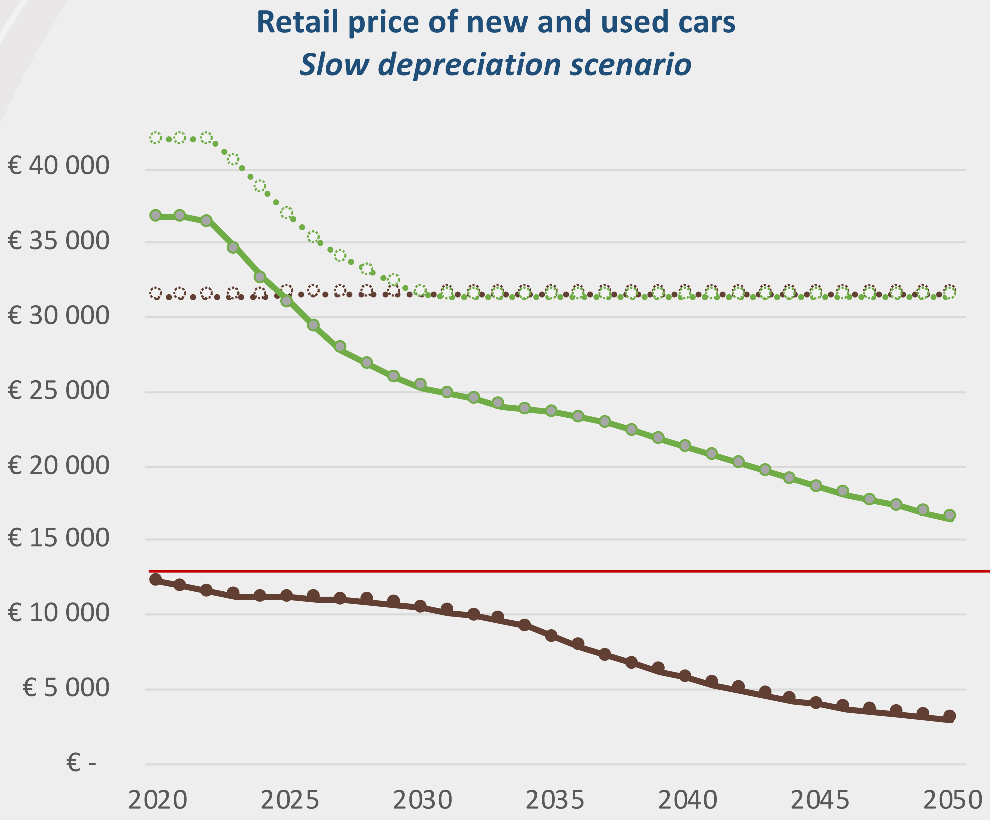
The gross depreciation curve does not factor the effect of retail price drops (for new EVs) on used cars resale prices.

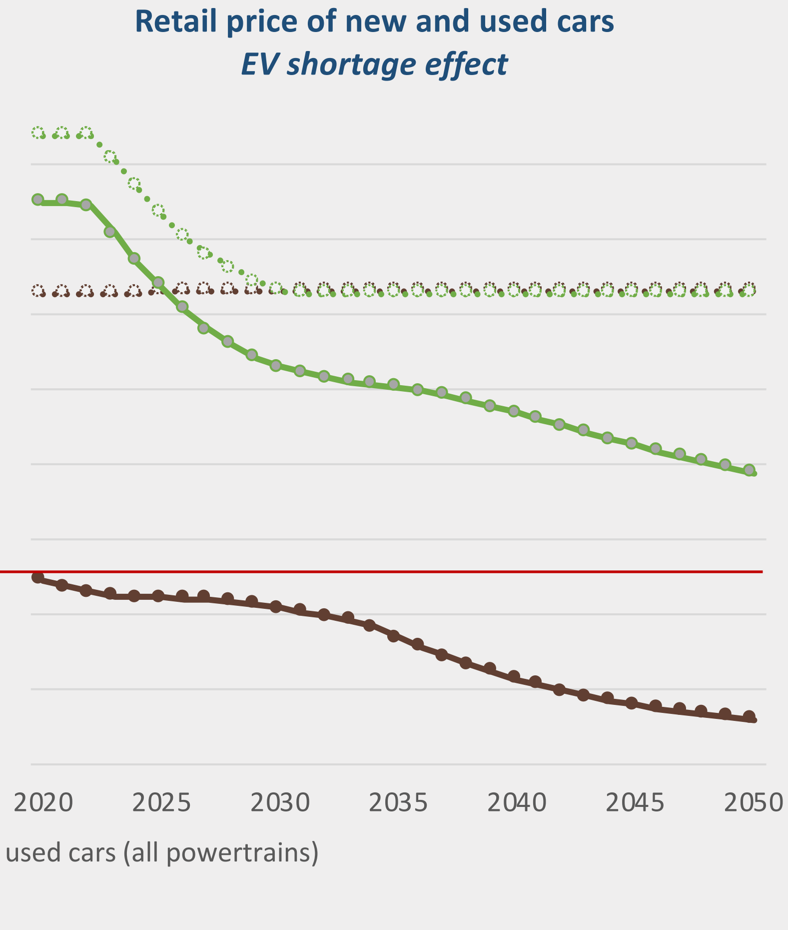
Step 3: Depreciation of EVs



Even assuming similar (baseline) or faster depreciation for EVs (relative to fossil cars), their average resale value remains way above the ICE cars resale value due to the young age of the EV fleet. This inflated resale value only fades away in 2050 at best.

Step 3: Depreciation of EVs

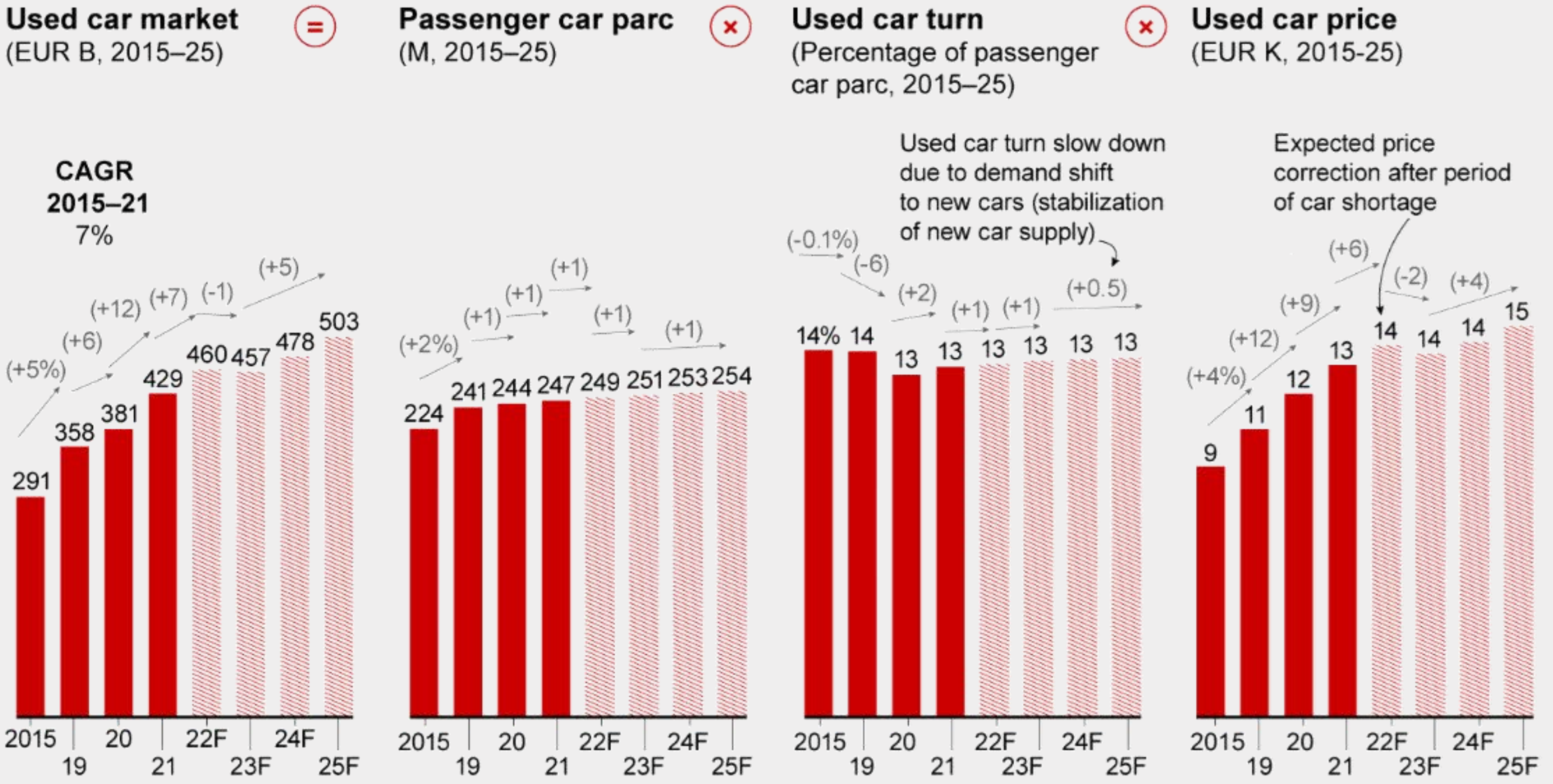




If EV depreciation turn to be slower (relative to fossil cars) or face inflation due to a shortage of old used EVs, the average resale value would be much higher and would not reach the current price range of used cars during the forecast period. These two scenarios are factored in the model.

Historical data informing the analysis

EU used car market forecast



Source: Bain Market Model

Source: Bain & Company (2023)

Different market drivers are at play in the European used car market

Car parc trends ↗

- ↗ Moderate population growth
- → More remote work
- ↗ Suburban lifestyle
- → Shared mobility

Used car turnover →

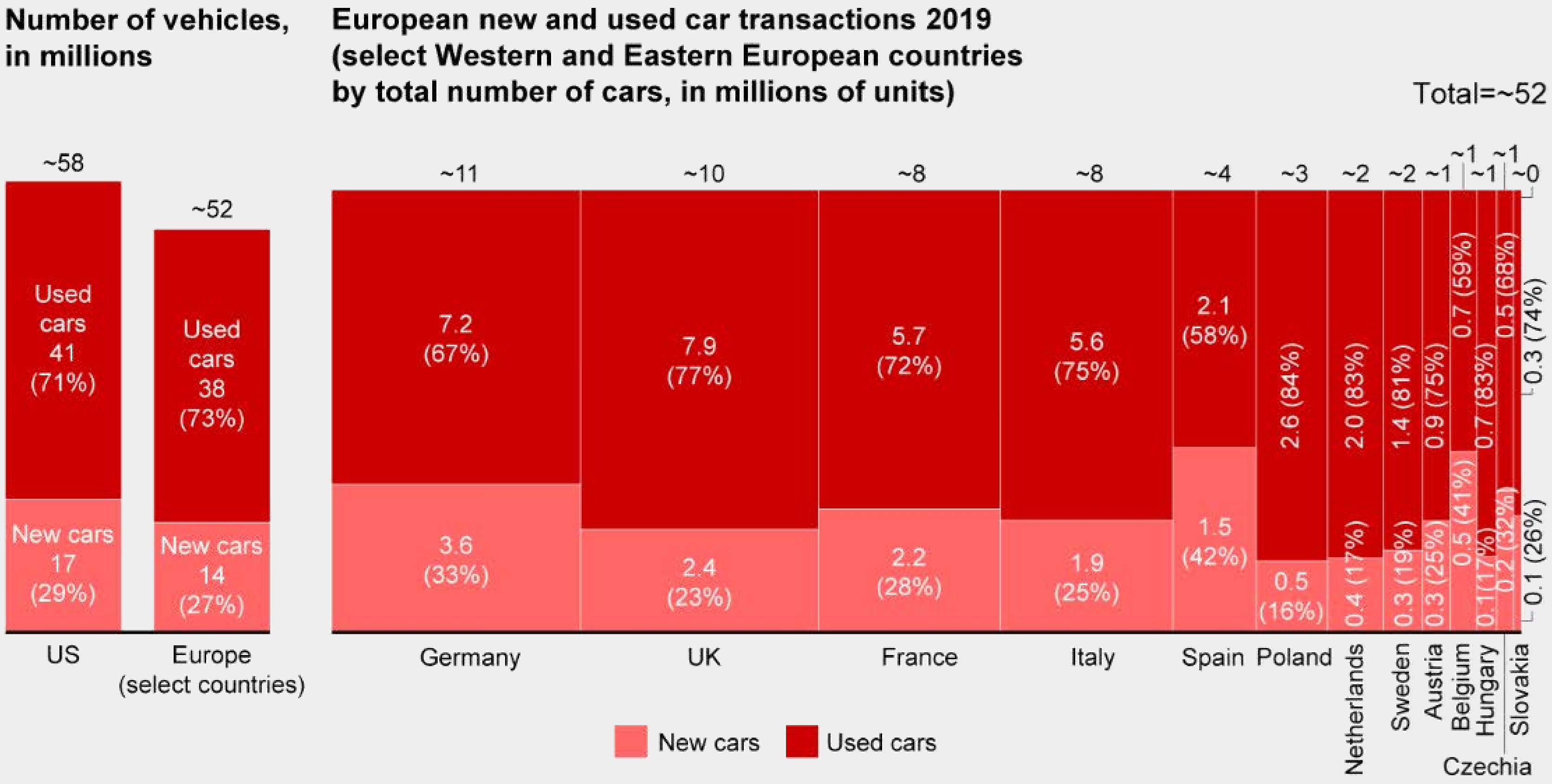
- ↘ Fewer new car purchases: limited offer
- ↘ Longer vehicle lifetime: less demand
- → High used car prices
- ↗ Shift to leasing and subscription: more churn
- ↘ Wait for EV advances: fewer purchases
- → Covid-19 lock downs: demand backlog

Used car prices ↗

- ↗ Shortage of new cars and resulting shortage of used cars
- ↗ Used car prices follow rising new car prices
- ↗ Younger cars, more extras
- ↘ EV trend: lower demand for combustion engine used cars

Source: Bain & Company (2023)

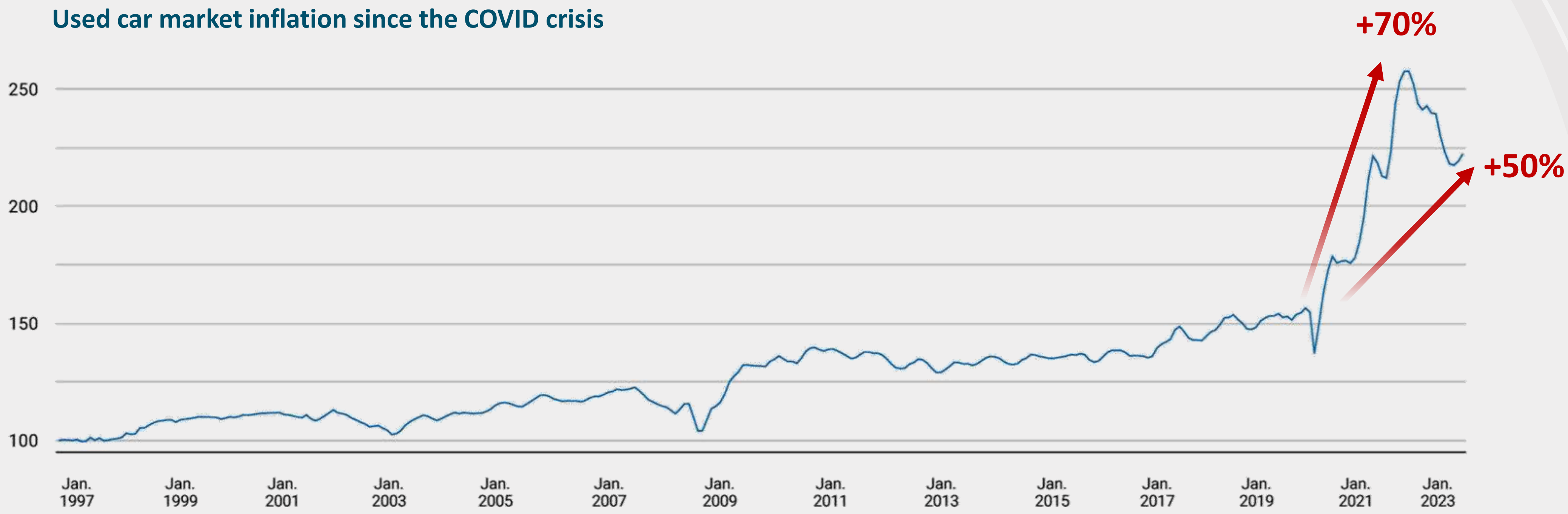
Different market drivers are at play in the European used car market



Note: Select European countries incl. Germany, UK, France, Italy, Spain, Netherlands, Sweden, Austria, Belgium, Poland, Hungary, Czechia, Slovakia
Sources: ACEA; Edmunds; Manheim; US Department of Transportation; DAT; KBA; SMMT; Lit. search; Bain analysis

Source: Bain & Company (2023)

Used car market inflation since the COVID crisis

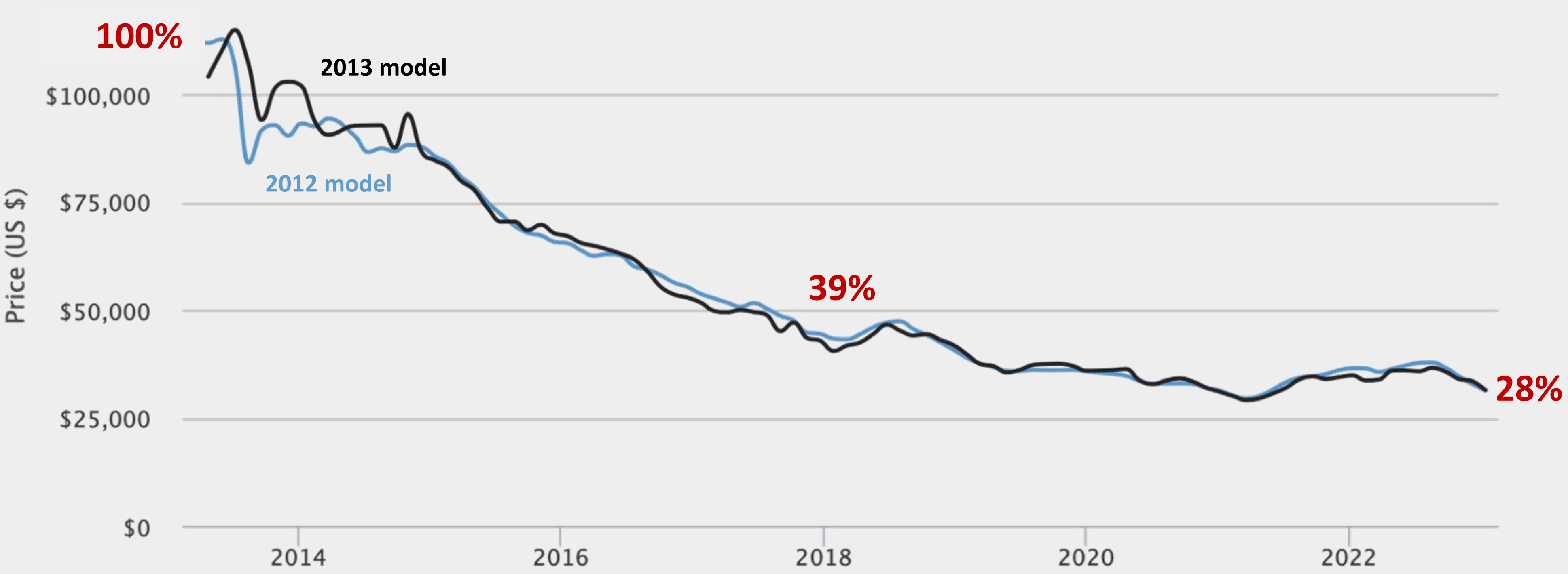


This chart shows the impact of the COVID crisis on the price index for used cars in the US. It illustrates the magnitude of the impact a shortage of used cars can have on price levels

Source: Cox Automotive/Manheim (2023)

Historical data informing the analysis

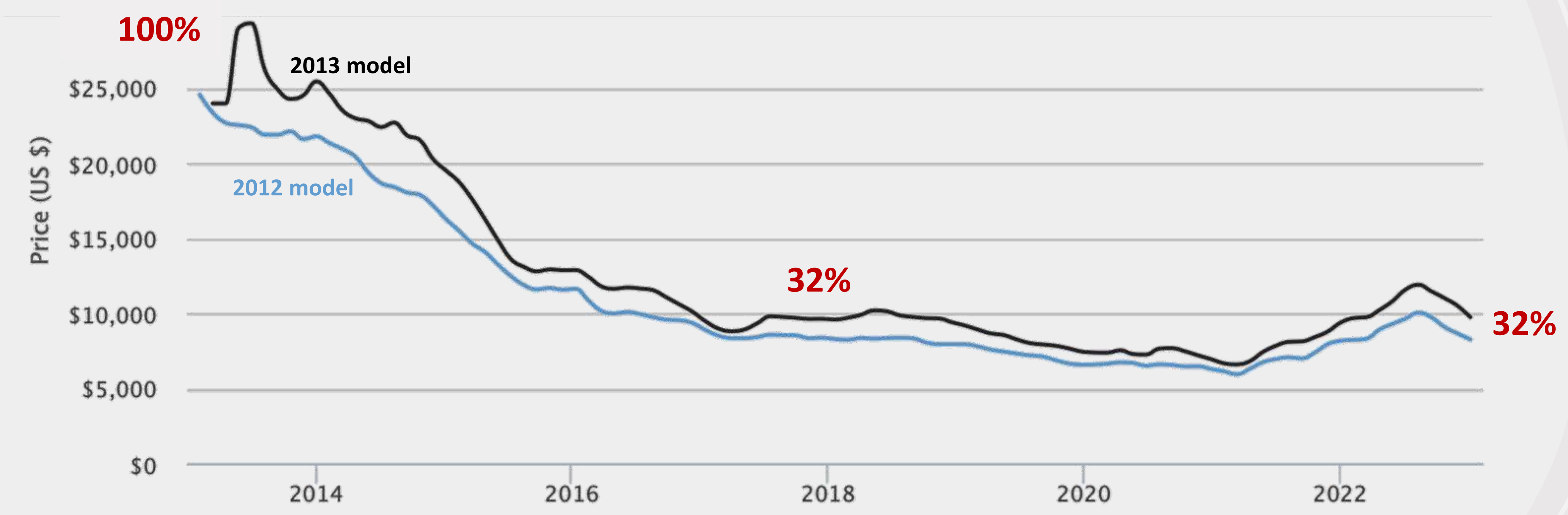
Average resale value of 10-year old EVs in the US: Tesla Model S (large car)



This chart shows an example of depreciation curve for one of the first mass-produced car.

Source: Car Gurus(2023)

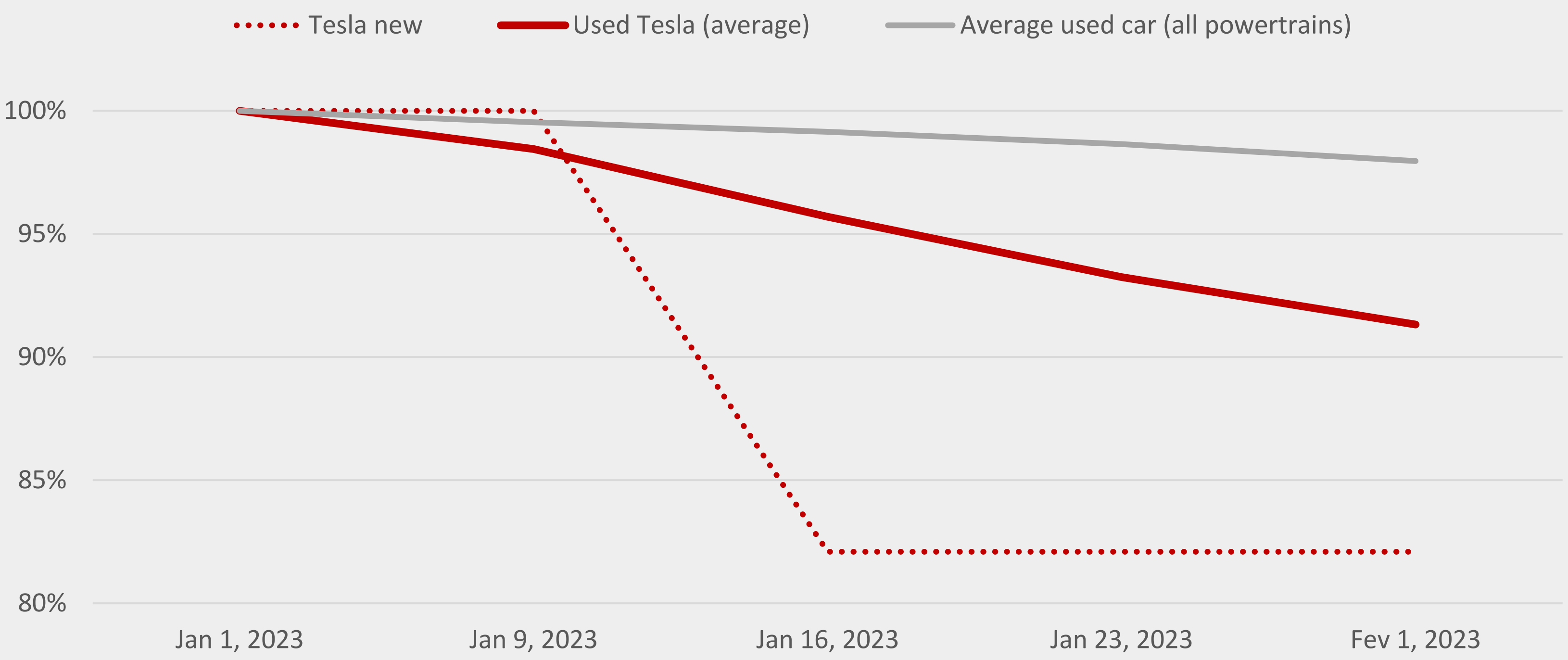
Average resale value of 10-year old EVs in the US: Nissan LEAF (city car)



This chart shows an example of depreciation curve for one of the first mass-produced car.

Source: Car Gurus(2023)

Impact of Tesla 2023 price drop on the resale value of used Tesla cars - USA



This chart shows the impact of Tesla price drop (announced on January 12th, 2023) for new cars on the average resale value of Tesla used cars. It provides empirical evidence on the potential impact of declining new EVs retail prices on the resale value of used EVs.

Source: CarGurus.com (2023)

EV Depreciation *"There is still no consensus and a lot of uncertainty about the depreciation scheme of electric vehicles relative to ICEVs. The earliest findings on EV resale value showed high depreciation rates because of the rapidly changing technology and the entry of new models onto the market. More recent data on the second-hand market for EVs indicate the opposite. Under the influence of a shortage of supply in the new car market, demand inflation occurs, which drives up prices on the used-car market." "We develop two scenarios for electric vehicles that impact the affordability of these cars."*

Scenario low depreciation BEV
+20%

Baseline scenario
= depreciation rate of ICE

Scenario high depreciation BEV
-20%

Sources: Transport & Mobility Leuven (Nov. 2022)

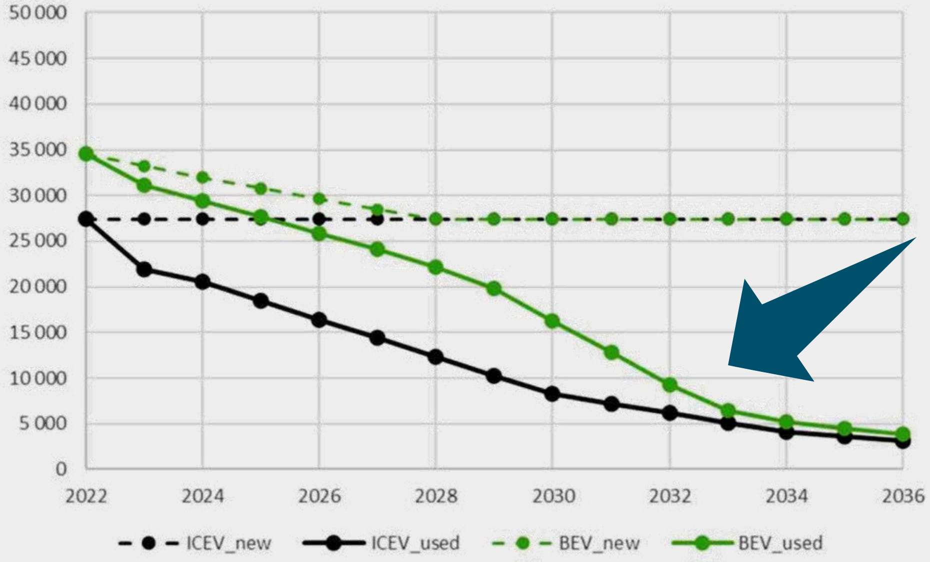
Study on the implications of EU policies for the affordability of car use in the future

NB: This study factors the BEV premium into the calculation of the resale value of used BEVs, and tests the sensitivity of a slower depreciation rate (-20%).

However, it does not study the shortage of old BEVs and the impact on the average price of used EVs – which is our focus in our High Adoption and 1.5°C scenarios.

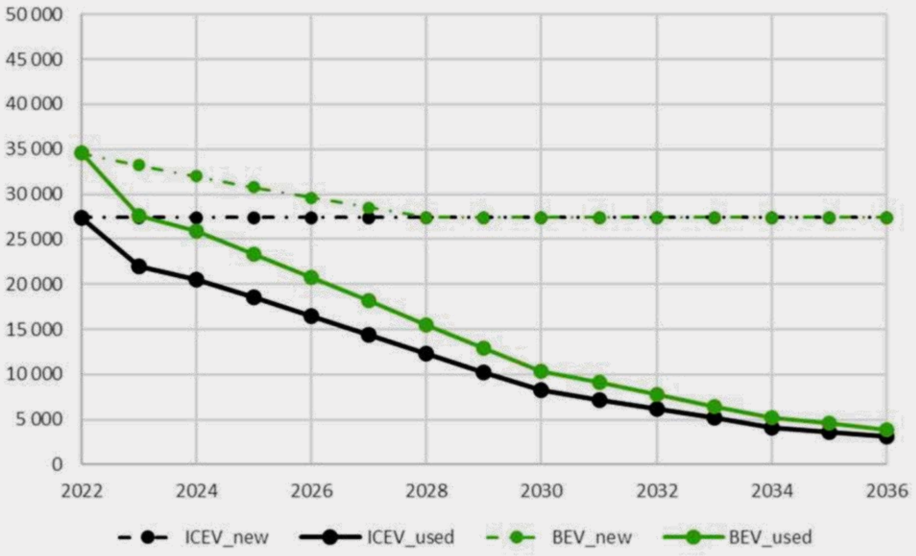
Small cars (segment B)

Scenario low depreciation BEV

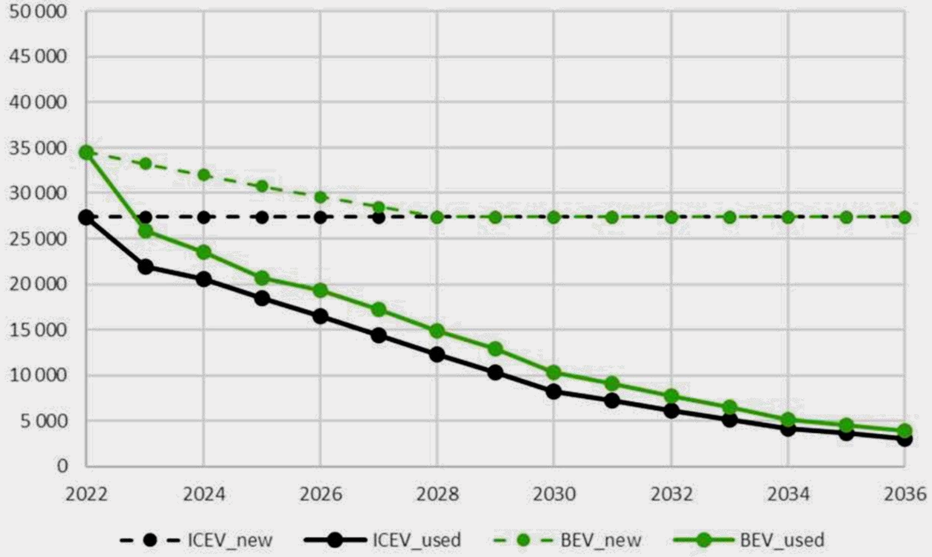


"If EVs depreciate at a slower pace than ICEVs, the price difference between used EVs and ICEVs remains large for a long time."

Baseline scenario



Scenario high depreciation BEV



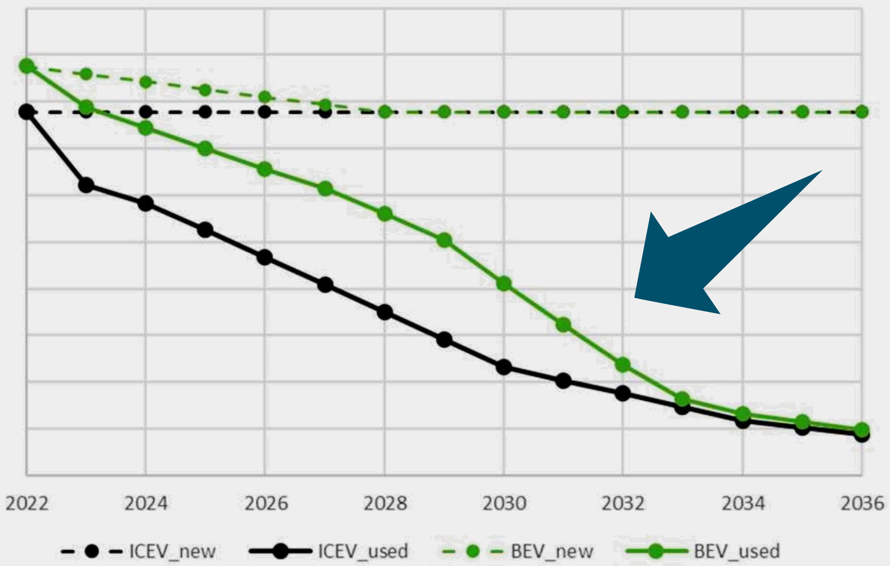
Sources: Transport & Mobility Leuven (Nov. 2022)

Study on the implications of EU policies for the affordability of car use in the future

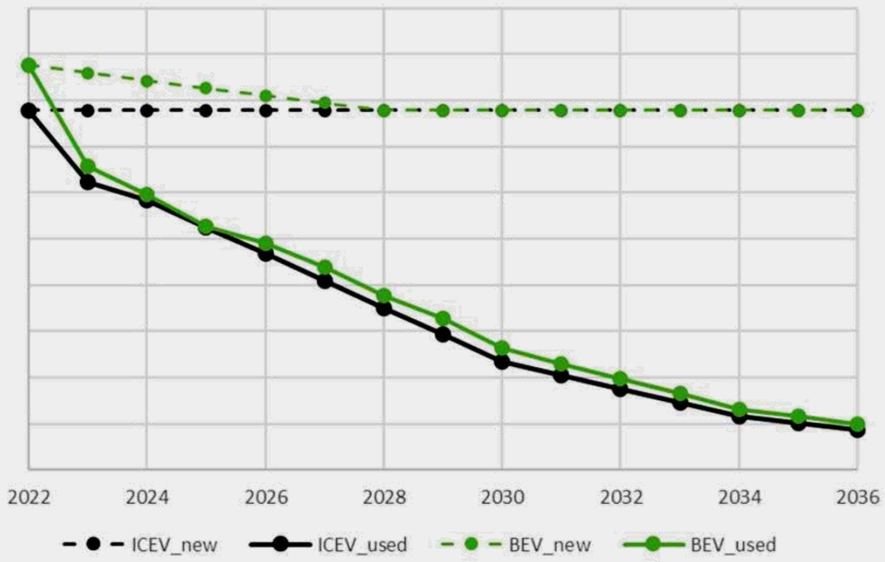
Evolution of the used 2022-model's price, assuming a yearly mileage of 15 000 km.

Mid-size cars (segment C)

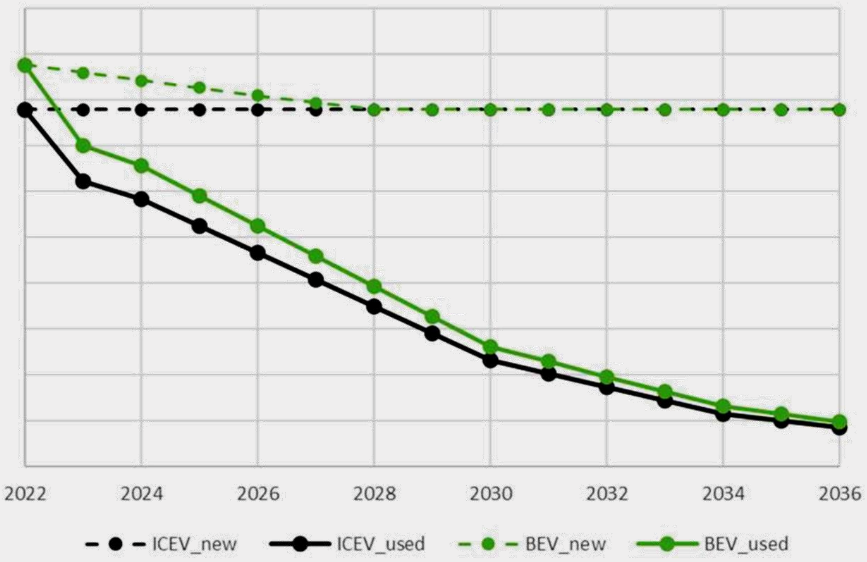
Scenario low depreciation BEV



Scenario high depreciation BEV



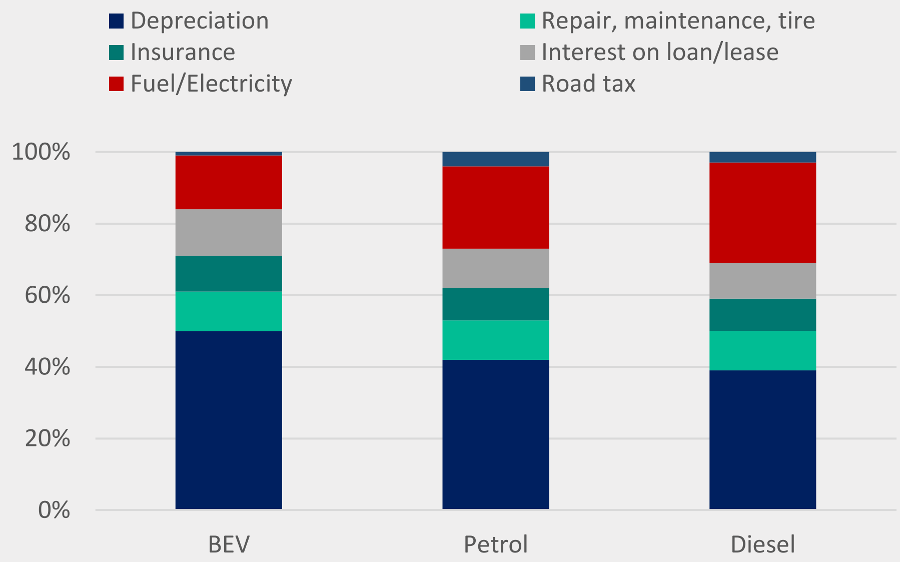
Baseline scenario



Sources: Transport & Mobility Leuven (Nov. 2022)

Study on the implications of EU policies for the affordability of car use in the future

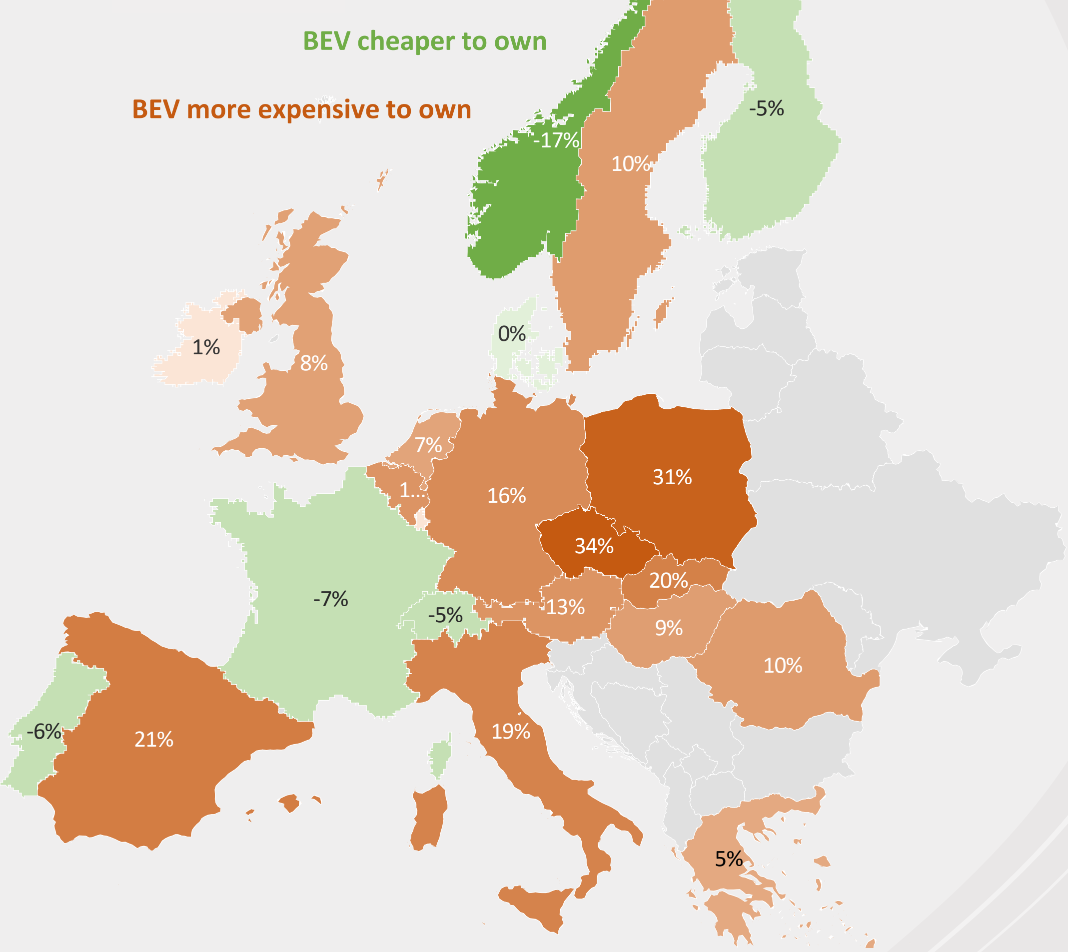
Total Cost of Ownership breakdown for 22 EU countries in 2022



Source: Lease Plan Car Cost Index 2022.
First four years of ownership, assuming an annual mileage of 30,000km. Average for all car categories, VAT excluded, subsidies included.

The annual mileage corresponds to heavy users, such as daily commuters using the highway or travelling salespeople, which represents about 5% of consumers (BEUC 2021)

Total Cost of Ownership for a Small car: Additional cost of EV vs ICE in 2022*

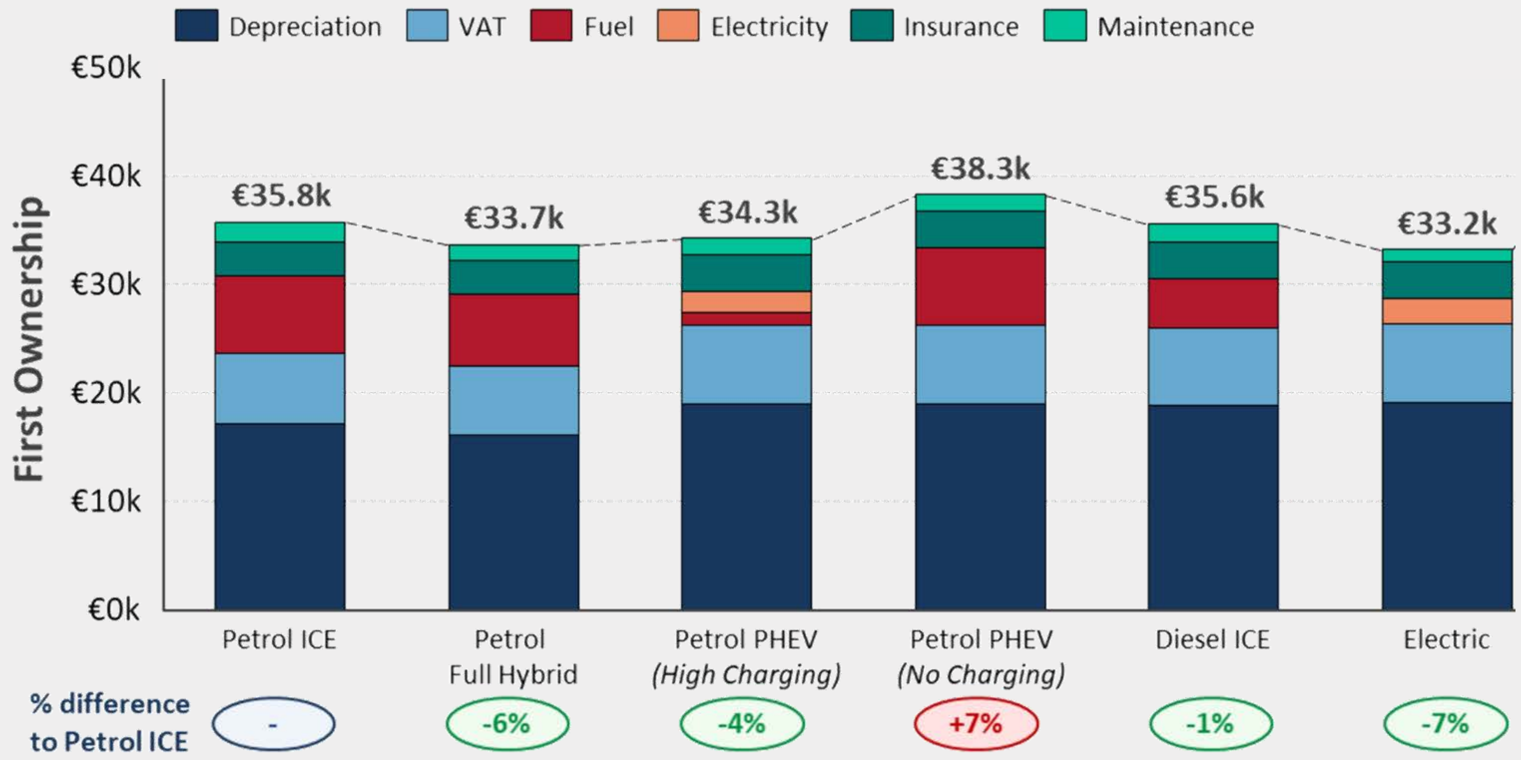


Map: small cars (e.g. Polo, 208). EV compared with ICE least costly option (Diesel or Petrol).

Source: Lease plan 2022

TOC: first owners, 2025

Outlook for an average new car bought new in 2025 - First owner (for 4 years)

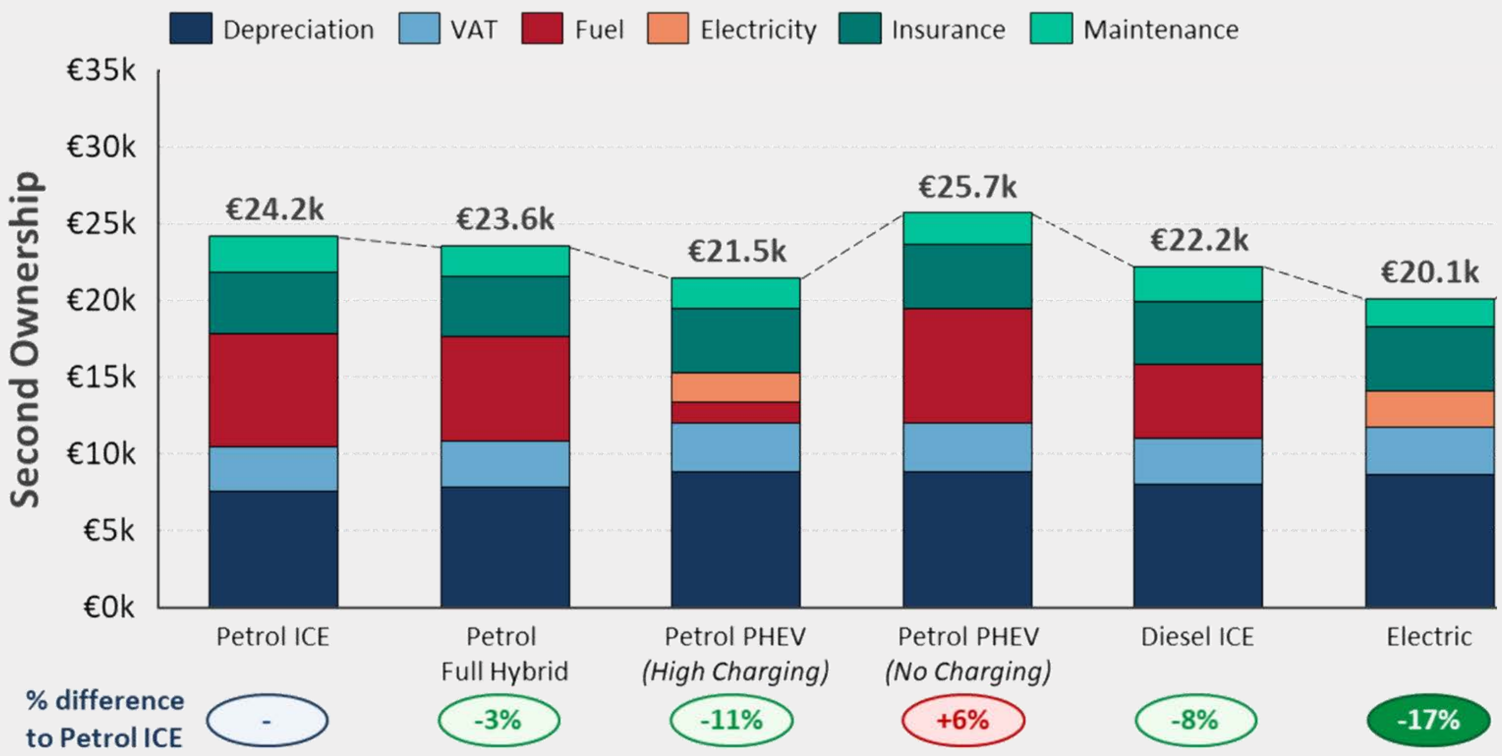


Medium-size car bought new in 2025. First ownership: 4 years over a 16 years lifetime. Price excluding subsidies.

Source: BEUC (2021)

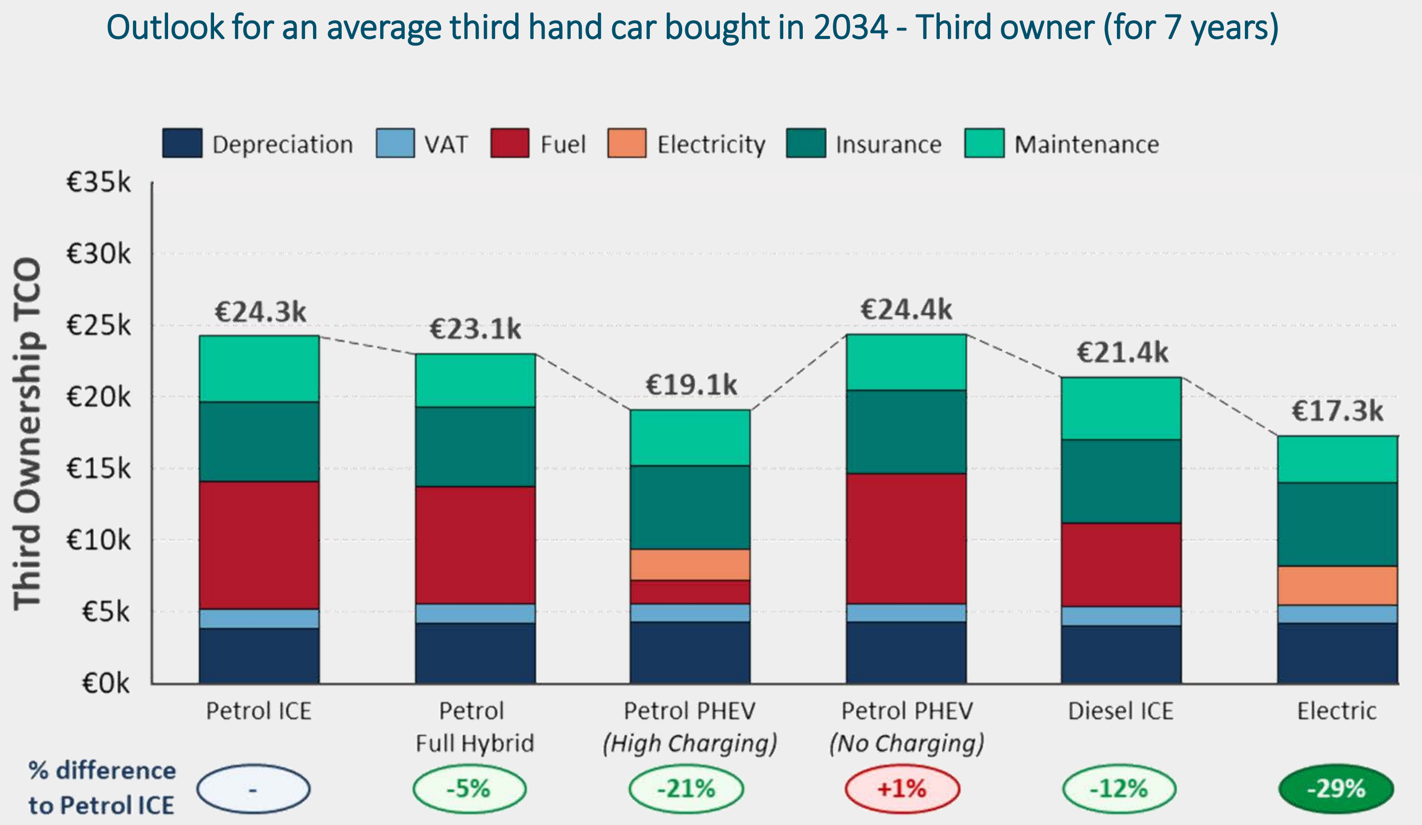
Electric Cars: Calculating the Total Cost of Ownership for Consumers

Outlook for an average second hand car bought in 2029 - Second owner (for 5 years)



Medium-size 4 year-old car bought in 2029. Second ownership: 5 years over a 16 years lifetime. Price excluding subsidies.

Source: BEUC (2021)



Medium-size 10 year-old car bought in 2034. Third ownership: 7 years over a 16 years lifetime. Price excluding subsidies.

Source: BEUC (2021)

"The impact assessment of the European Commission found that the Fit for 55 policies would not threaten the affordability of a Battery Electric Vehicles (BEVs). In all scenarios considered by the Commission, BEVs will become affordable over time. However, for low-income households, new passenger cars are never affordable and can only afford purchasing used cars."
(...)

"Total Cost of vehicle Ownership (TCO) calculations assume a decrease of the BEV's purchase price due to declining production costs. Recent literature has challenged these assumptions. For instance, van Velzen et al. (2019) argue that many EVs are currently sold below production costs and that, even when production costs decline, manufacturers will keep prices high to recover the high investment costs. Therefore, to assess the future affordability of passenger cars, it is important to consider alternative scenarios with respect to the purchase price of electric vehicles."

Key takeaway

- The Total Cost of Ownership (TCO) of EVs is lower than the TCO of ICE vehicles in many European countries factoring subsidies. Experts expect EVs to become more cost effective to own, on average in Europe, without subsidies, from 2025 onwards.
- This conclusion is expected to apply to used EVs including second and third hands.
- A significant percentage of the TCO for EVs is the depreciation cost, which depends on the original retail price and the speed of depreciation
- As a result, reaching TCO parity highly depends on the assumptions regarding:
  - Retail price parity (new EVs vs ICEVs)
  - The speed of depreciation (EVs vs ICEVs)

Source: BEUC (2021)

1. Sales & fleet size forecast

2. Fleet aging

3. Price of new & used cars

4. CO_2 emissions vs carbon budget

5. External cost

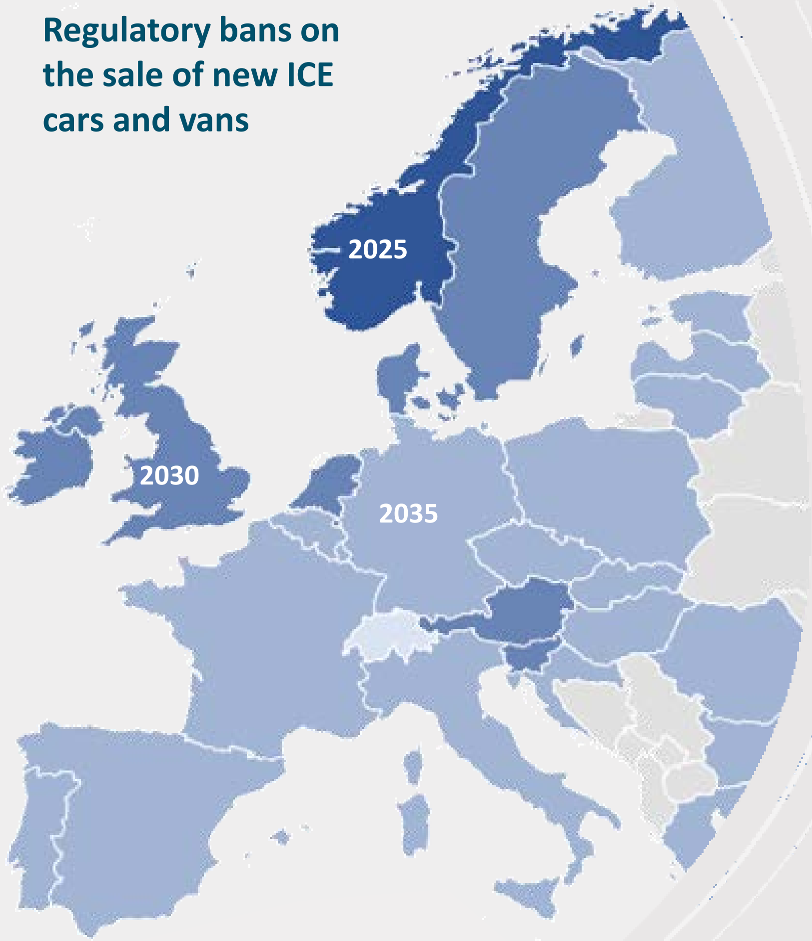
6. Affordable EV shortage

7. Exported used fossil ca

Volontary target dates of car manufacturers for 100% BEV sales

Size of the squares proportional to 2022 EU sales by brand (ACEA)

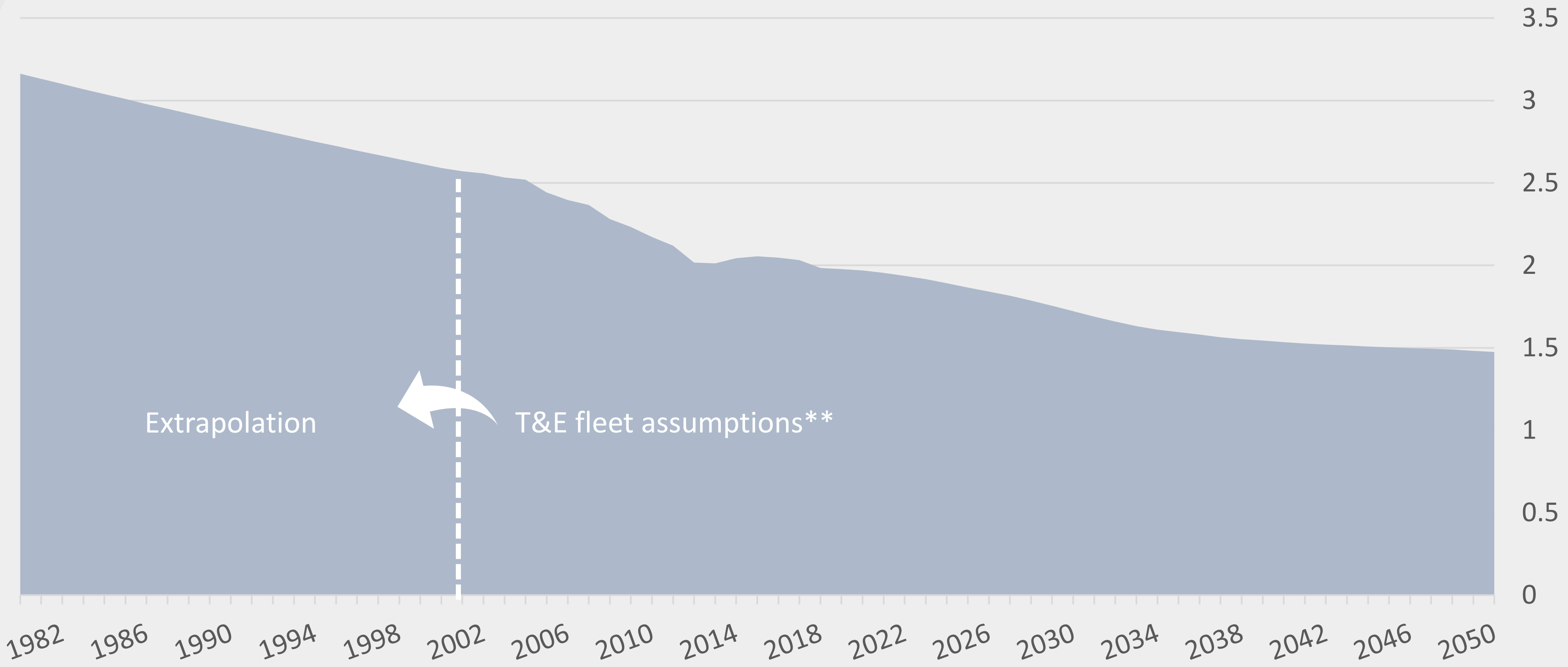
Regulatory bans on the sale of new ICE cars and vans



Sources: T&E (2022), Authors

Starting point: Carbon intensity forecast

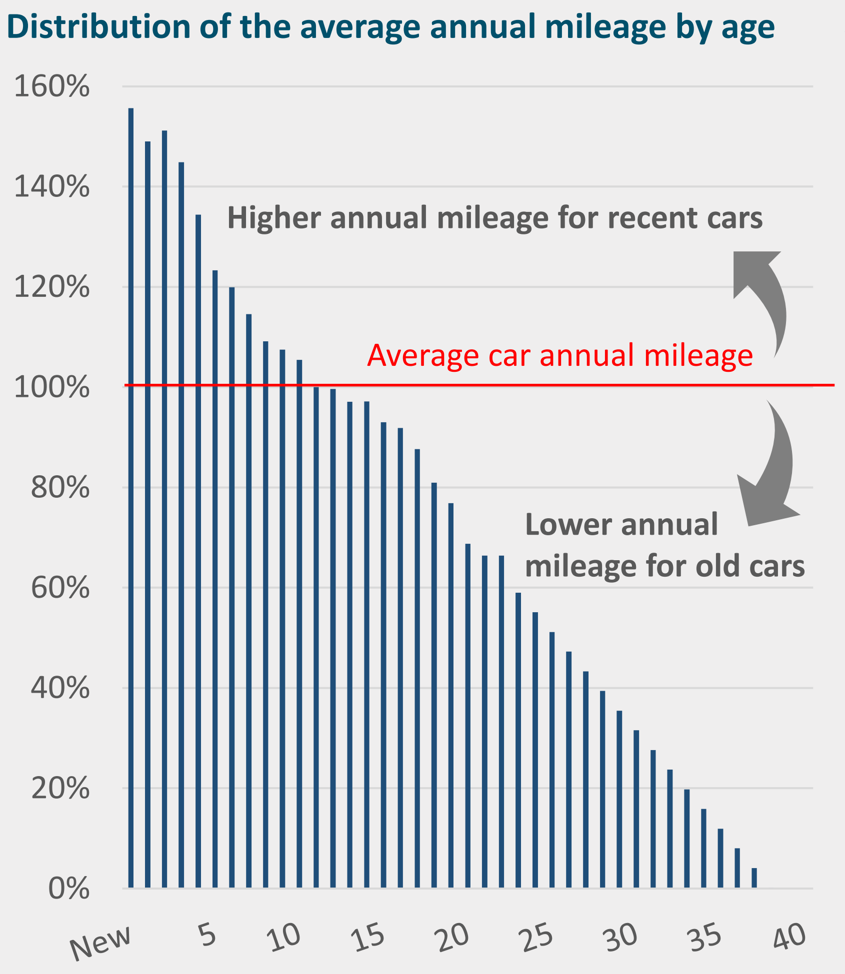
Gross average annual emissions per year per ICE* car in tCO2e

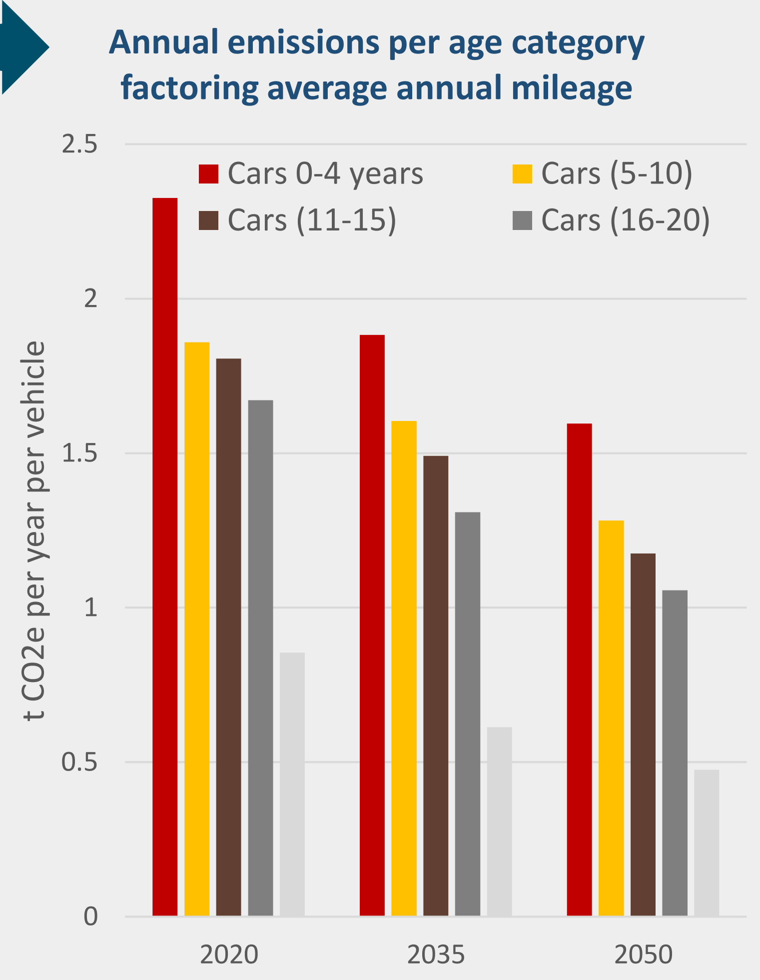


*Including Petrol, Diesel, Hybrid, Plug-in-Hybrid
** For EU-27 (extrapolated to the whole region)

Sources: T&E assumptions (2022)

Step 1: Factor decreasing annual mileage

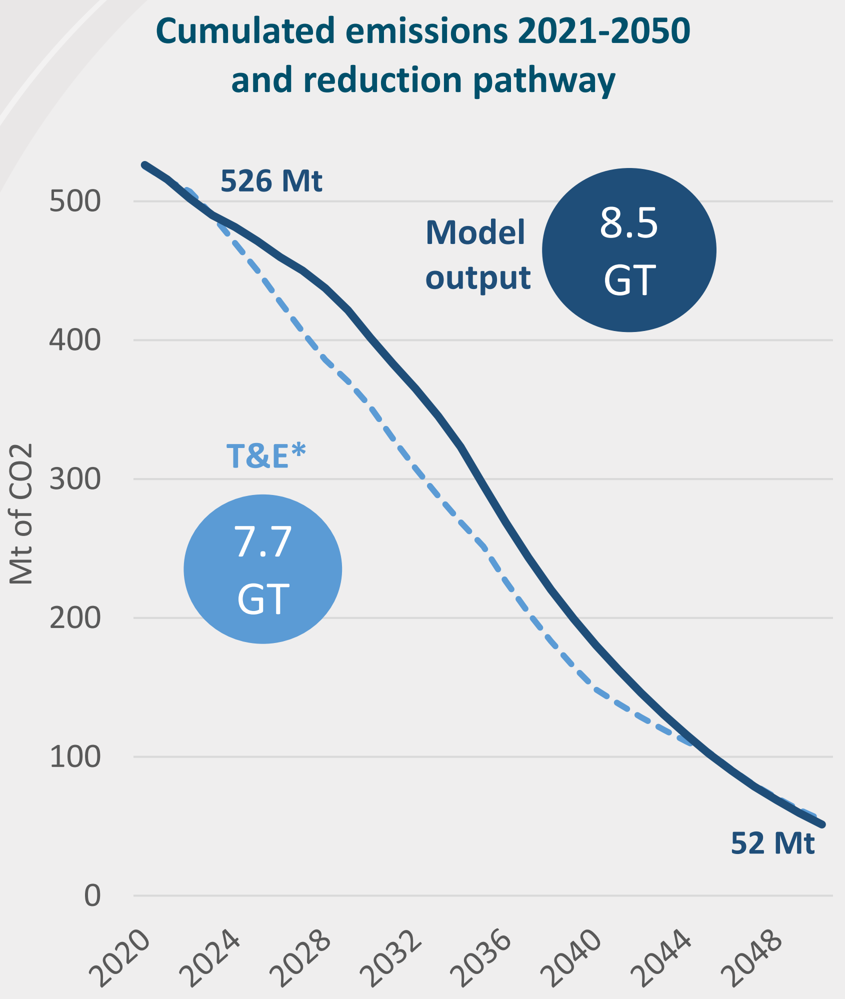


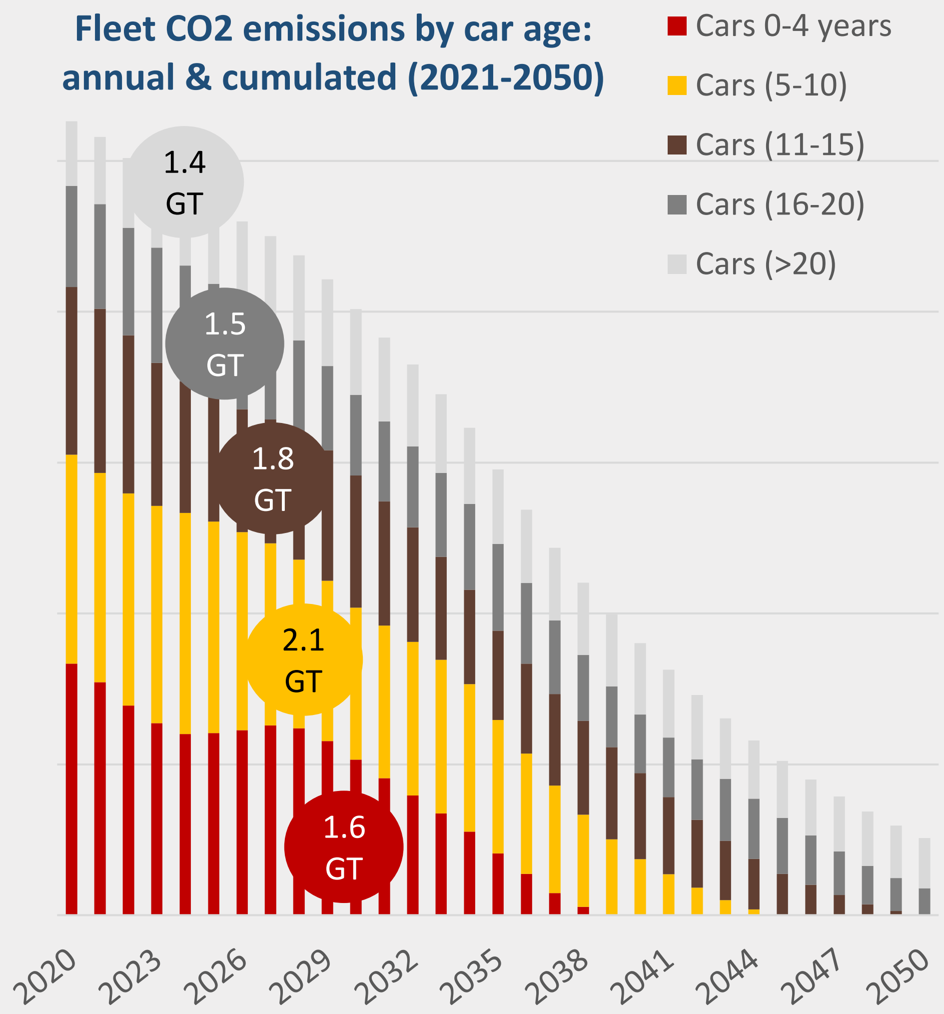


Formula: gross annual CO2 emissions x usage coefficient = net annual emissions

Sources:
Transport & Mobility Leuven (2016); Caseniri et al (2013), Ricardo/EC (2013)

Step 2: Calculate future CO2 emissions





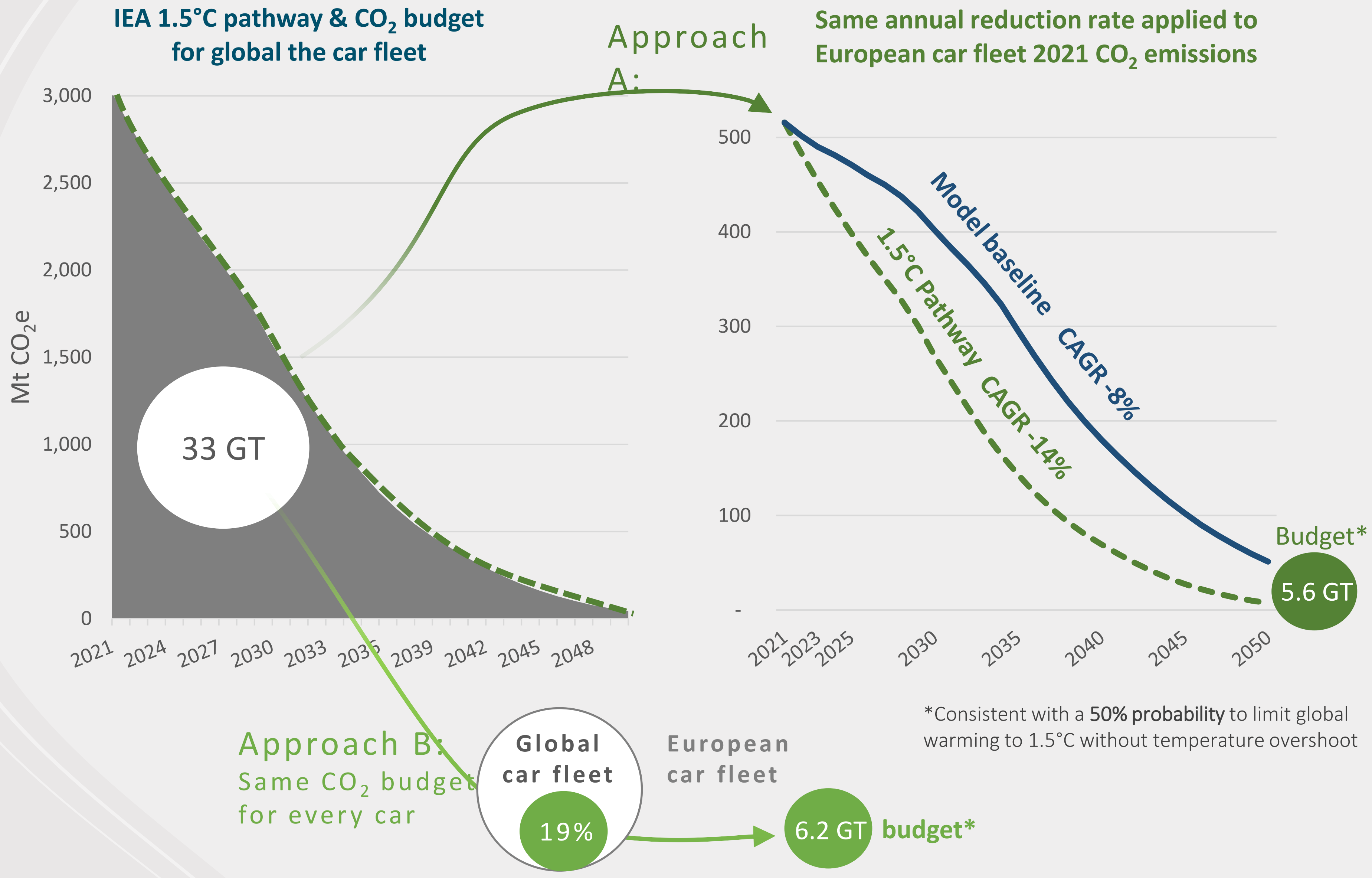
Formula:

$$\sum_{age=0}^{60} \#\text{cars x net annual } CO_2 \text{ emissions} = \textbf{\textit{net annual } } \boldsymbol{CO_2} \textbf{\textit{ emissions}}$$

$$\sum_{Year=2021}^{2050} net\ annual\ emissions = \boldsymbol{cumulated\ CO_2\ emissions}$$

*Source: T&E's ICE 2035 ICE ban scenario (2018)

Step 3:
Set a 1.5°C carbon budget for Europe

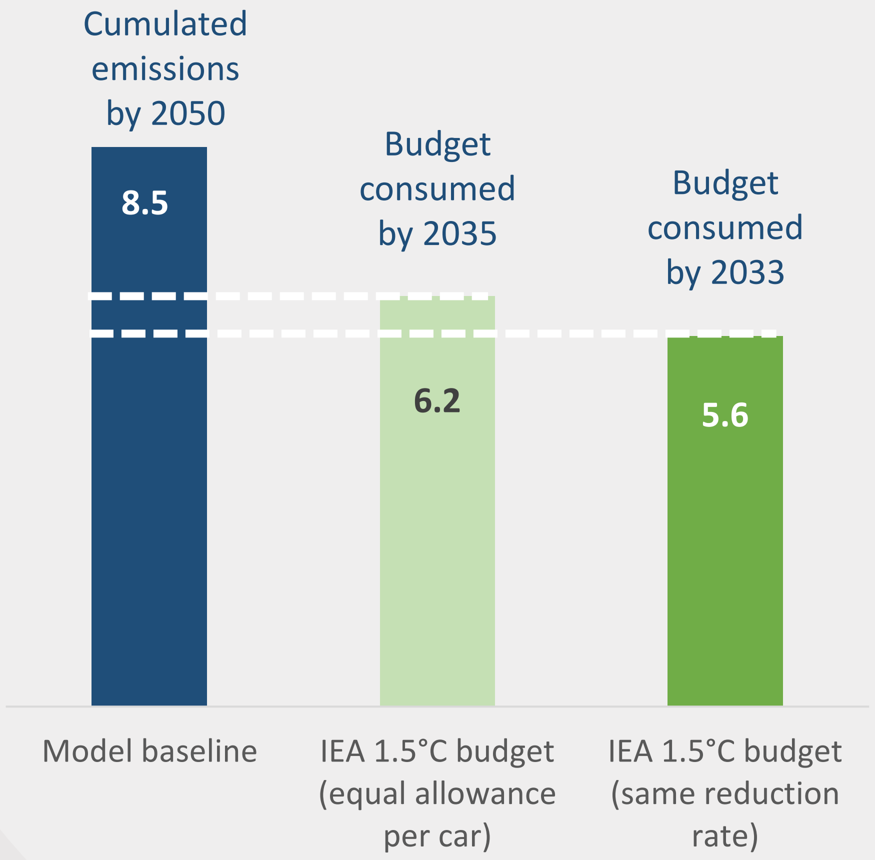


*Consistent with a **50% probability** to limit global warming to 1.5°C without temperature overshoot

Source: IEA Net Zero 2050 Scenario 2022

Step 3: Set a 1.5°C carbon budget for Europe

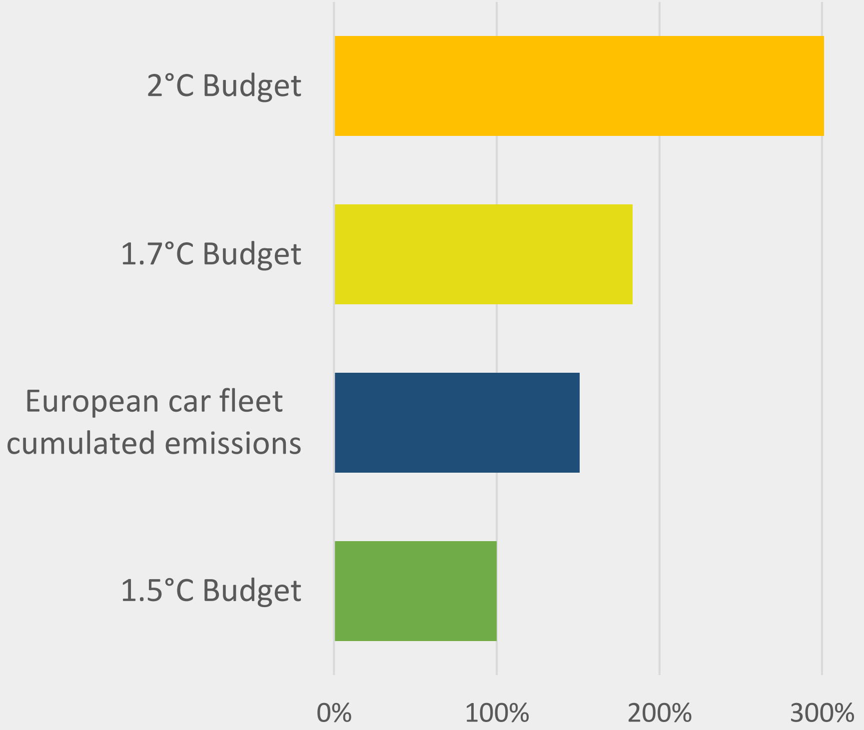
1.5°C carbon budget 2021-2050 for European cars ($Gt\ of\ CO_2e$)



Based on our model, the European car fleet is currently on a pathway below 2°C but above 1.5°C.

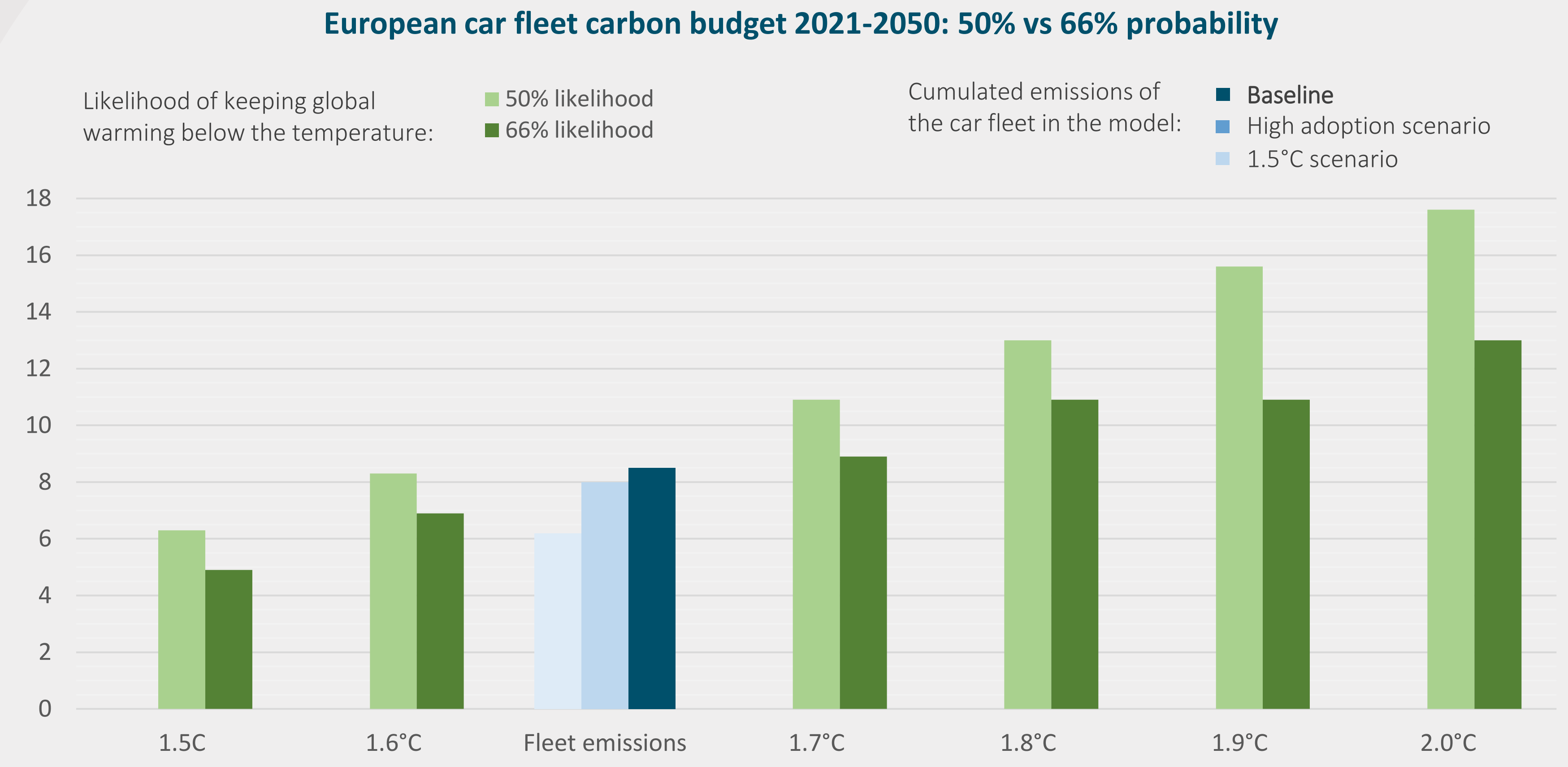
Comparison with other carbon budgets

2021 carbon budgets based on **50% probability** of limiting global warming below the temperature



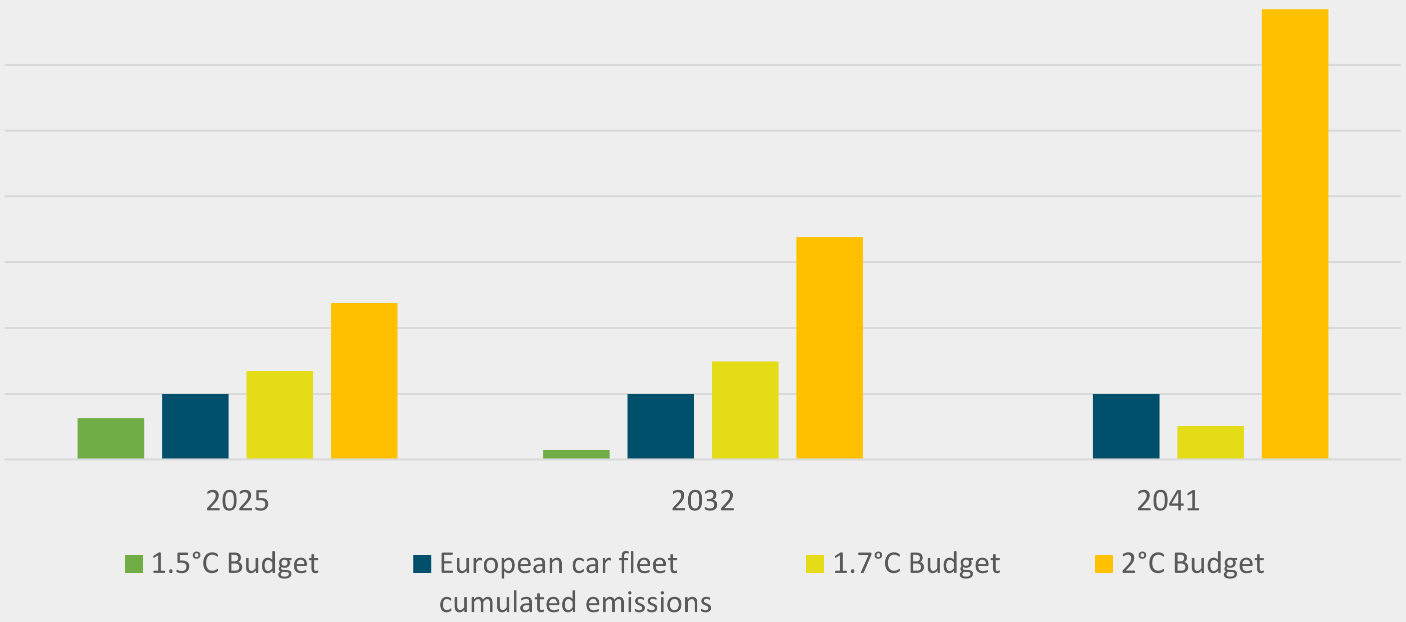
Source (fig 2): Friedlingstein et al. (2022)

Step 3: Set a 1.5°C carbon budget for Europe



Depending on the likelihood (50% as the IEA or 66%) of reaching the target temperature selected to calculate the carbon budget, the baseline emissions of the fleet are on a 1.6°C or 1.7°C trajectory.

Alignment of the European fleet cumulative CO2 emissions (base 100) with different remaining carbon budgets over time

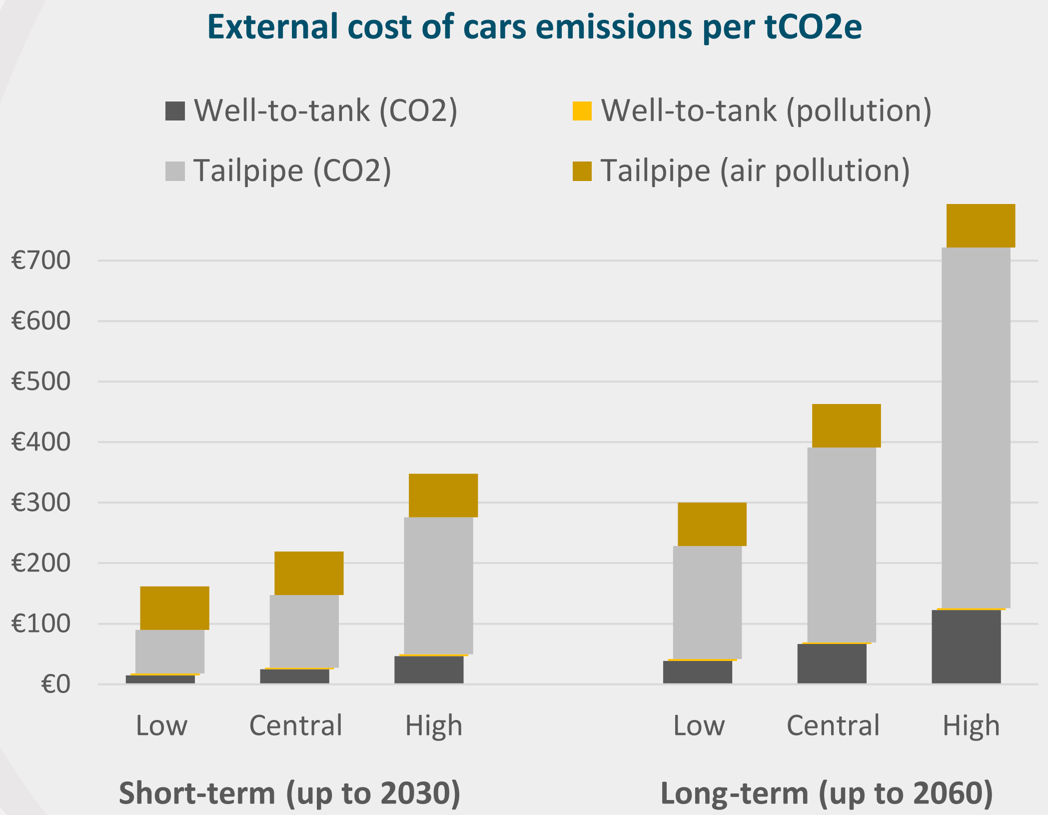


In 2021, global CO_2 emissions returned to their 2019 levels (Friedlingstein et al. 2022), leaving 11 year of carbon budget left to reach 1.5°C.

The remaining carbon budgets for 1.5°C and 1.7°C shrink faster than the emission reductions of the European car fleet: in 2041 it will be above the 1.7°C path (based on the 50% likelihood budget)

Step 4: Forward-looking perspective

Starting point: EC data on the external cost of transport



The EC provides estimates (high, central, low) of the external cost of CO2 and air pollution related to passenger cars and other externalities such as noise and infrastructure use that are not included in our calculations.

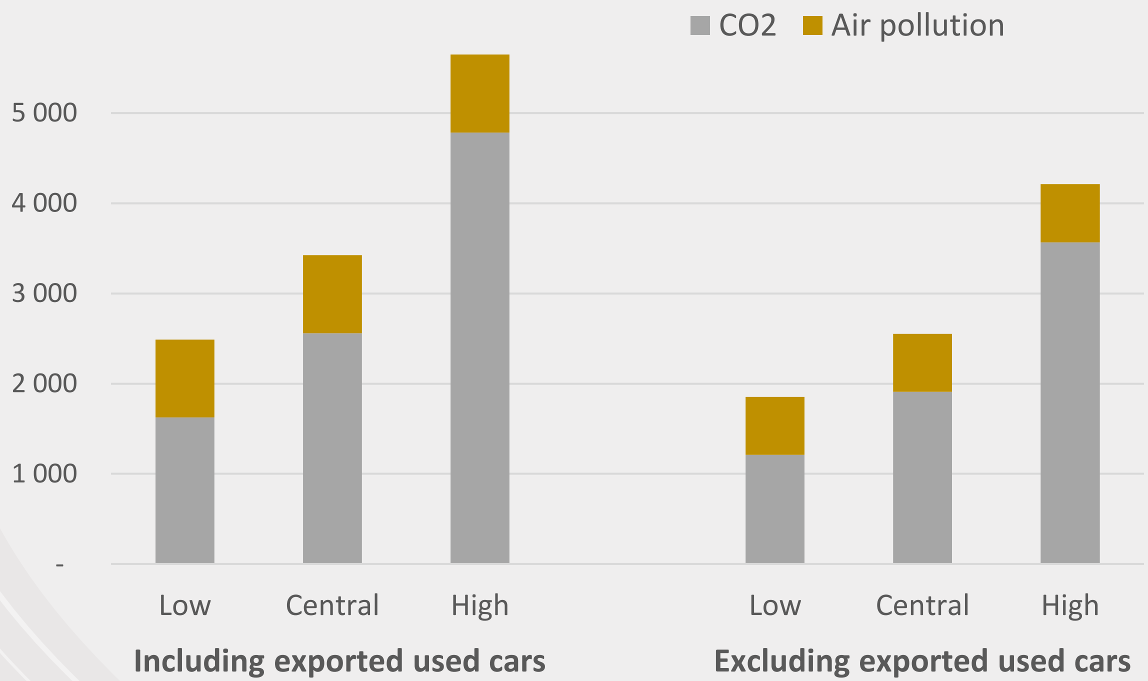
The original data is provided in $€_{2016}$ and has been adjusted for inflation in $€_{2023}$ (+19.7%).

Our estimates for air pollution assumes a linear relationship with tailpipe CO_2 emissions.

Source: Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities (European Commission, June 2019)

Step 1: Application to the European car fleet emissions

Absolute external cost of the European fossil car fleet from 2021 onwards, in €Bn

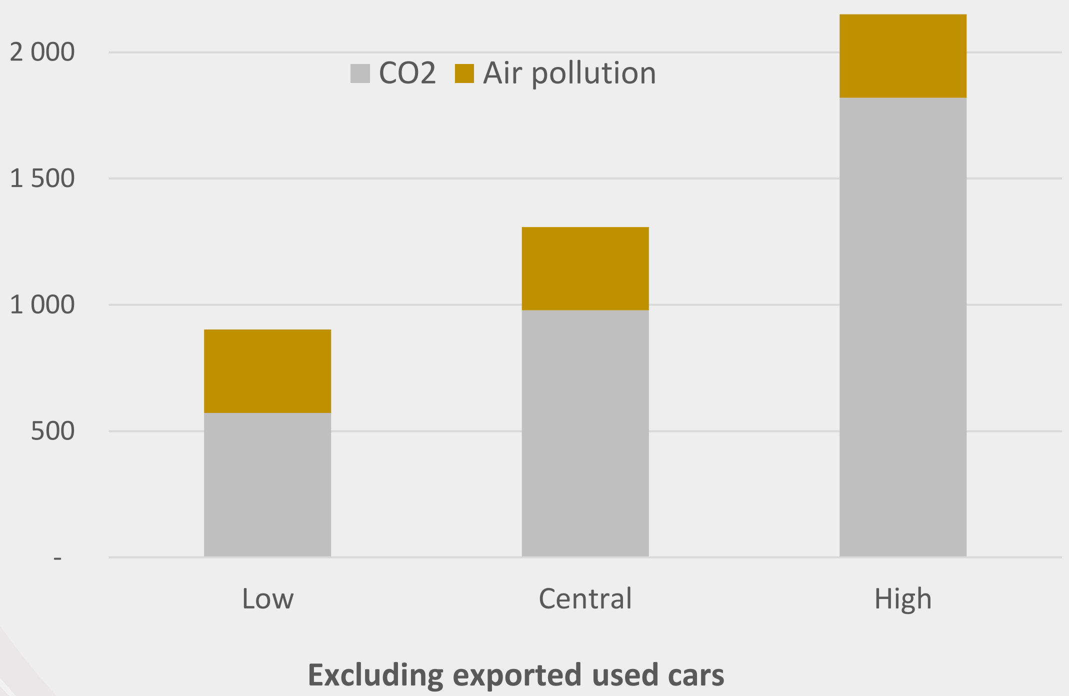


Based on our estimates of the fleet CO_2 emissions, and using the EC guidance, we estimated the "absolute" external cost of the European fossil car fleet over its lifetime and "second life" for exported used cars.

The scope is limited to CO2 and air pollution, excluding noise, infrastructure use and a range of other externalities that are not specific to fossil cars (as opposed to EVs).

Step 2: Marginal cost

Marginal external cost of the European fossil car fleet emissions relative to the 1.5°C scenario, in €Bn

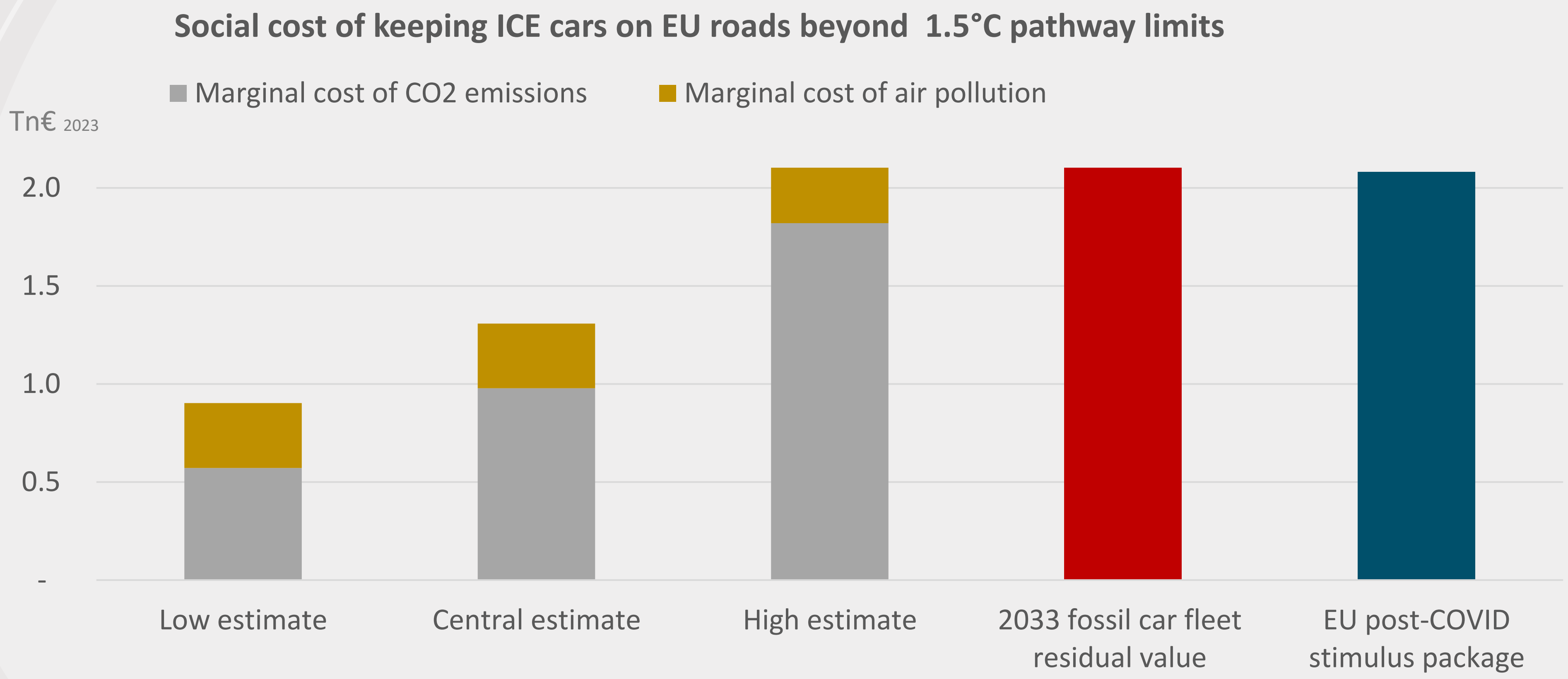


The "marginal cost" only covers the emissions in excess of the 1.5°C carbon budget (low estimate based on IEA NZS).

The calculation excludes emissions related to exported used cars.

Source: IEA Net Zero 2050 Scenario 2022

Step 3: Putting figures into perspective



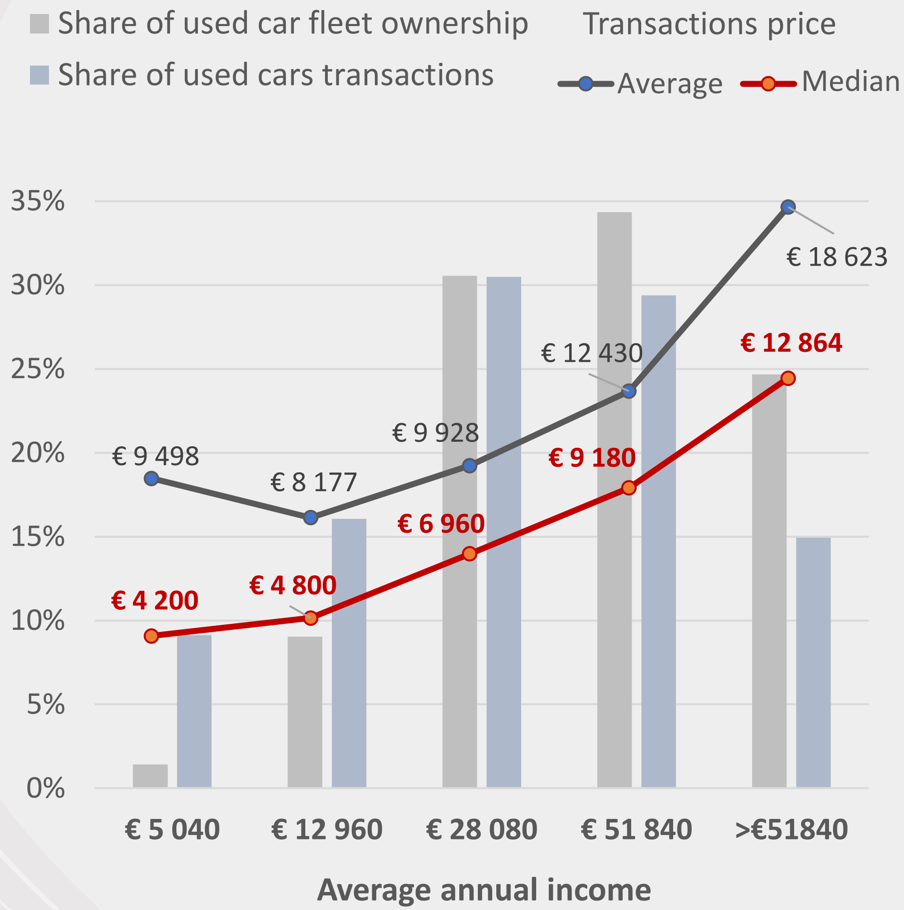
The high estimate of the marginal cost is equivalent to:

- the EU post COVID stimulus package, and
- the residual value of the car fleet that will emit the CO_2 beyond the 1.5°C budget.

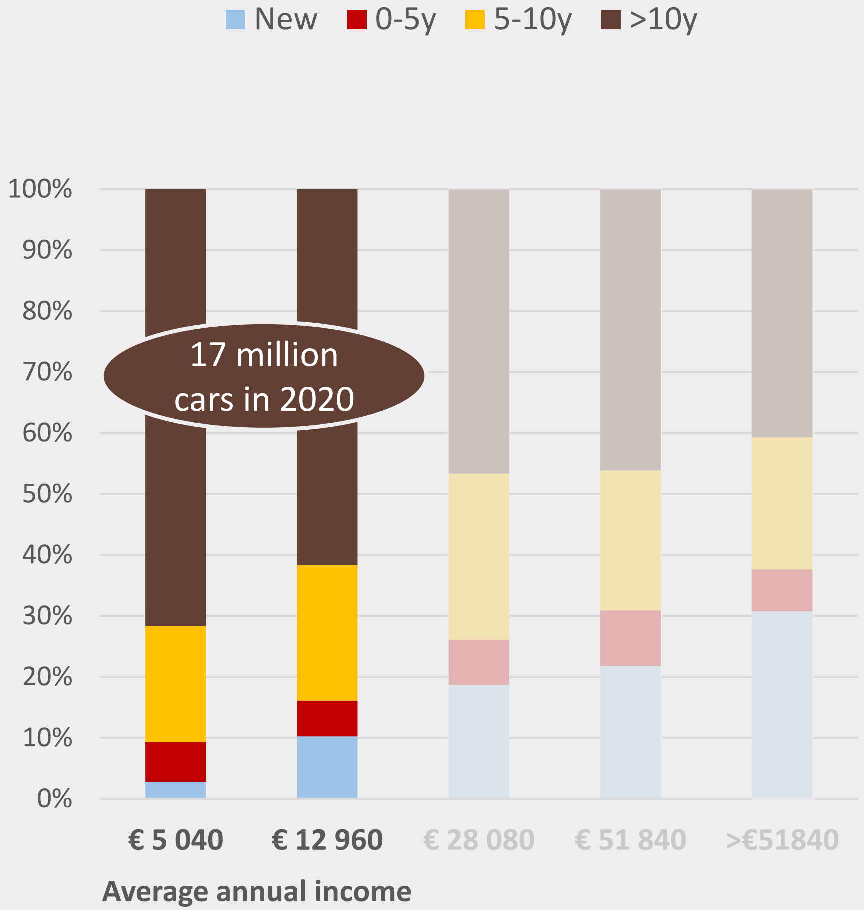
1. Sales & fleet size forecast
2. Fleet aging
3. Price of new & used cars
4. CO_2 emissions vs carbon budget
5. External cost
6. Affordable EV shortage
7. Exported used fossil cars

Starting point: Cars owned by low-income households

Weight of each income group in used car market



Age of the fleet owned, by income group in Europe



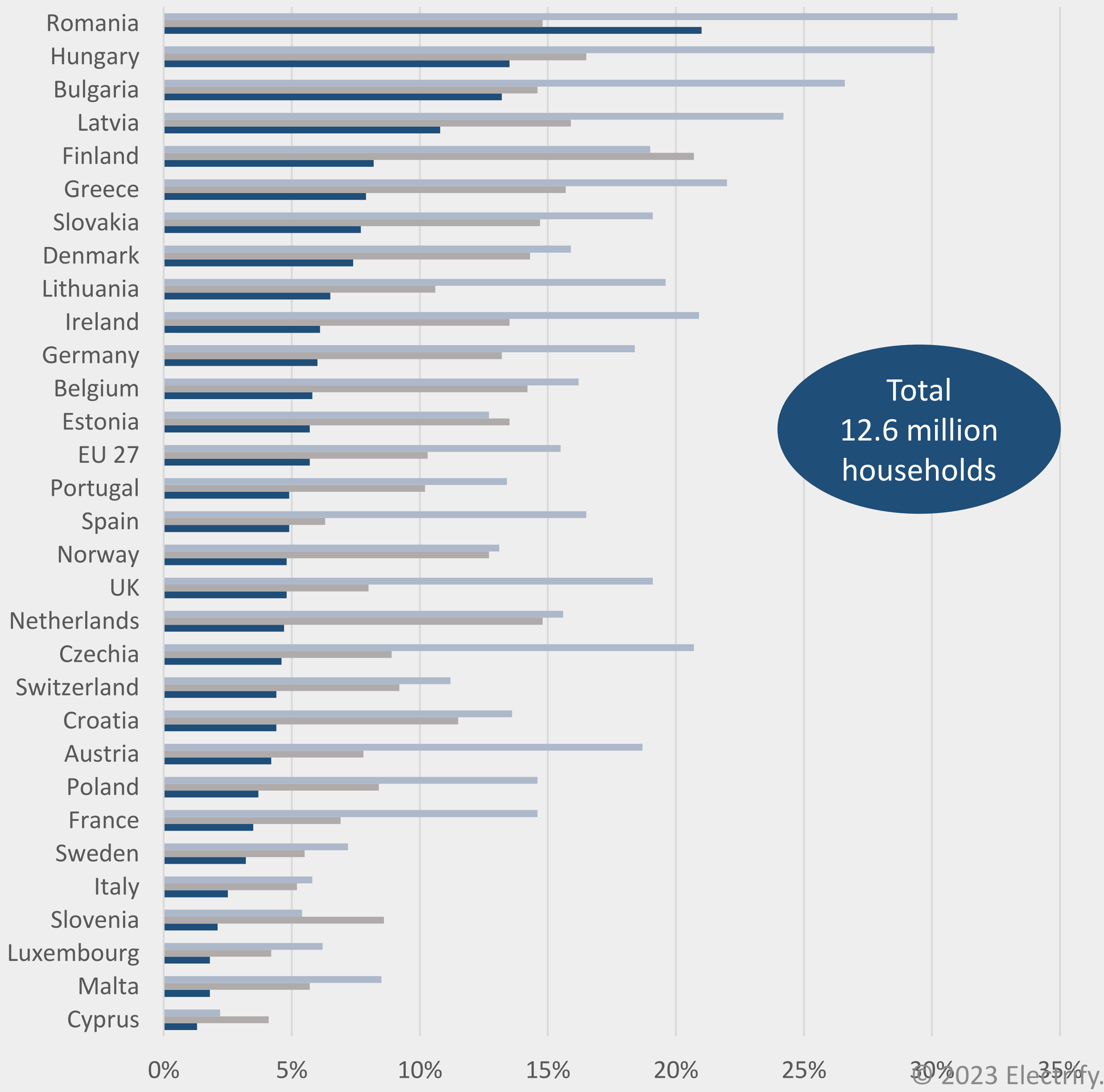
"Low-income households" corresponds to the first two income categories in the charts

Sources: Transport & Mobility Leuven (2016), Eurostat (2022)

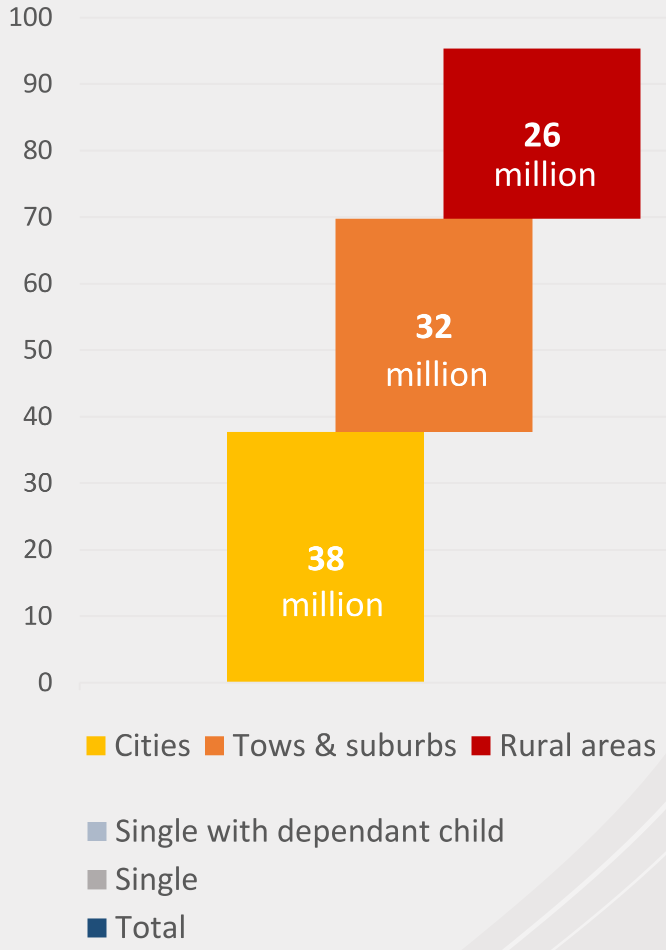
Market data for 2016 extrapolated to 2020 fleet. Prices and income levels in $€_{2023}$

Background data: gap in car ownership

Percentage of households who cannot afford a personal car (Eurostat 2021 survey)



Europeans at risk of poverty (millions)



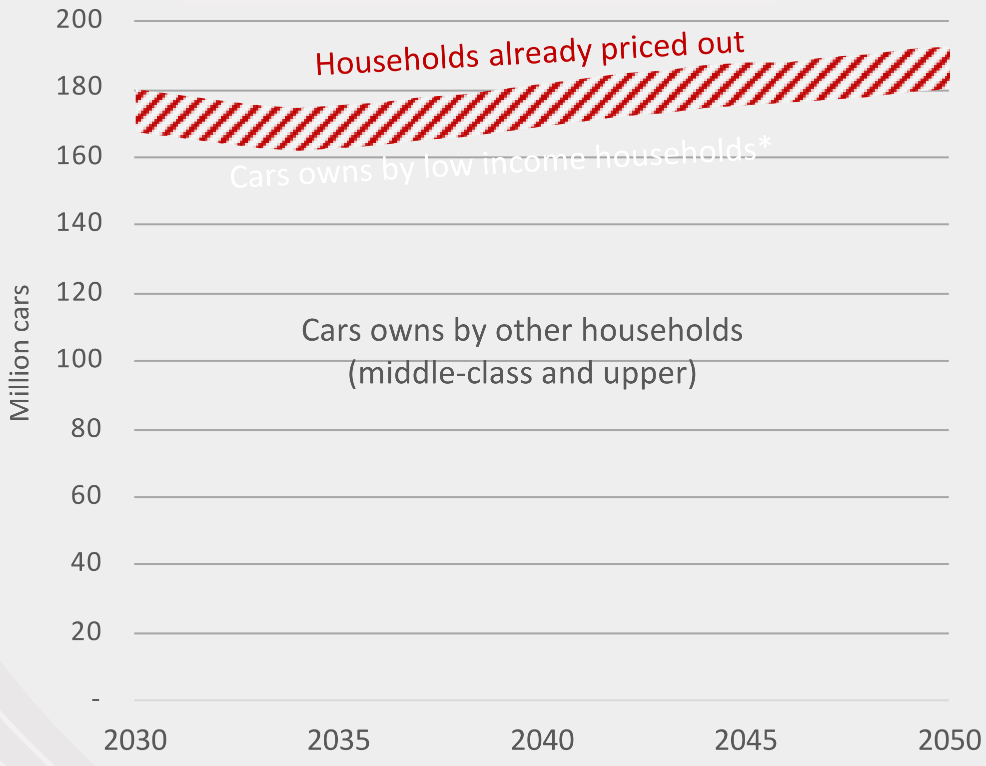
Conclusion:
≈ 30 million affordable old used cars needed

Step 1: Demand for affordable used cars

180 million old cars owned

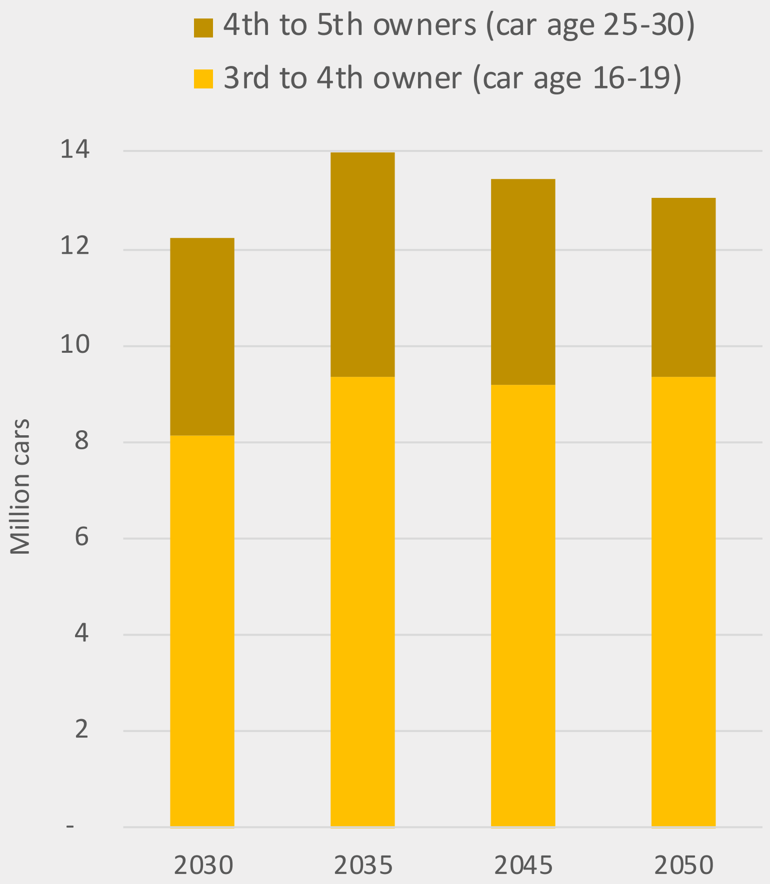
12-14 million old cars sold each year

Projection of demand for affordable used cars (>10 years): ownership by income group



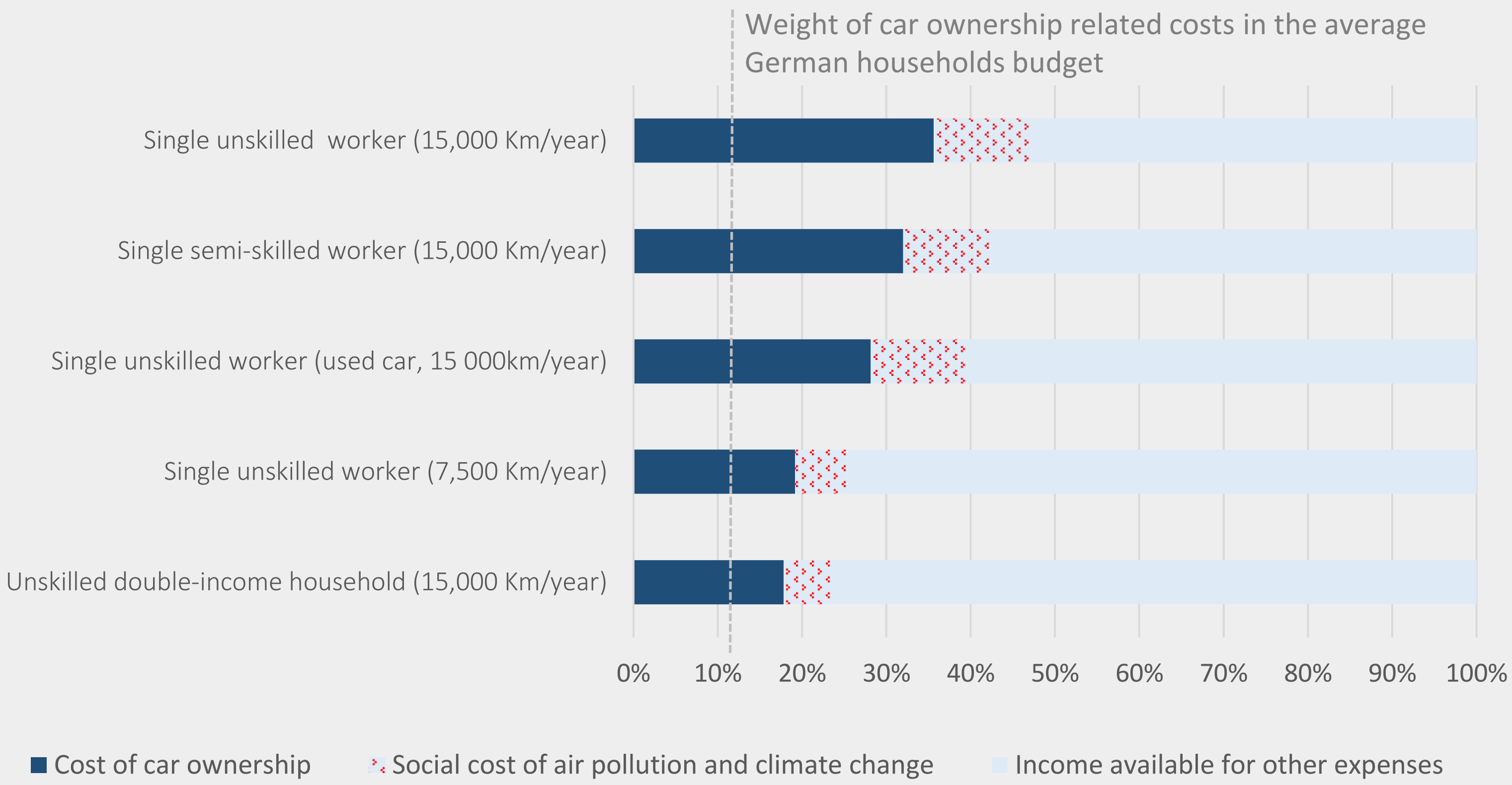
*Income groups 1 & 2, respectively 5k€ and 13k€ in $€_{2023}$

Old used cars market in volume



Sources: Transport & Mobility Leuven (2016)

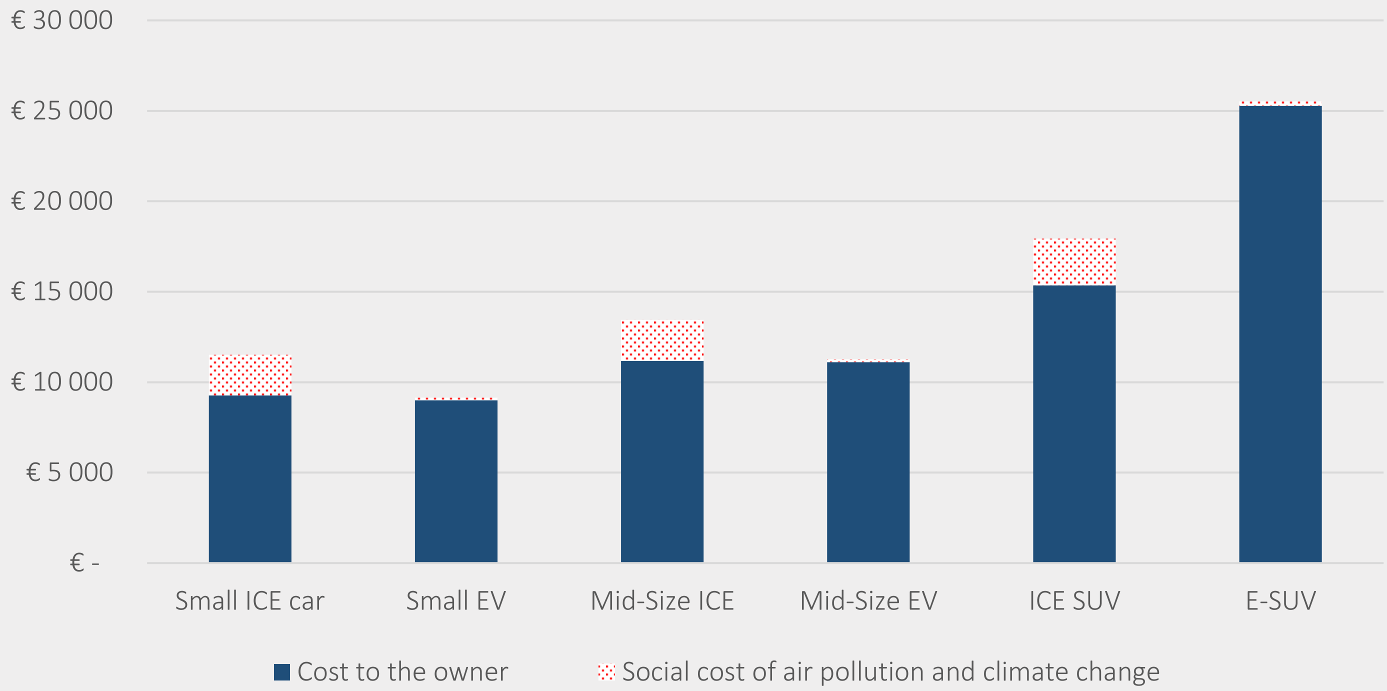
Affordability of a small ICE car for low income households in Germany (2020)



Background research: share of expenses associated with car ownership for low-incomes households

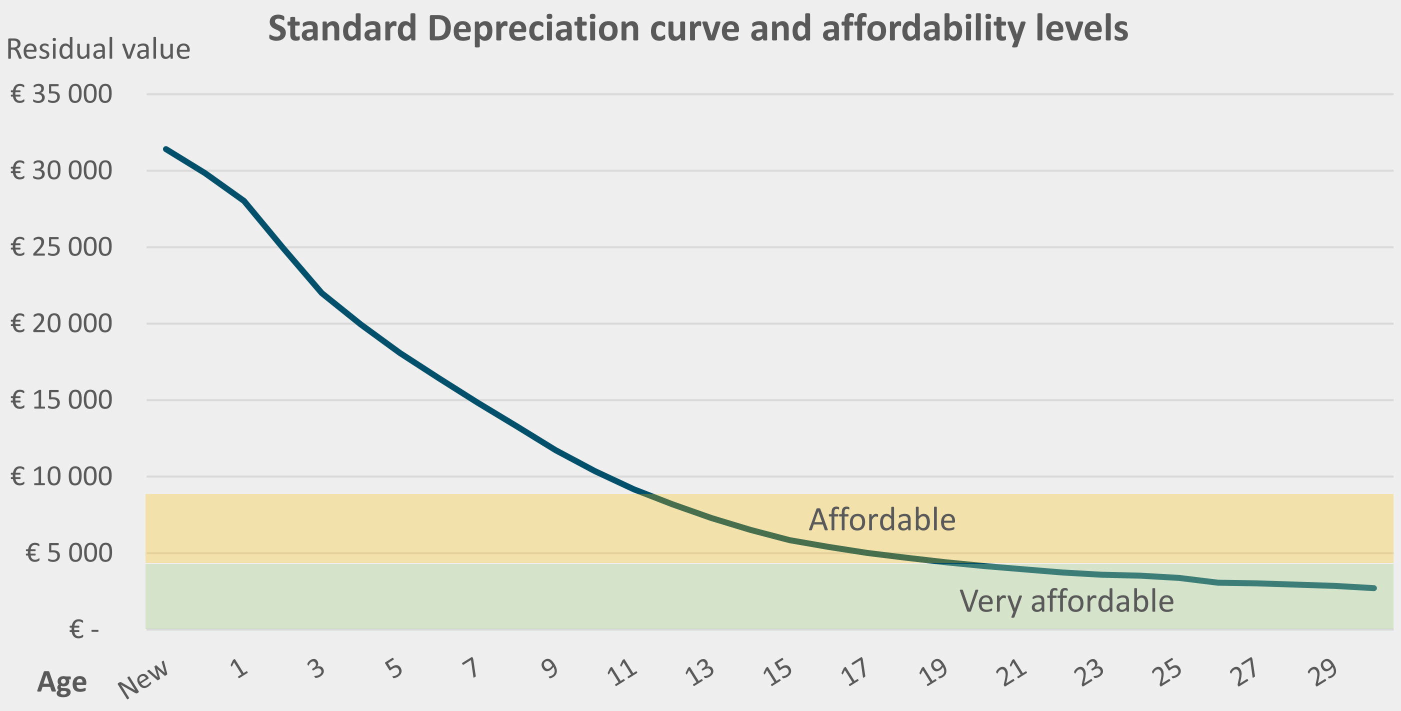
Sources: Gössling (2020)

Total annual cost of using a vehicle in Germany (2022, 15,000 km/year) including taxes and subsidies



Background research: exposure to potential increase of carbon taxes

Sources: ADAC 2022, Gössling



Most studies conclude that the residual value is primarily based on total mileage, while professional calculators factor in mileage and age. For our default curve, we assume 225,000 km in 30 years, with a decreasing annual mileage.

Our assumptions on the depreciation curve and the affordability levels are based on the following studies:

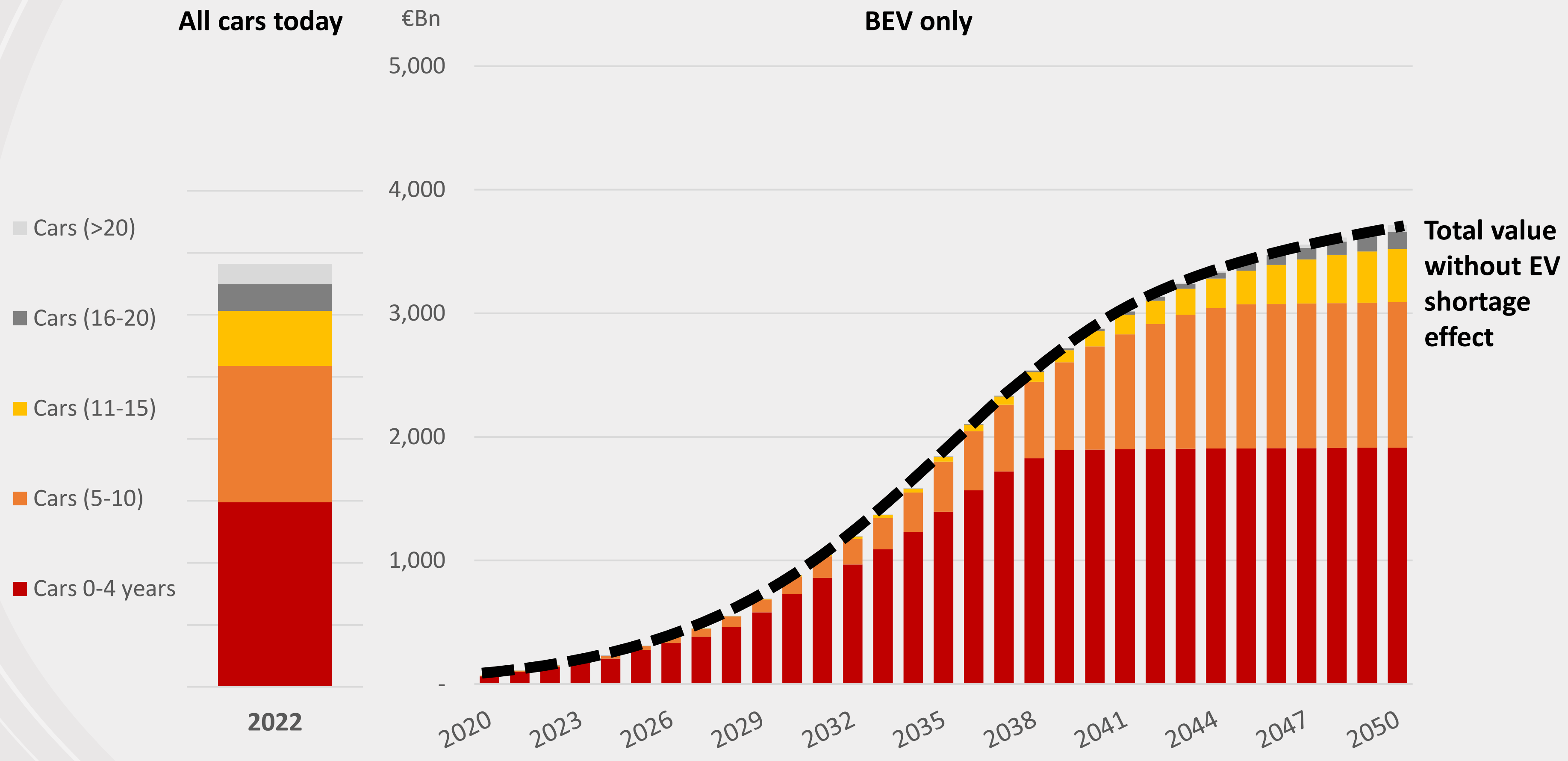
- *"Study on the implications of EU policies for the affordability of car use in the future"* (Transport & Mobility Leuven Nov. 2022)
- *"Electric Cars: Calculating the Total Cost of Ownership for Consumers*" (BEUC, April 2021)

We completed the analysis by a review of typical models depreciation on French (La Central) and German (ADAC) car websites.

Sources: Transport & Mobility Leuven (2016), BEUC (2021)

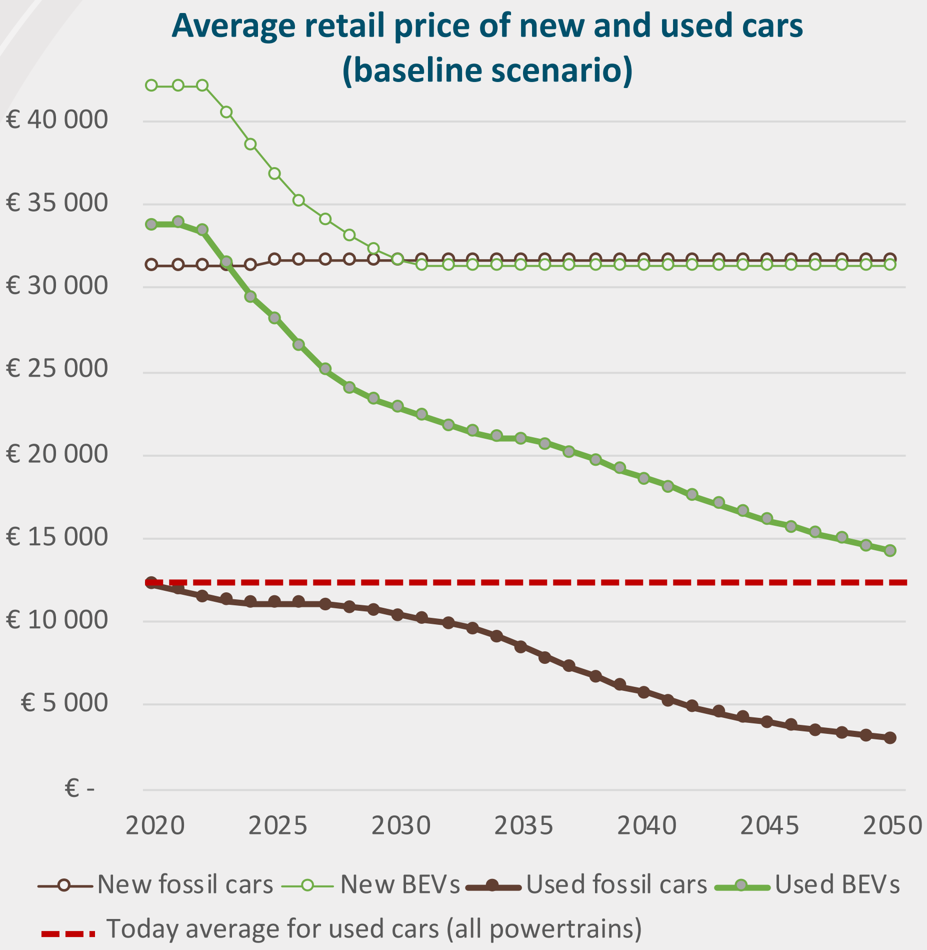
Step 3: Residual value of the EV fleet

Residual value of the fleet in billion euros by age category (with EV shortage effect)



The stock of old used BEVs will only become comparable in size to today's stock of cars from 2045 onwards.

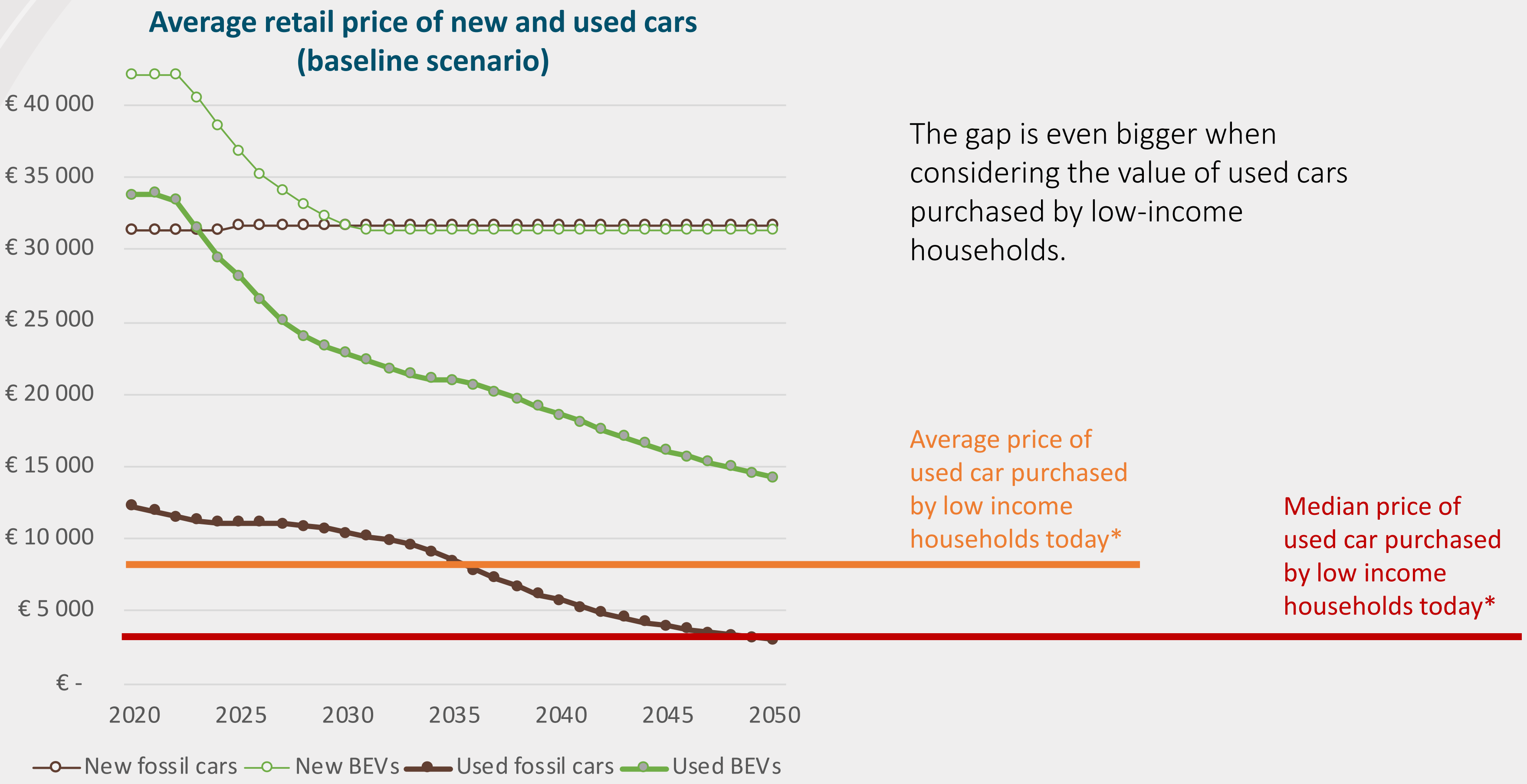
Step 3: Residual value of the EV fleet



Our results suggest that the average used BEV in the fleet will remain much more expensive than the average used car today due to two factors:

- The EV fleet is much younger;
- New EVs will remain more expensive to purchase until 2035 (although the gradual drop in the price of new cars is immediately mirrored in the residual value of EVs in our model – as observed in Tesla Dec 2022 discount).

Step 3: Residual value of the EV fleet



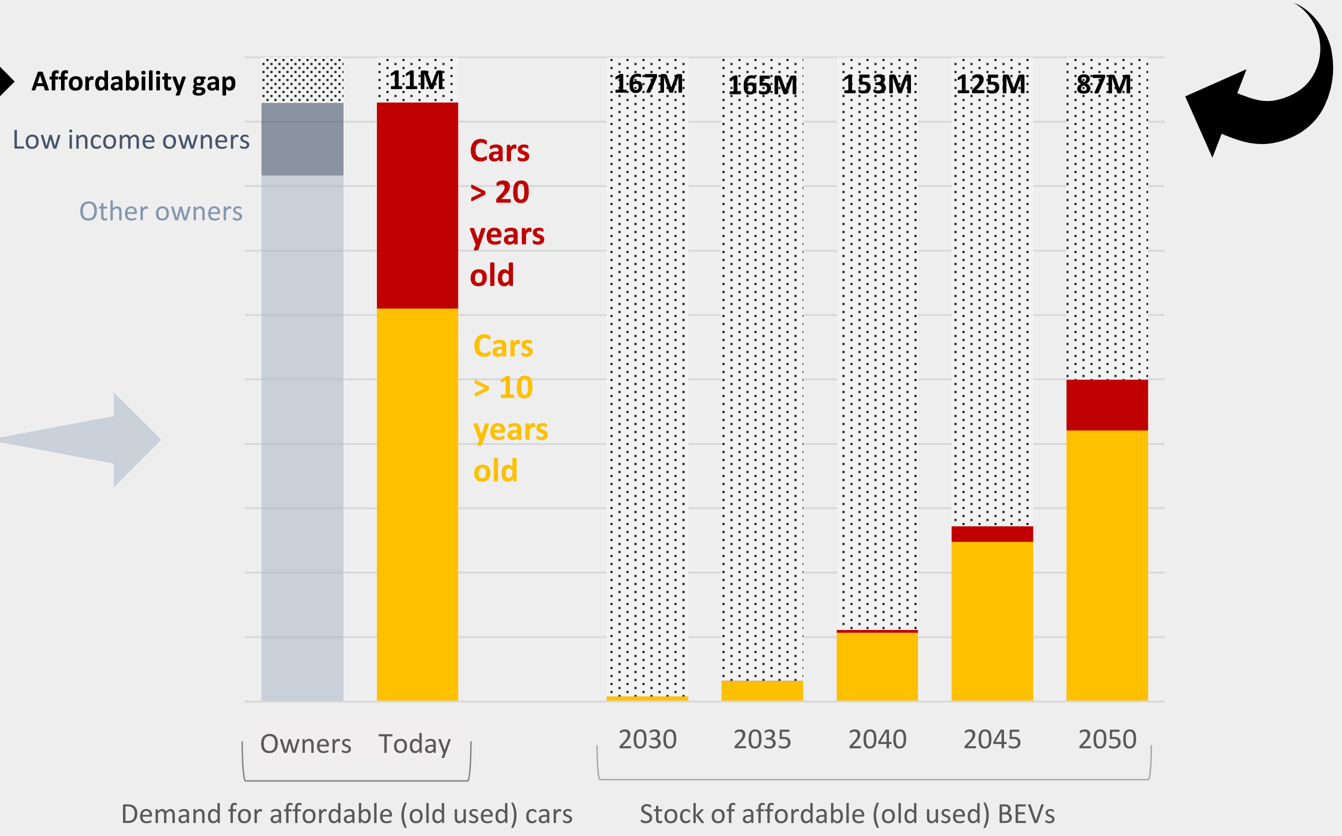
The gap is even bigger when considering the value of used cars purchased by low-income households.

Affordable used car ownership needs vs stock of affordable/old used cars

We can then compare the demand for old used cars with the future stock of old EVs to calculate the "affordable used EV gap"

According to the above-mentioned survey results 11 million Europeans cannot afford a car today

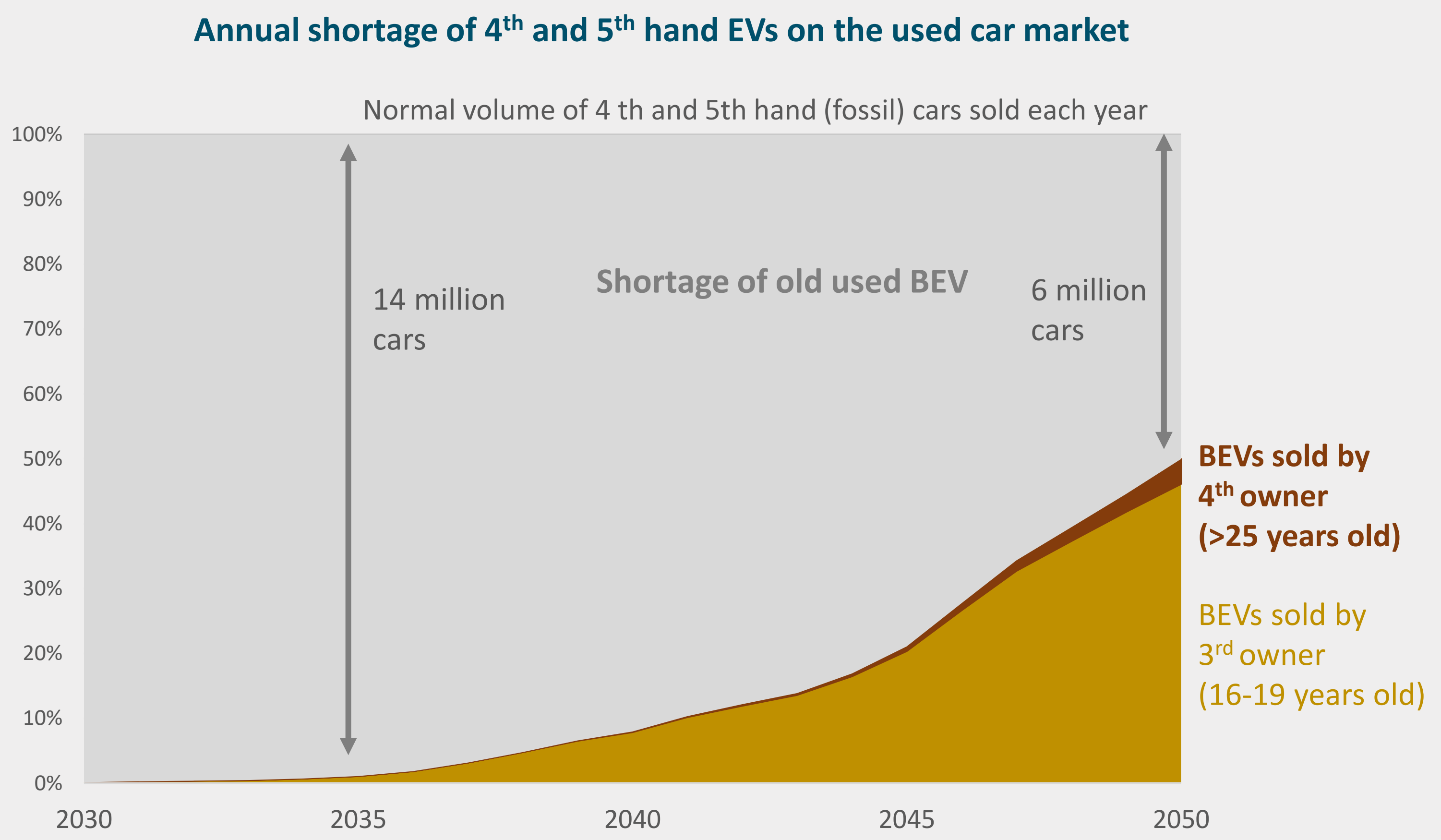
We used the number of old cars owned today as a proxy for the demand for old (affordable) cars.



Step 4: Affordability gap: stock & used car market

In an ICE phase-out scenario (ban or TCO pricing out low-income households), the stock of old used BEVs will be too limited to meet the usual demand for old used cars.

Step 4: Affordability gap: stock & used car market



In an ICE phase-out scenario, the shortage of old used BEVs in the fleet (stock) will translate into a shortage in the used car market (annual flow) offer for 4th and 5th-hand cars.

1. Sales & fleet size forecast

2. Fleet aging

3. Price of new & used cars

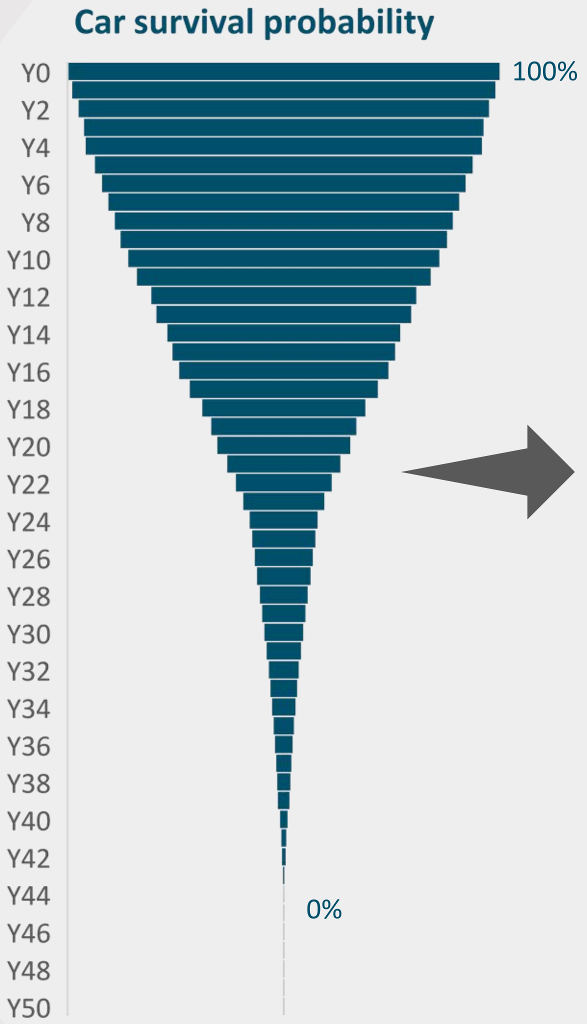
4. CO_2 emissions vs carbon budget

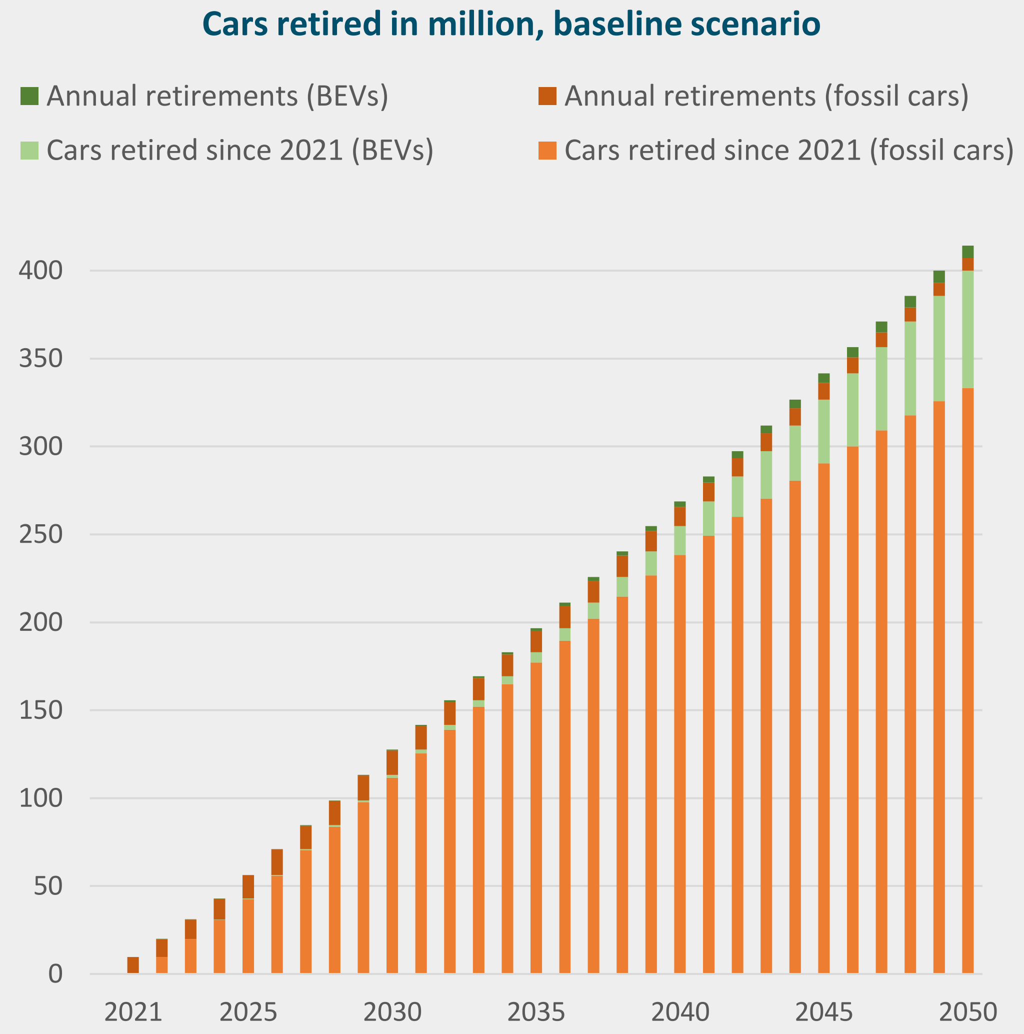
5. External cost

6. Affordable EV shortage

7. Exported used fossil cars

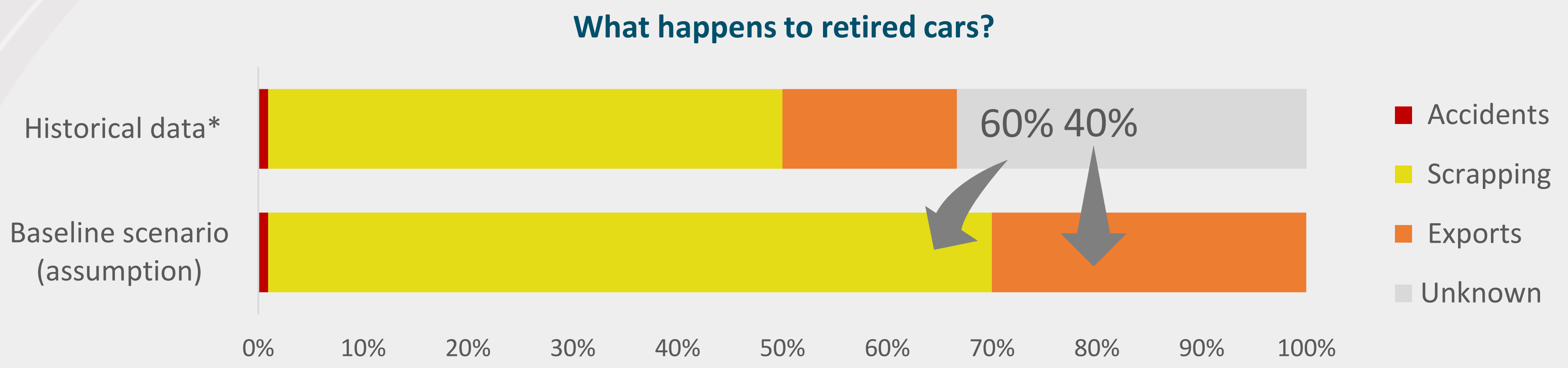
Starting point: Retirements





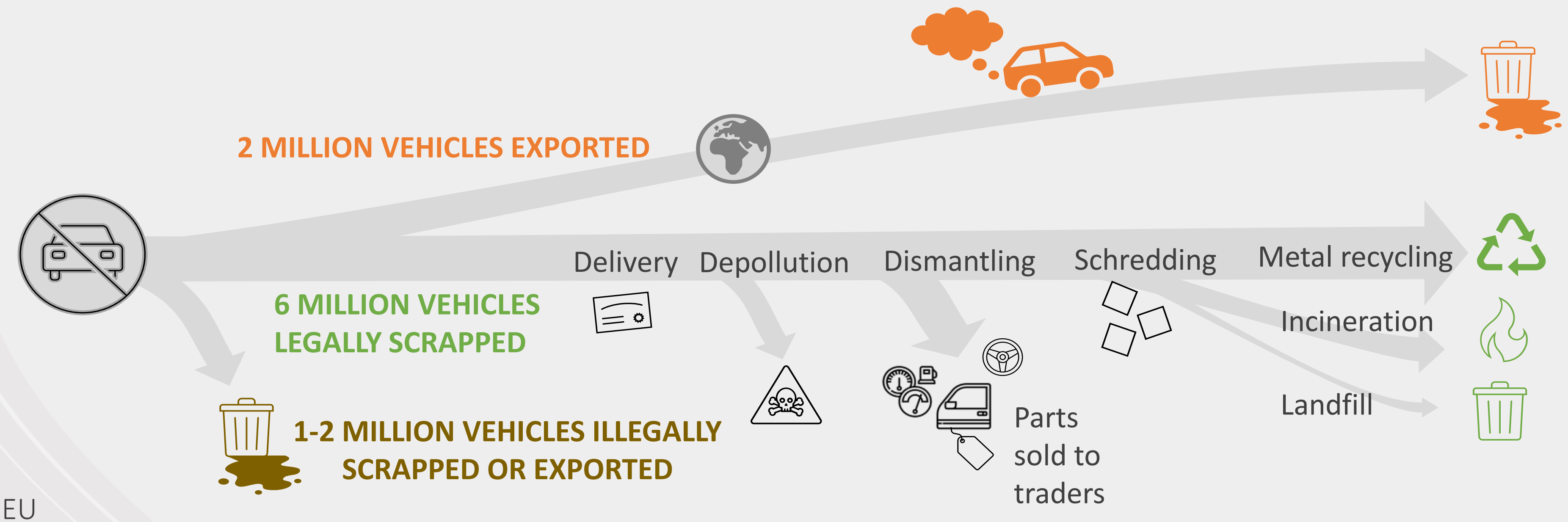
The equivalent of a second European ICE car fleet in volume (>300M) will be retired (i.e. scrapped or exported) from 2021 to 2050

Step 1: Data about retired cars whereabouts



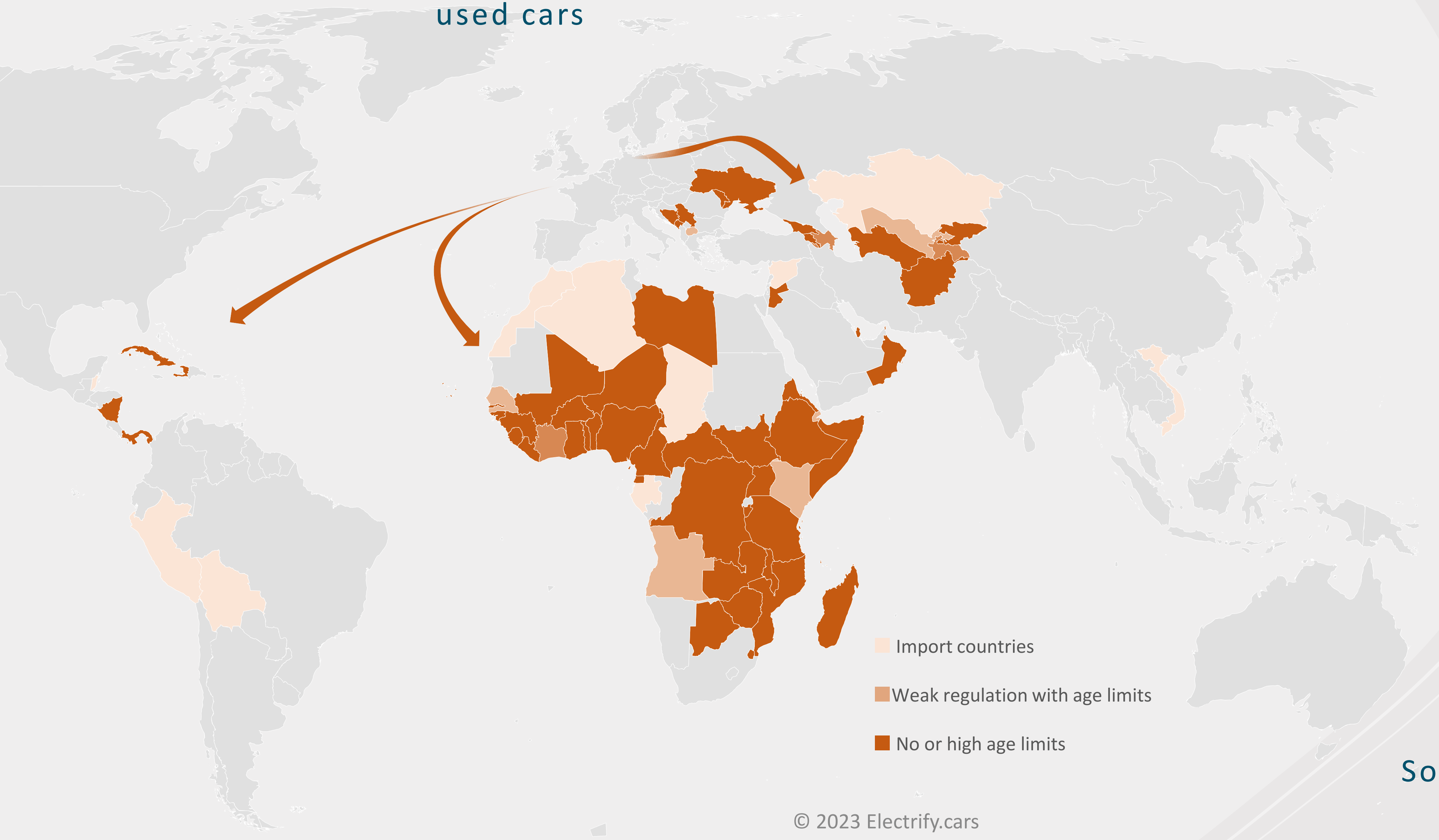
Uncertainty

Nb: The volume of unknown whereabouts, due to gaps in EU statistics generates significant uncertainty on the volume and carbon emissions associated with used cars exports



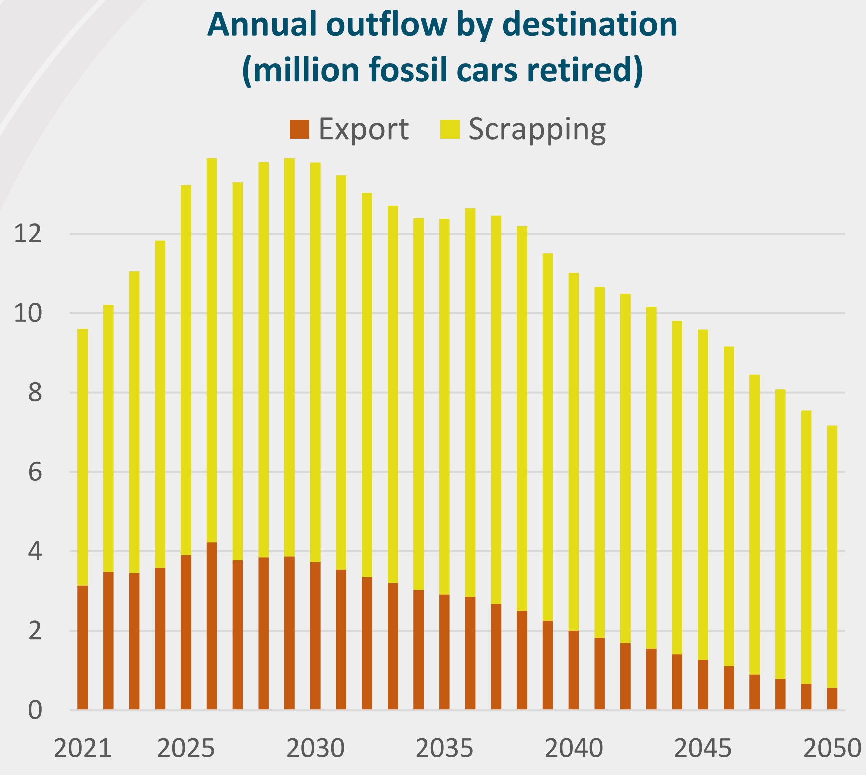
Sources: Eurostat, UNEP, German Environmental Agency, Heinrich Böll Stiftung, Oko-Institut/UNCE, CUIN

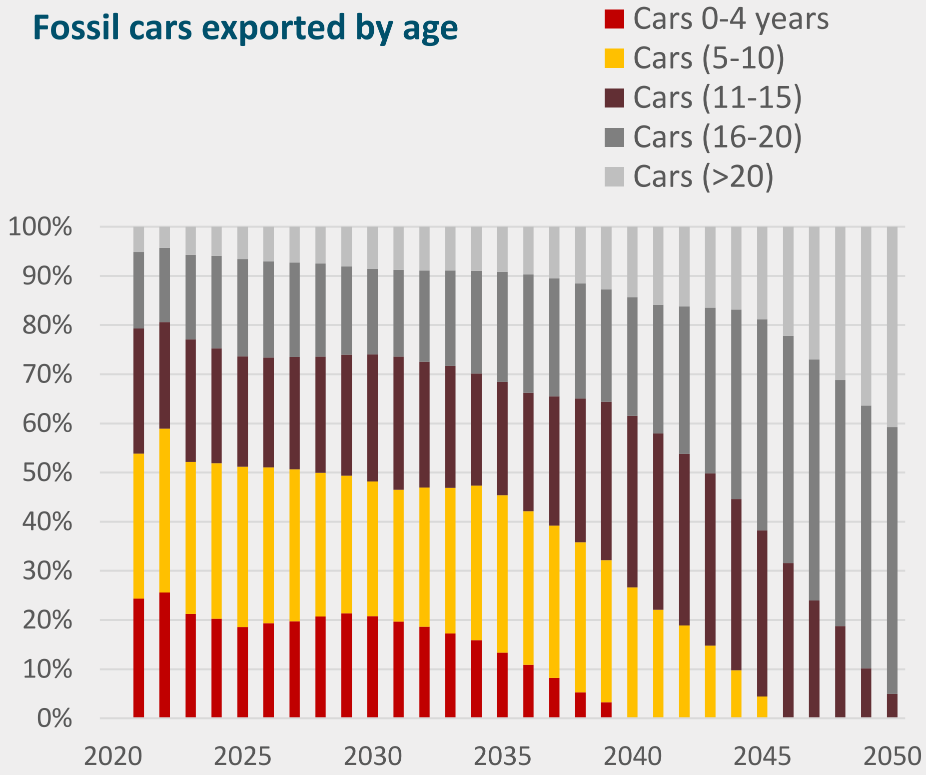
Export destinations for European used cars



Source: UNEP 2020

Step 2: Hidden fossil fleet size estimate





Nb: The breakdown of export/scrapping is defined by age based on an adjusted version of the survival probability curve. The underlying logic is that the likelihood of being scrapped (as opposed to exported) is correlated with the age of the car. As illustrated in Step 1, we control for accidents with total loss (which affect all age classes).

Uncertainty

Based on the EU reference scenario (evolution of the stock) and sales forecasts (annual inflow), our baseline scenario features an increase in the outflow (scrapping + exports) from 2021 to 2030. This increase might result from an inconsistency between the latest sales forecast and the EU reference scenario (assuming fewer sales).

Year of manufacturing: older cars are less efficient

A simplified assessment of the remaining lifetime CO_2 emissions for each age and year is estimated.

The CO_2 intensity factor applied is based on age and the average year of manufacturing.

Age of the cars: older cars are less used

Step 3: Exported carbon emissions estimates

Remaining lifetime emissions per car in t CO2

Average age	9,9	9,7	10,3	10,5	10,6	10,7
Exported in…	2021	2022	2023	2024	2025	2026
Manufactured in	2012	2013	2013	2014	2015	2016
t CO2/car	58,8	58,6	58,6	59,5	59,9	59,7
0	58,77	58,65	58,65	59,54	59,87	59,65
1	55,63	55,51	55,51	56,36	56,68	56,47
2	52,62	52,52	52,52	53,32	53,61	53,42
3	49,58	49,47	49,47	50,23	50,51	50,32
4	46,65	46,56	46,56	47,27	47,53	47,36
5	43,94	43,85	43,85	44,52	44,77	44,61
6	41,46	41,37	41,37	42,00	42,24	42,08
7	39,04	38,96	38,96	39,55	39,77	39,63
8	36,73	36,65	36,65	37,21	37,42	37,28
9	34,53	34,46	34,46	34,98	35,18	35,05
10	32,36	32,29	32,29	32,79	32,97	32,85
11	30,23	30,17	30,17	30,63	30,80	30,69
12	28,22	28,16	28,16	28,59	28,75	28,64
13	26,21	26,15	26,15	26,55	26,70	26,60
14	24,25	24,20	24,20	24,57	24,70	24,61
15	22,29	22,24	22,24	22,58	22,71	22,62
16	20,41	20,37	20,37	20,68	20,80	20,72
17	18,56	18,52	18,52	18,81	18,91	18,84
18	16,79	16,76	16,76	17,02	17,11	17,05
19	15,16	15,13	15,13	15,36	15,45	15,39
20	13,61	13,58	13,58	13,79	13,87	13,82
21	12,23	12,20	12,20	12,39	12,46	12,41
22	10,89	10,86	10,86	11,03	11,09	11,05
23	9,55	9,53	9,53	9,67	9,73	9,69
24	8,36	8,34	8,34	8,47	8,52	8,48
25	7,25	7,23	7,23	7,34	7,38	7,36
26	6,21	6,20	6,20	6,30	6,33	6,31
27	5,26	5,25	5,25	5,33	5,36	5,34
28	4,39	4,38	4,38	4,45	4,47	4,45
29	3,59	3,59	3,59	3,64	3,66	3,65
30	2,88	2,87	2,87	2,92	2,93	2,92
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Total exported emissions for each year

The locked-in CO_2 emissions associated with each exported car are added up to calculate the “exported emissions”

The lifetime emissions of the cars exported are allocated to the year of export

Remaining lifetime emissions of the 20-year old cars exported in 2021

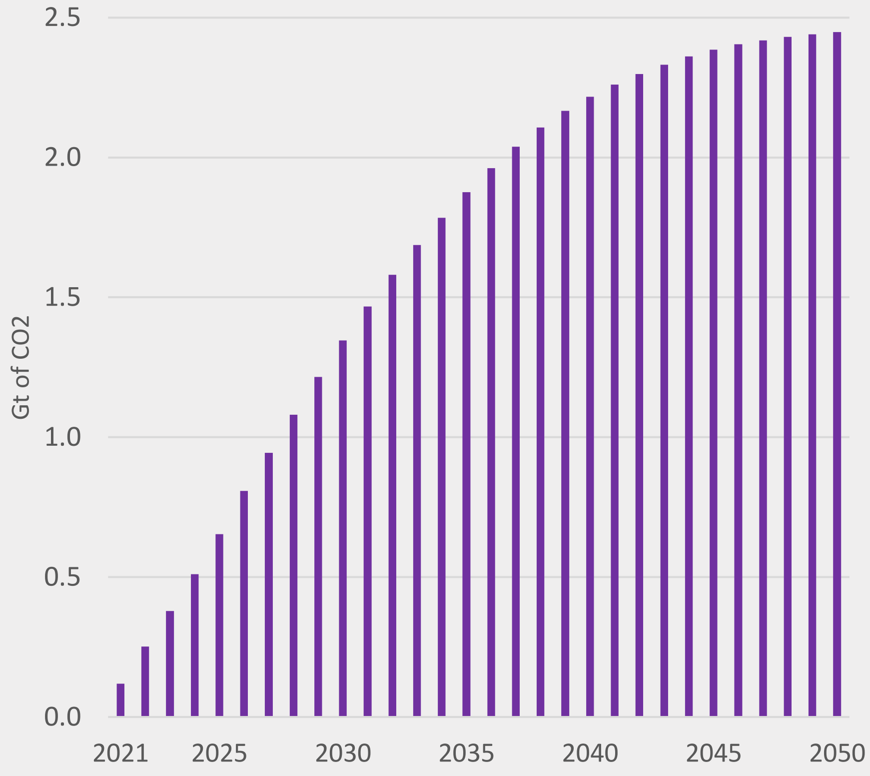
Step 3: Exported carbon emissions estimates

Lifetime emissions of all fossil cars exported per year and age in Mt CO2

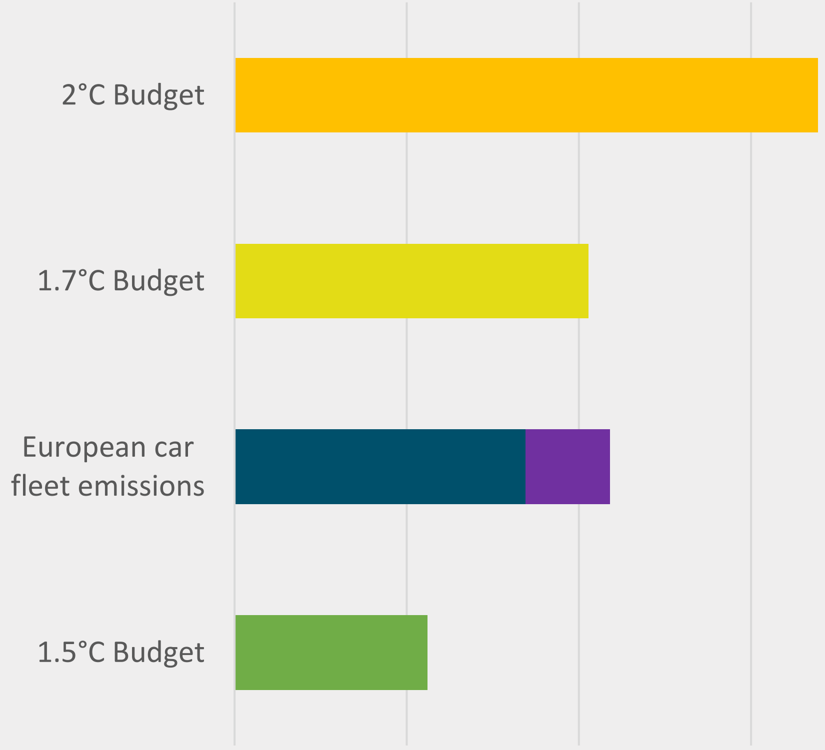
Mt of CO2	119	133	127	132	143
	2021	2022	2023	2024	2025
0	6,50	10,41	6,25	7,35	9,24
1	12,38	10,98	9,51	9,05	11,19
2	9,50	3,02	7,64	7,53	7,51
3	2,55	15,79	2,84	2,15	2,21
4	13,32	11,11	15,59	16,12	12,86
5	8,79	8,48	10,74	11,38	12,33
6	6,80	7,13	8,50	9,16	10,17
7	5,82	5,80	7,13	7,89	8,92
8	4,88	6,98	5,70	6,29	7,29
9	6,26	7,60	6,66	7,22	8,36
10	6,54	11,70	6,63	6,97	7,93
11	9,77	3,81	10,12	10,00	11,03
12	3,34	7,77	3,17	3,17	3,27
13	6,52	3,40	6,24	6,29	6,59
14	2,18	3,10	2,86	2,62	2,77
15	2,36	4,01	3,36	3,41	3,28
16	3,22	4,22	3,71	4,68	4,99
17	3,17	2,61	3,45	3,79	5,00
18	1,50	1,10	2,08	2,12	2,44
19	0,78	1,45	1,13	1,17	1,25
20	1,01	1,00	1,27	1,66	1,80
21	0,69	0,68	0,84	0,90	1,23
22	0,44	0,44	0,52	0,59	0,66
23	0,30	0,12	0,35	0,36	0,43
24	0,07	0,09	0,09	0,10	0,11
25	0,07	0,07	0,08	0,08	0,09
26	0,04	0,06	0,05	0,06	0,07
27	0,03	0,03	0,05	0,05	0,06
28	0,02	0,02	0,03	0,03	0,03
29	0,01	0,01	0,02	0,02	0,03
30	0,01	0,01	0,01	0,01	0,02
31	0,01	0,01	0,01	0,01	0,01

Step 3: Exported carbon emissions estimates

Cumulated exported emissions: 2.4 GT by 2050



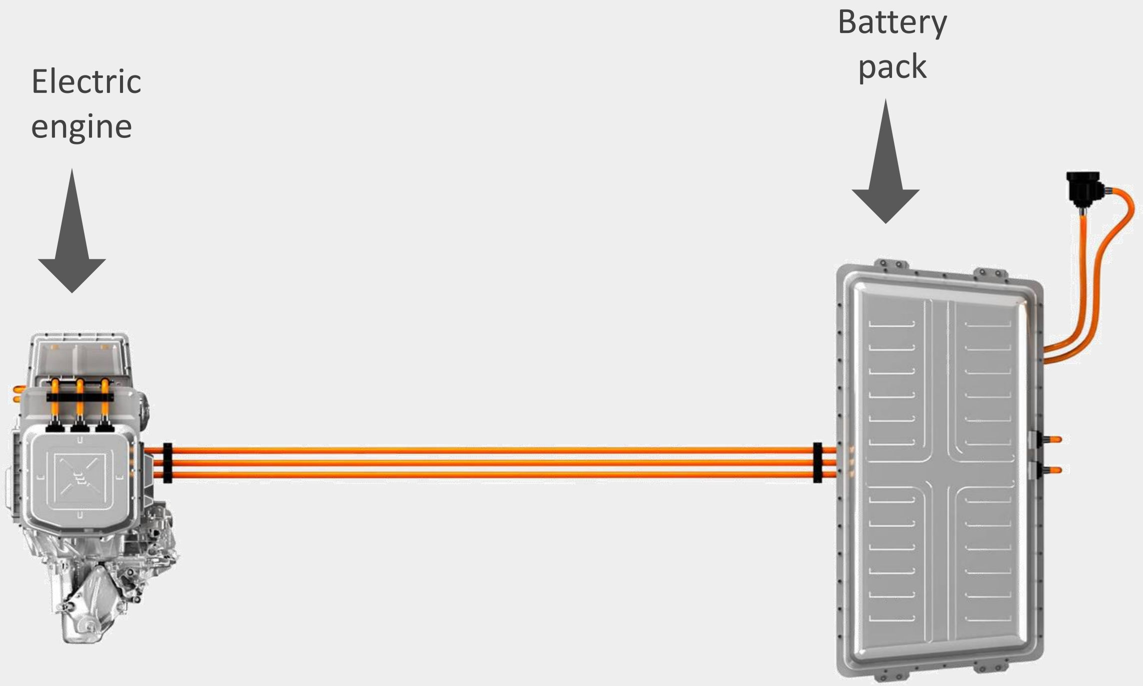
Impact of exported emissions on the alignment with decarbonization pathways



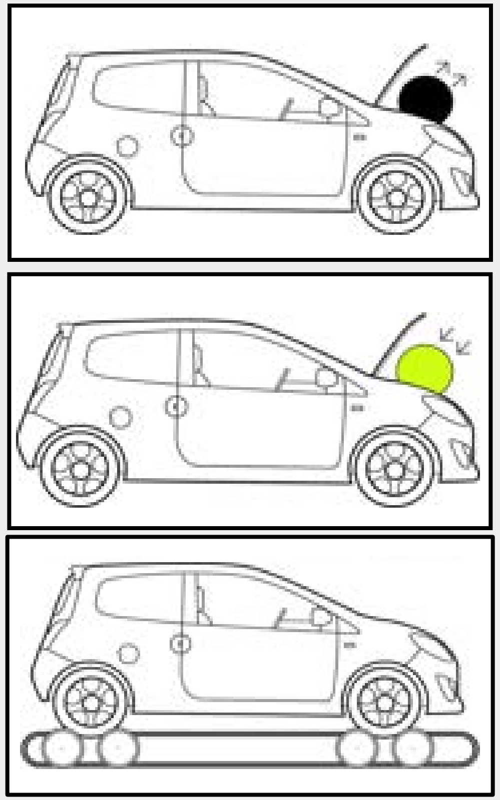
Factoring in the used cars exported, the European car fleet emissions increase by 30% to reach 10.9 Gt, which corresponds to 1.7°C to 1.8°C pathway (with respectively 50% and 66% probability).

CHAPTER II
E-RETROFIT AS A POTENTIAL SOLUTION

Light e-Retrofit



© Transition One

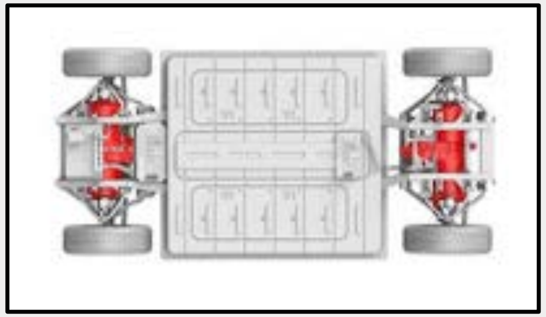


Heavy e-Retrofit

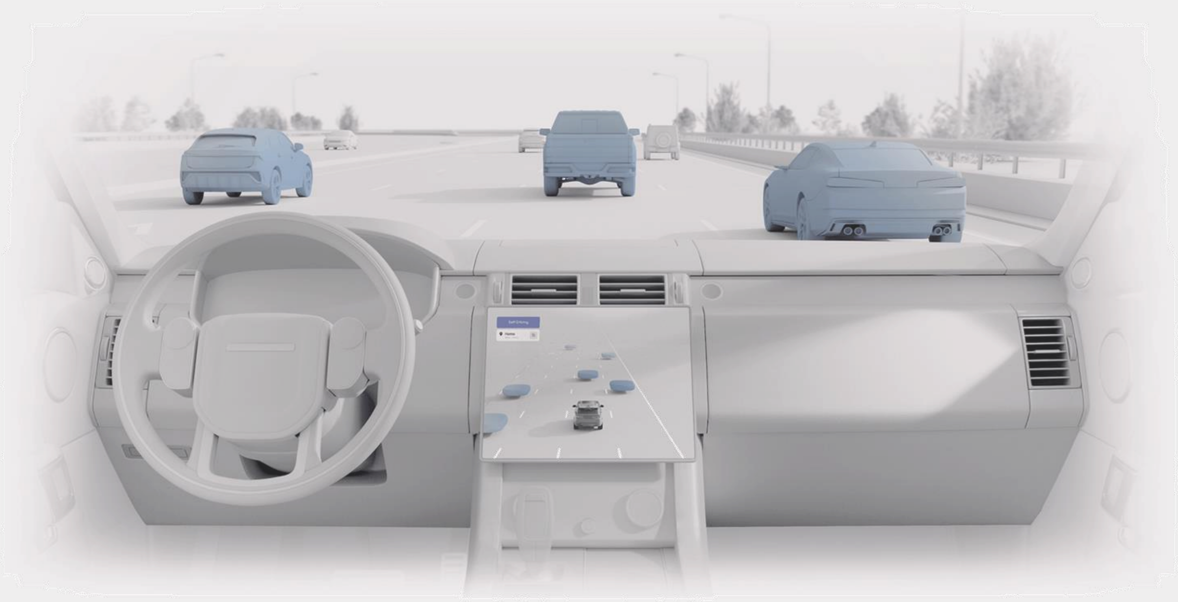
Old body

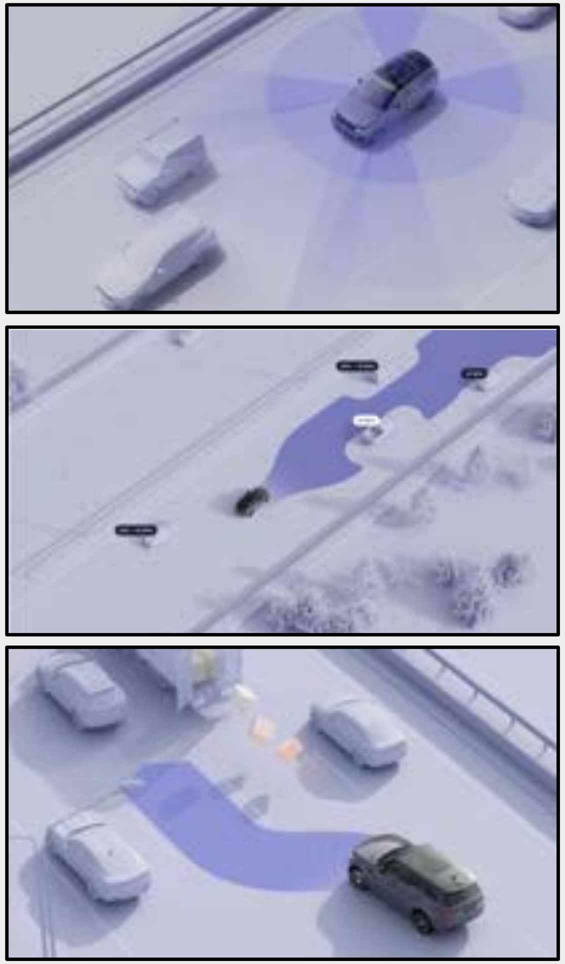
© ZeroLabs

New
“skateboard”



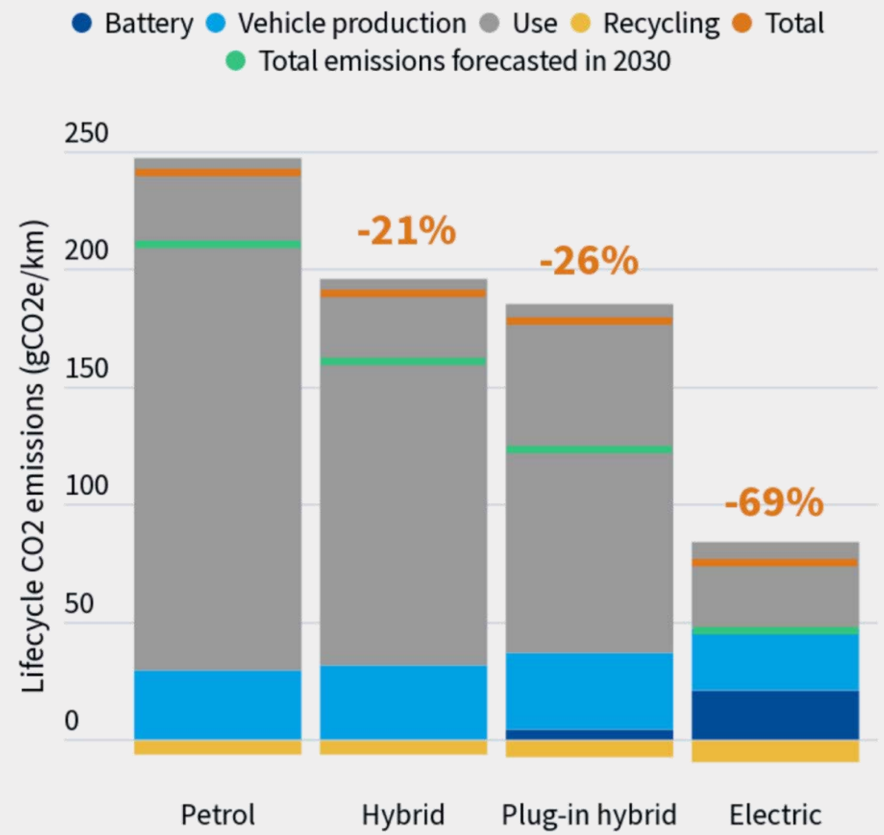
ADAS retrofit





Starting point: Life cycle emissions of cars by powertrain

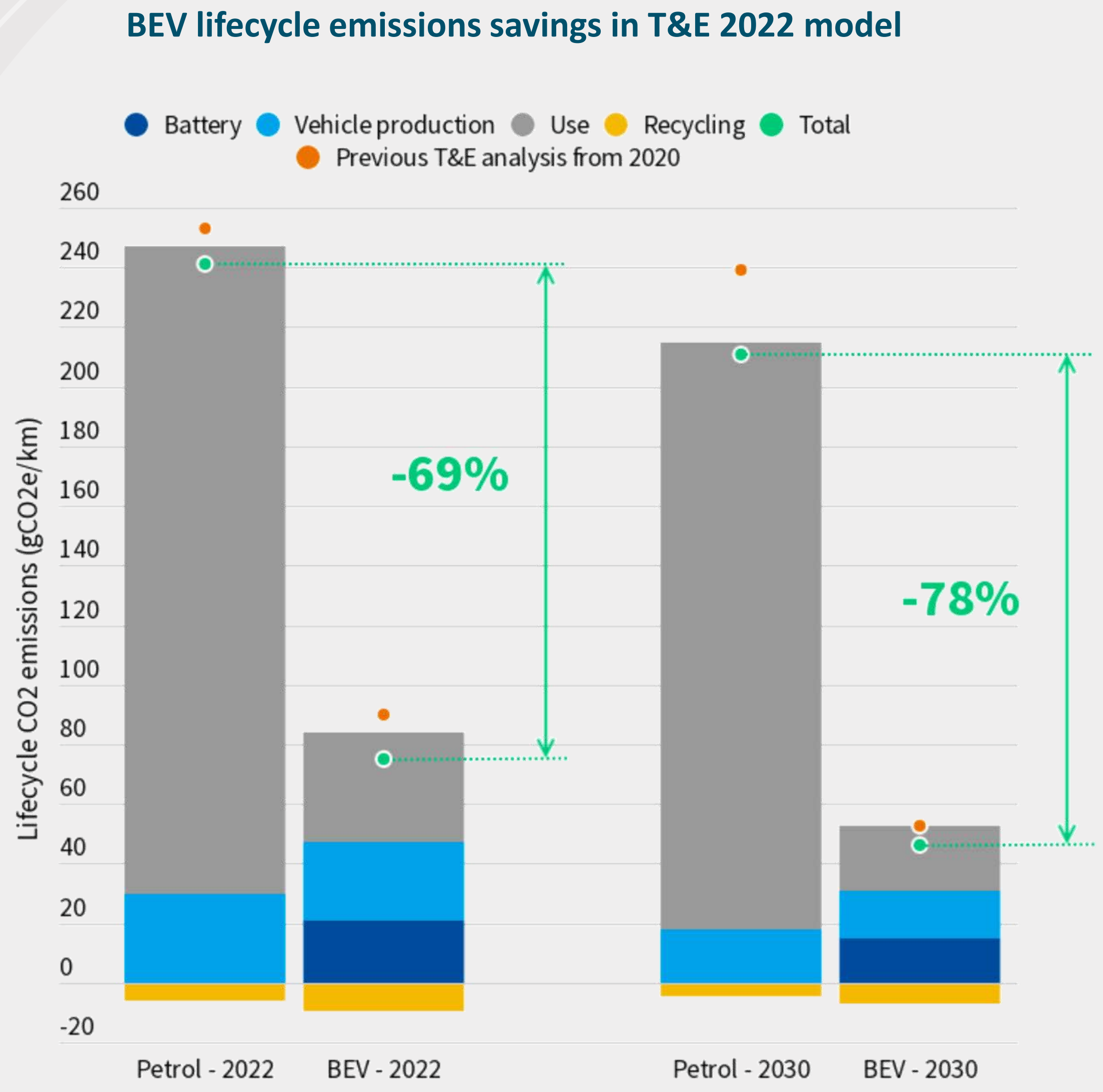
Lifecycle emissions by powertrain in T&E 2022 model



T&E LCA analysis of a medium-sized car, battery assumed to be produced with the EU27 average grid, BEV/PHEV charging with the EU 27 average grid.

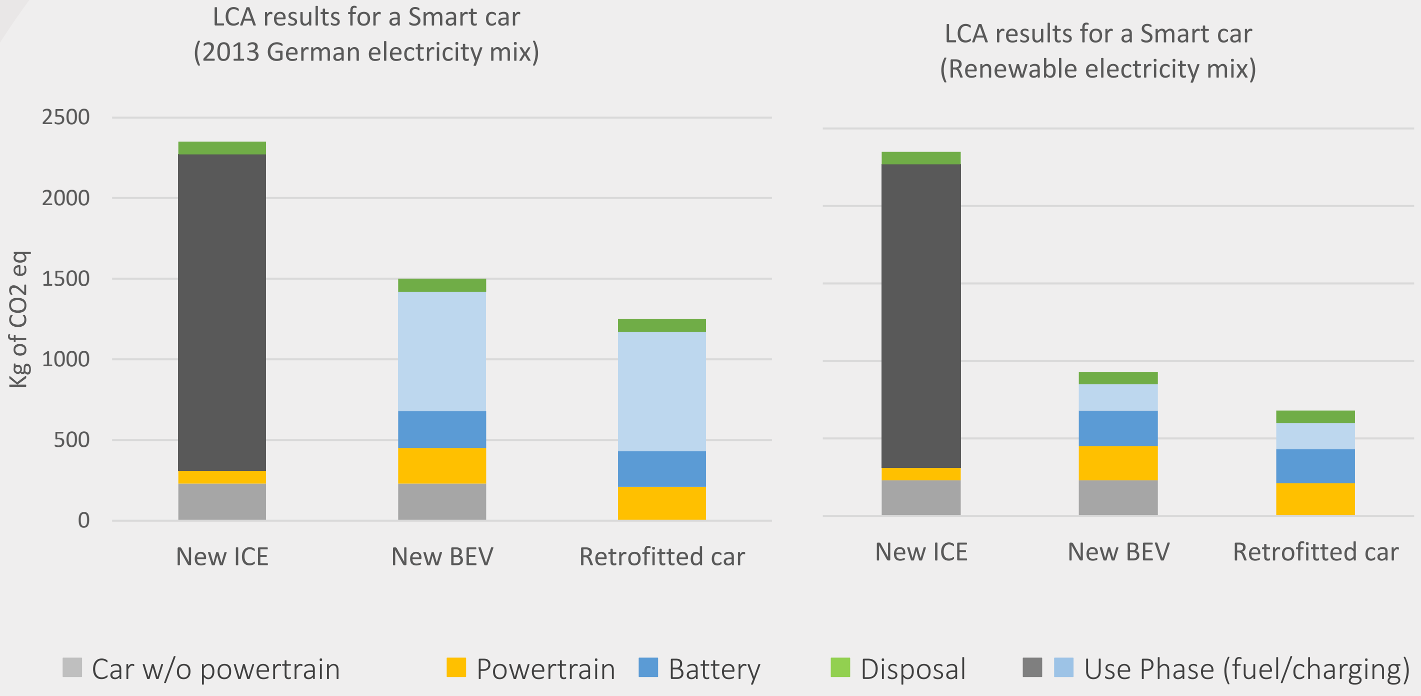
Source: Transport & Environment (2022)

Starting point: Life cycle emissions of cars by powertrain



Source: Transport & Environment (2022)

Step 1: Review of existing LCA studies on e-retrofit



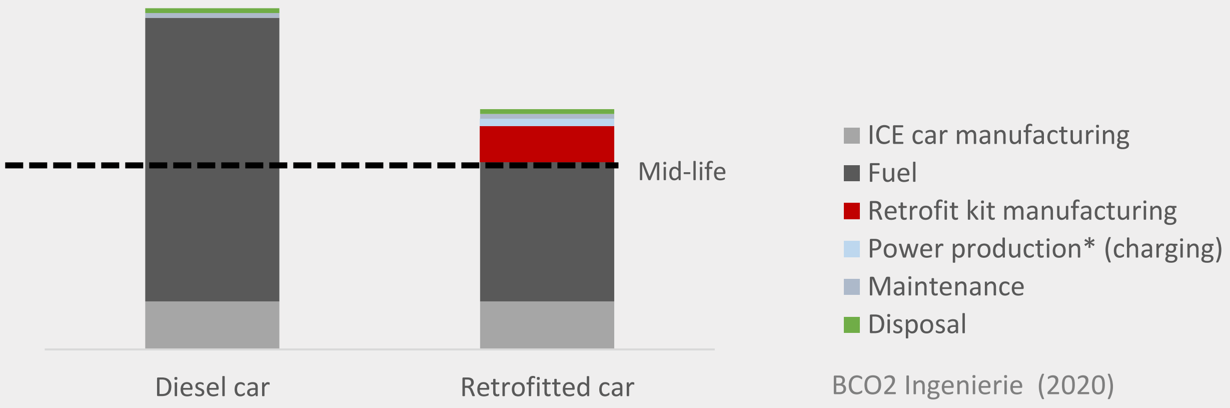
A 2017 LCA (Helmers et al.) has compared the conversion of an 11 year-old/100 0000 km Smart performed in 2011, to a new ICE Smart and a new full-electric Smart (first generation). Another 100 000 km of lifespan is assumed for each vehicle, the electric vehicles being charged in Germany (707 g CO_2e/kWh). The analysis compares 26 scenarios, including different driving styles and electricity mixes. It concluded that e-retrofit reduces the carbon emissions and the broader environmental footprint significantly compared to purchasing a new ICE car or a new BEV.

Source: (Helmers et al, 2017)

Electric car life cycle assessment based on real-world mileage and the electric conversion scenario

Step 1: Review of existing LCA studies on e-retrofit

Carbon emission reductions associated with e-retrofitting a car



The starting point is a 10-year old ICE vehicle. Three scenarios have been compared:

1) extension of the ICE vehicle life for another 10 years and 100,000km,
2) e-retrofit and use for another 10 years and 100,000km,
3) scrapping of the car and purchased of a new EV.

The analysis focused on the 10 years/100,000km of use following the decision.

A similar approach has been applied to other categories of vehicles, with similar conclusions:

Vehicle retrofitted (base) compared to…	Keep the ICE vehicle	Purchase new EV
Small diesel passenger car (10 000 km/year)	+66% CO_2	+47% CO_2
Utility Van (5000 km/year)	+61% CO_2	+56% CO_2
Heavy Duty Truck (16-19T)	+87% CO_2	+37% CO_2
Bus (12 m)	+87% CO_2	+37% CO_2

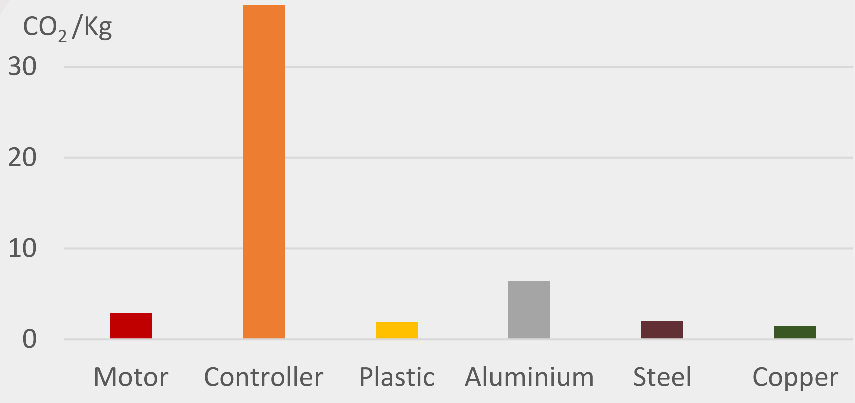
NB: the carbon footprint estimates for the retrofit kit assume the same weight and impact as for a full EV powertrain. We fine-tuned this estimate (see next slide) using the actual weight and composition of a retrofit kit.

Source: BCO$_2$ Ingenierie 2020

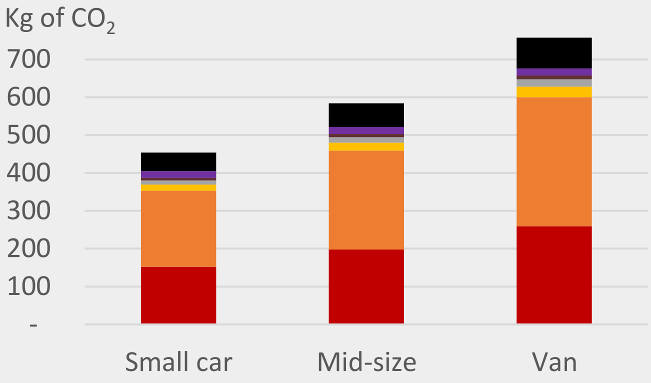
Step 2: Kit production phase calculation

We used as a baseline the stated or estimated weight of each component in an EV West kit for a small car, and then extrapolated it based on the weight ratio of the motor for different sizes (base 100 for small, 130 for mid-size, 170 for van/SUV size)

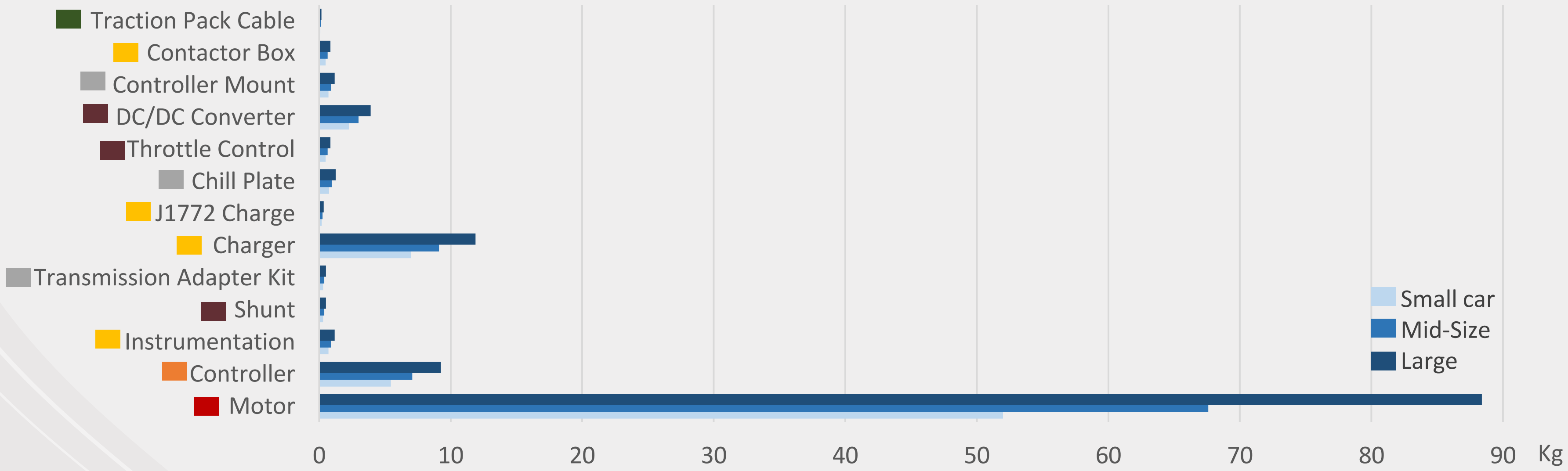
Emission factors: CO_2/kg[1]



Carbon footprint - kit manufactured 2022



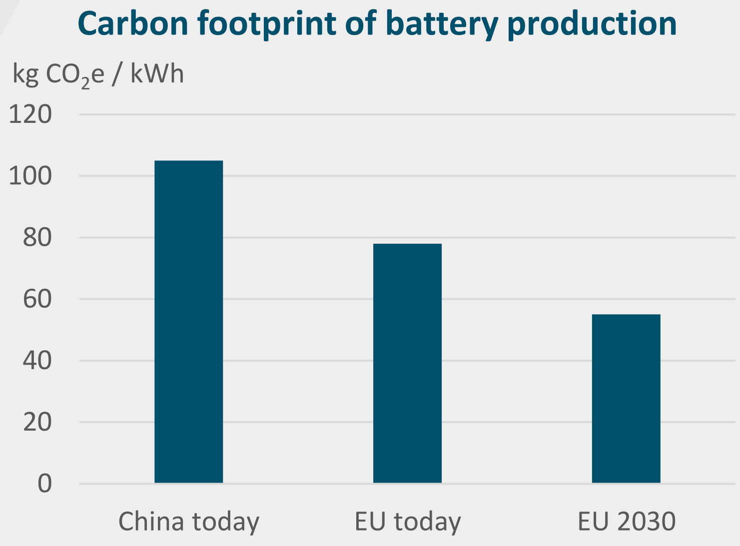
Weight of the components and assumptions on the main materials[2]

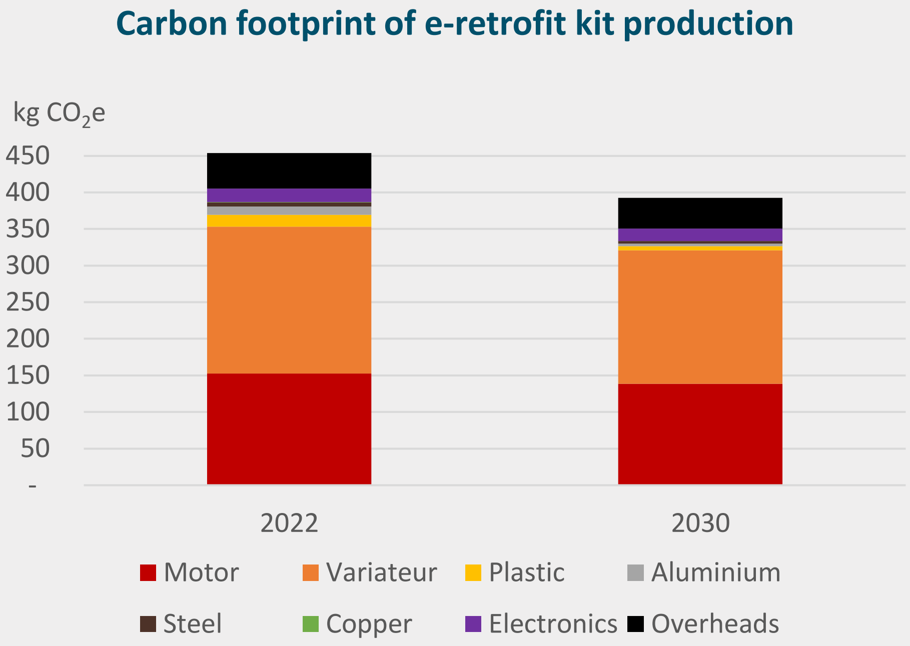


Sources: 1.Bilan Carbone (2022), 2.EV West (2022)

1. A CO_2/€ factor is applied to calculate impact of electronics and overheads

Step 3: Estimating efficiency gains 2022-2030

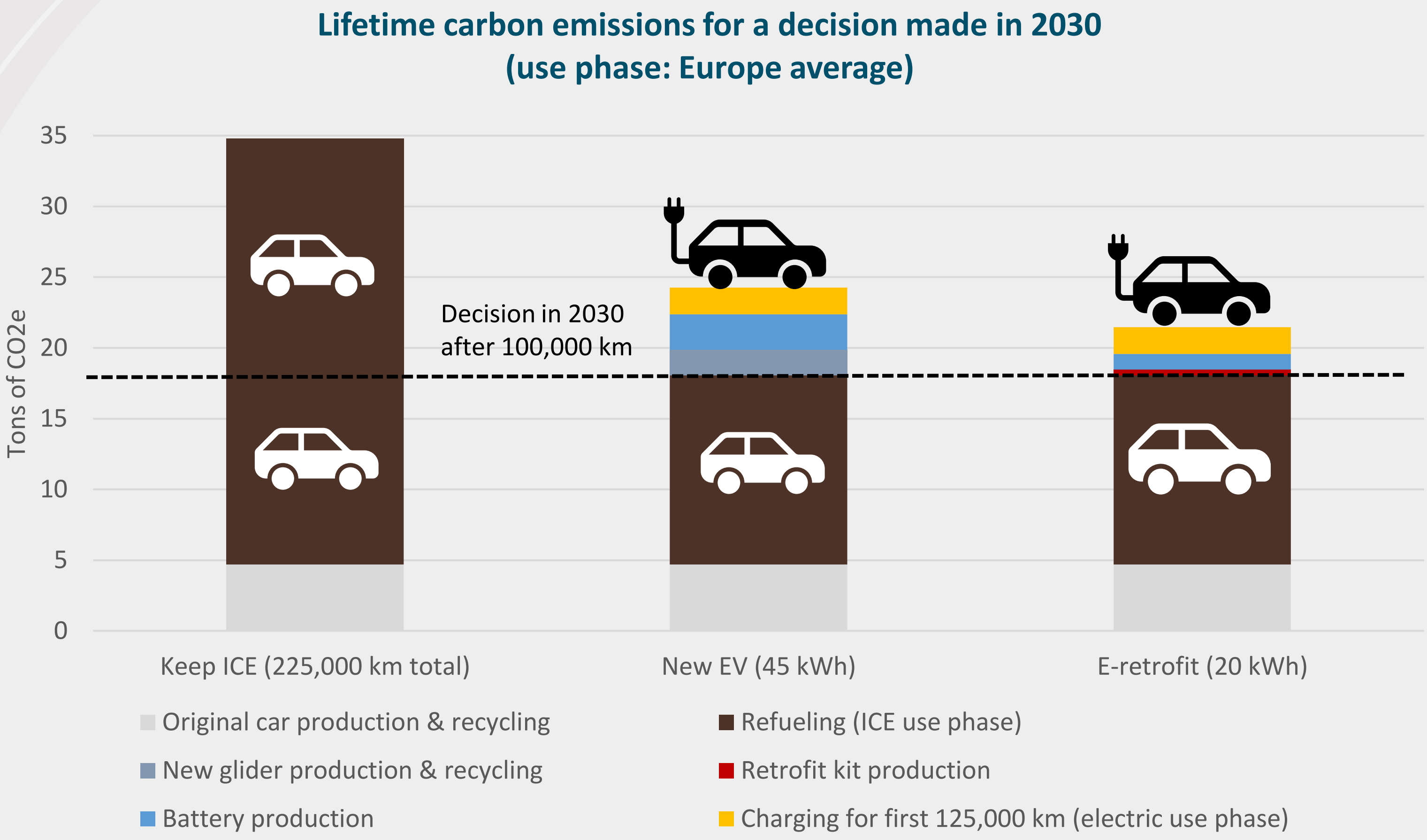




The purpose of the calculation being to compare e-retrofitted cars and new ICE and EVs, we want to factor (for e-retrofit) the efficiency gains accounted by T&E for electric and ICE vehicles. The T&E study assumes a -47.5% gain on the glider production and the gains featured in Fig 1 for batteries, assuming production carbon efficiency correlated with improvements in the electricity grid carbon intensity.

For the e-retrofit kit, the assumption that carbon emissions from production are correlated with the electricity carbon intensity doesn't hold since most materials (steel, aluminum, etc.) are not produced using electricity from the grid. To come up with a more precise estimate we have: i) adjusted the new/recycled ratio of metals and plastics from 80/20 to 20/80, and ii) adjusted the other factors, based on electricity efficiency gains in China (-9%). It is to be noted that these assumptions lead to more conservative results for e-retrofit than the ones applied to new cars (see Step 1).

Source: Authors



Source: model output

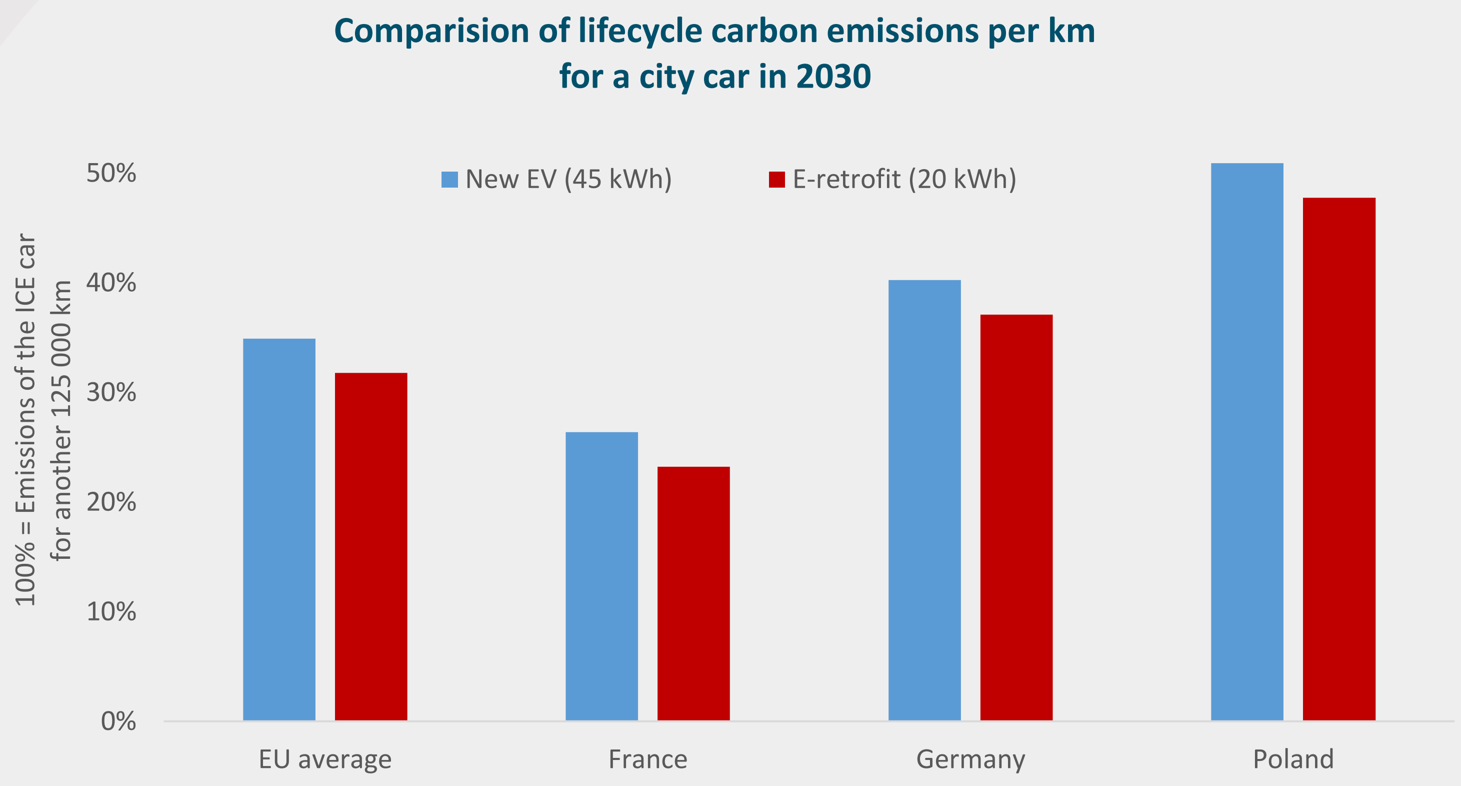
Step 4: Calculation of the use phase

To allow comparability, the use phase assumptions (for the ICEV, EV and regarding battery production, recycling and use phase for the e-retrofitted car) mirror the results of T&E's LCA analysis for a small city car (e.g. Renault Clio) – see source.
We assume a use phase of 15 years and 225,000km, and 2022 as a production year for the ICE car.

Battery and materials recycling is subtracted from the production impact and the result is amortized on 225,000km in all cases. The early retirement of the ICE car earlier triggers an allocation of the remaining production emissions to the next phase (EV or retrofit).

Source used: Transport & Environment (2022)

Step 4: Calculation of the use phase



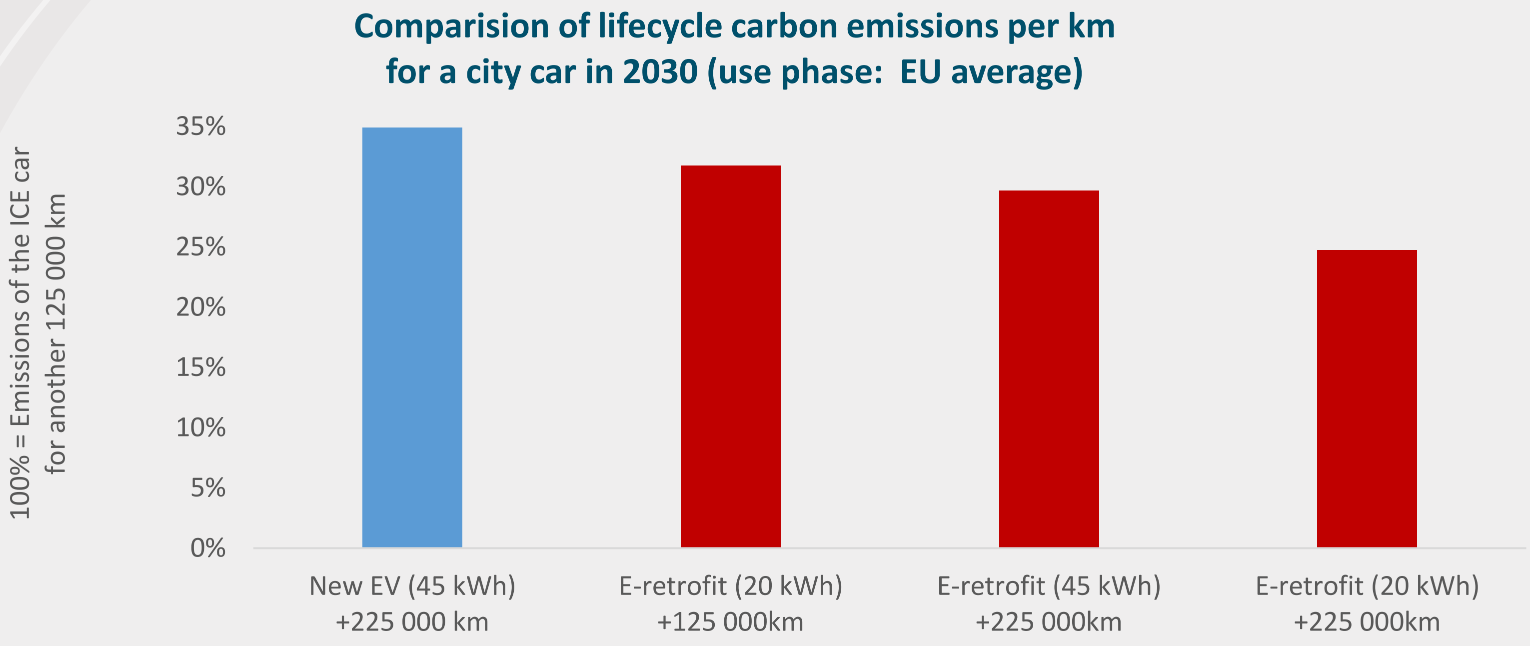
Source: model output

The carbon impact of electricity production (impact of charging the car) has been calculated to reflect the forecasted carbon intensity of the grid in different countries in 2030 (T&E data). France being the most carbon efficient and Poland the worse case.

The same energy consumption is assumed for the new EV and the e-retrofitted car although the later has a smaller battery
(see discussion on the technical constraints associated with e-retrofit).

Source used: Transport & Environment (2022)

Step 4: Calculation of the use phase

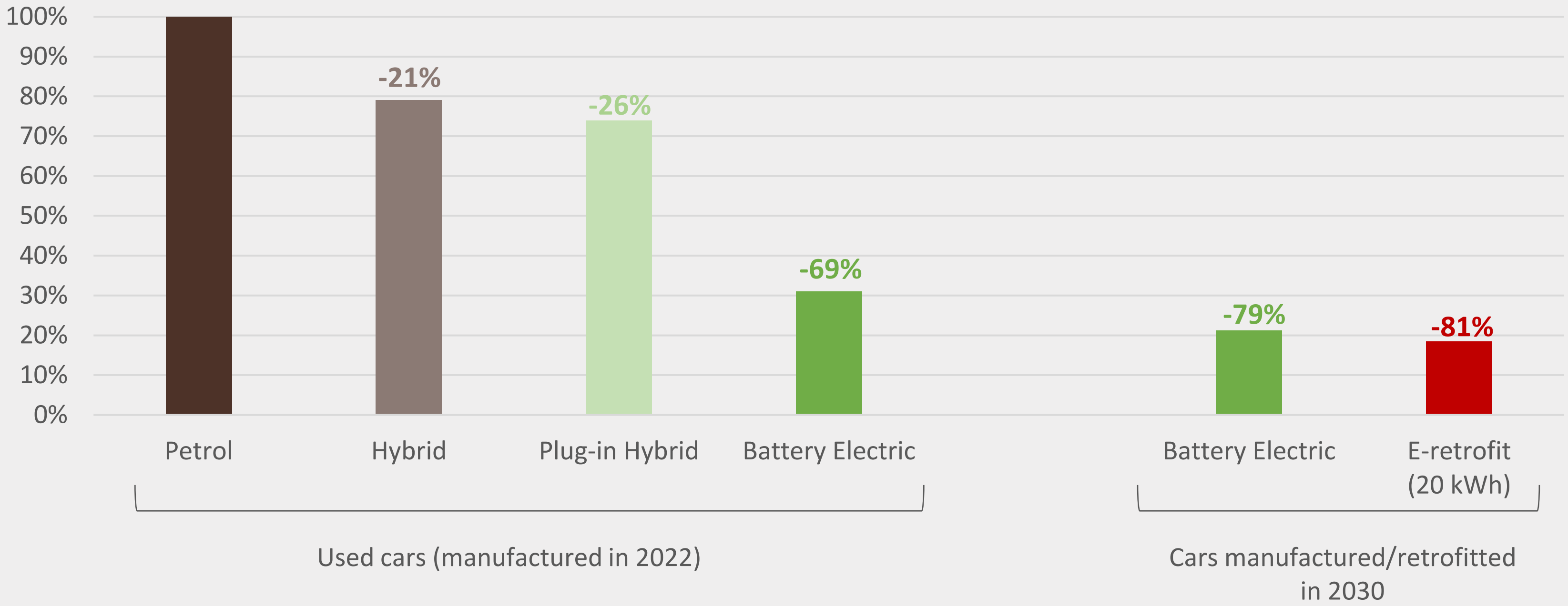


Source: model output

We have explored 3 scenarios for e-retrofit:

- **Scenario #1**. 20k Wh battery and 125,000 km and 225,000 km added to the first 100,000km of the 10-year old donor car. In this scenario, the battery can still be reused given its theoretical lifetime of 225,000 km (recent studies suggesting a potential closer to 900,000 km in 2030). We therefore discounted 100,000km for battery reuse (stationary use, other retrofitted car, etc.).
- **Scenario #2**. In a second scenario the donor car glider's lifetime is extended to 325,000 km, assuming that the key critical components of the glider (suspensions, tires, breaks, etc.) have been changed or fixed after 100,000 km. This premium conversion includes a bigger 45 kWh battery, aligned with the new EV capacity.
- **Scenario #3**. The last scenario combines the extended lifetime and the low-capacity battery.

Life cycle CO2 emissions per km: different powertrains compared with ICE (average estimates for Europe, 100% = ICE car manufactured in 2022)



In practice, in the scenario with a significant uptake, most e-retrofit operations take place between 2030 and 2035. For consumers, the competing options (from an environmental perspective) would then be to extend the lifetime of their existing car, purchase a used EV, purchased a new EV or retrofit their car. We compare here the various options based on the above-mentioned results.

Step 5: Putting results into perspective

Vintage Cars
France

Company name	
Website	
Activities	
Examples of cars retrofitted	
Starting price	
Comment	

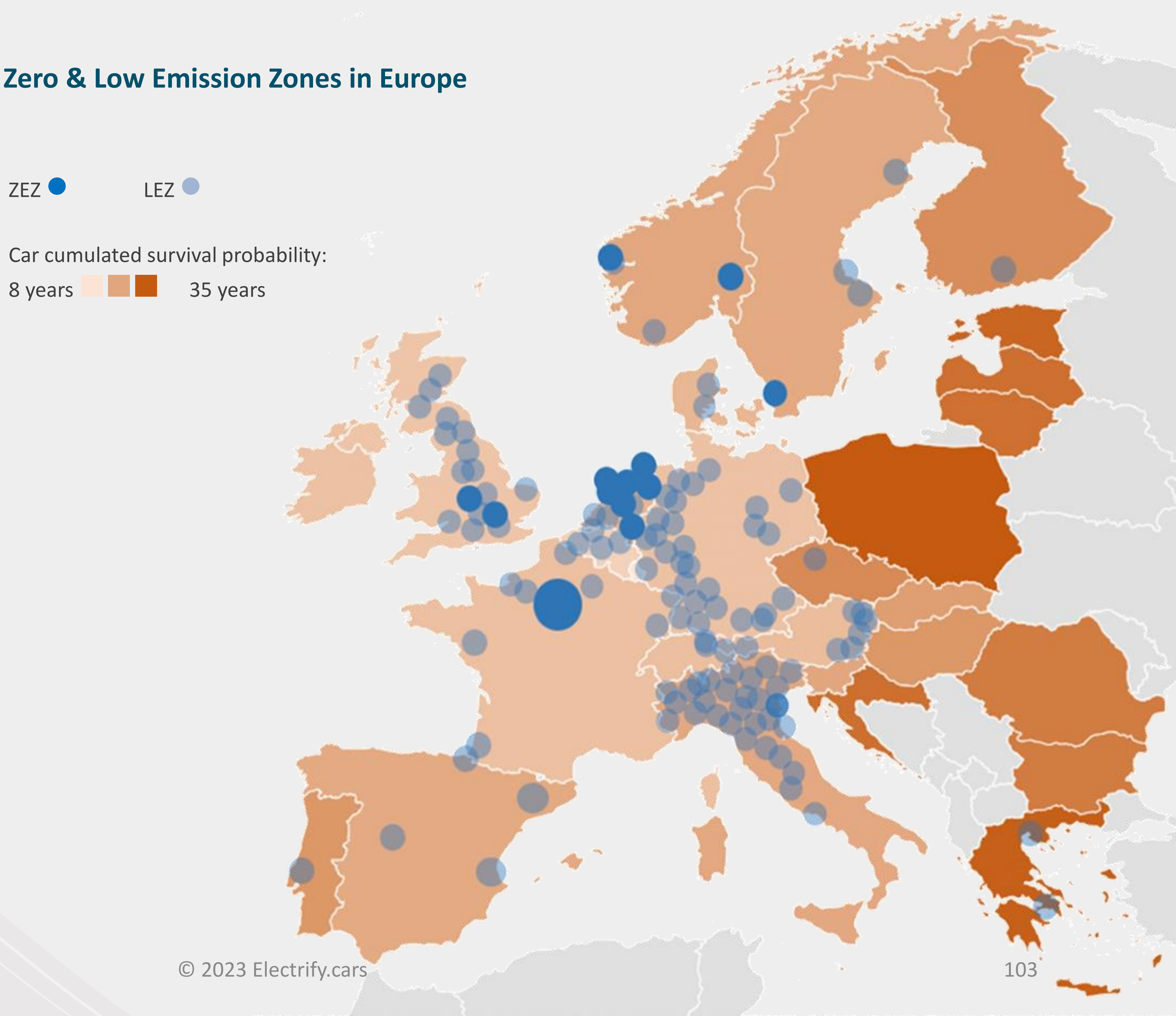
1. Zero & Low Emission Zones

2.Taxes

3. Subsidies

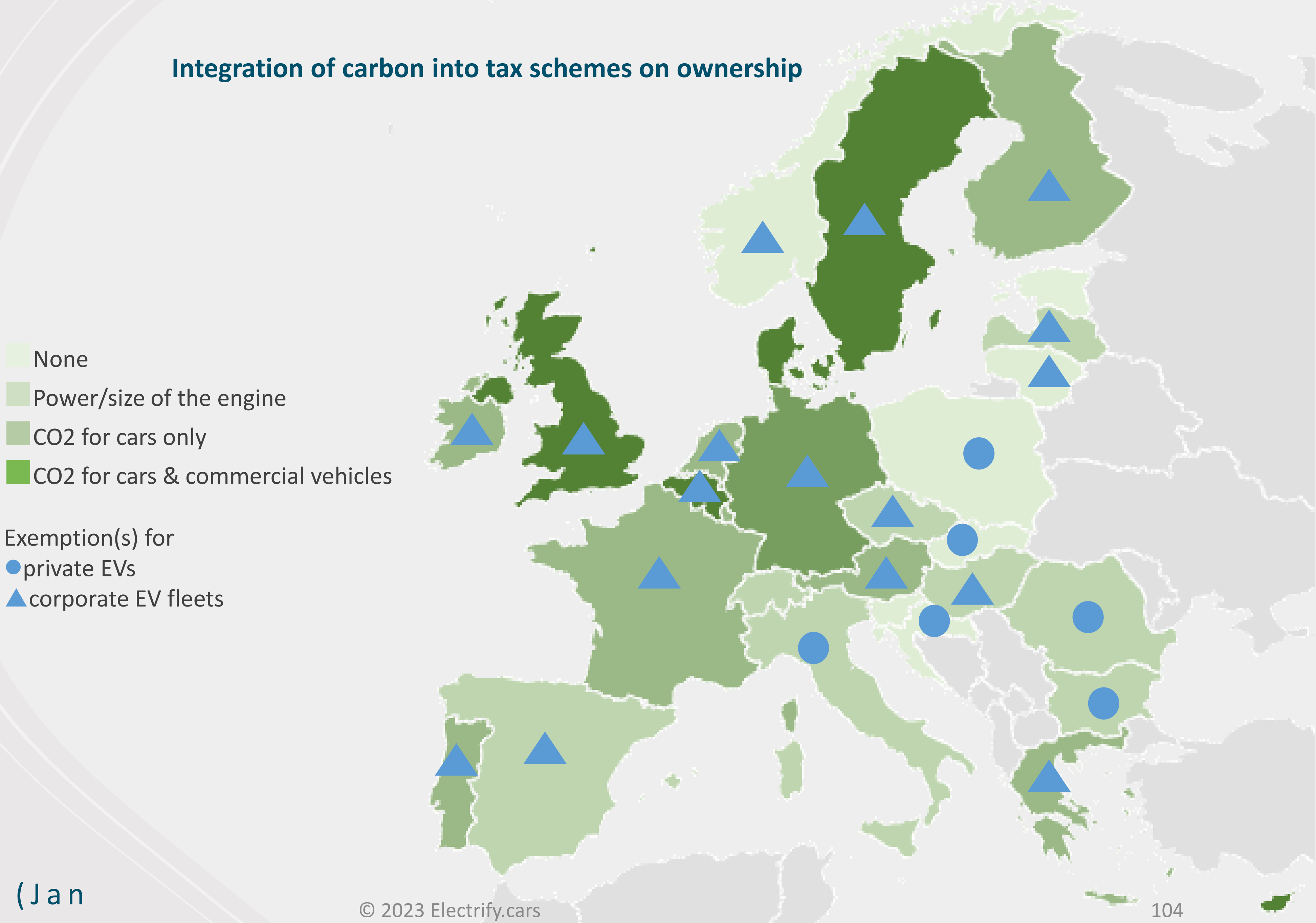
4. Consumer interest

Zero & Low Emission Zones in Europe



Source: Sadler consultants/EC 2022

Integration of carbon into tax schemes on ownership



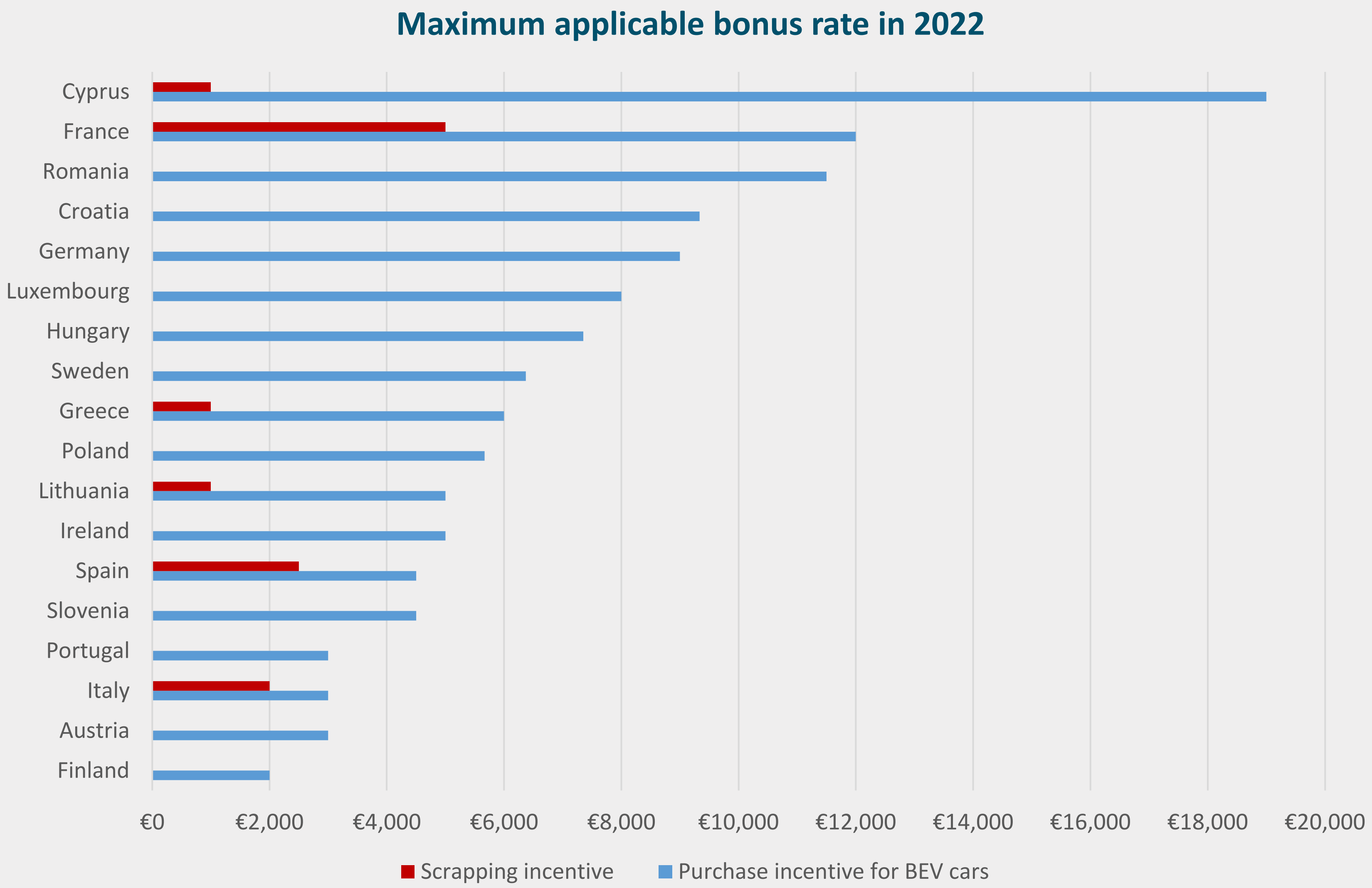
Source: ACEA (Jan 2022)

1. Zero & Low Emission Zones

2.Taxes

3. Subsidies

4. Consumer interest



Source: ACEA (Jan 2022)

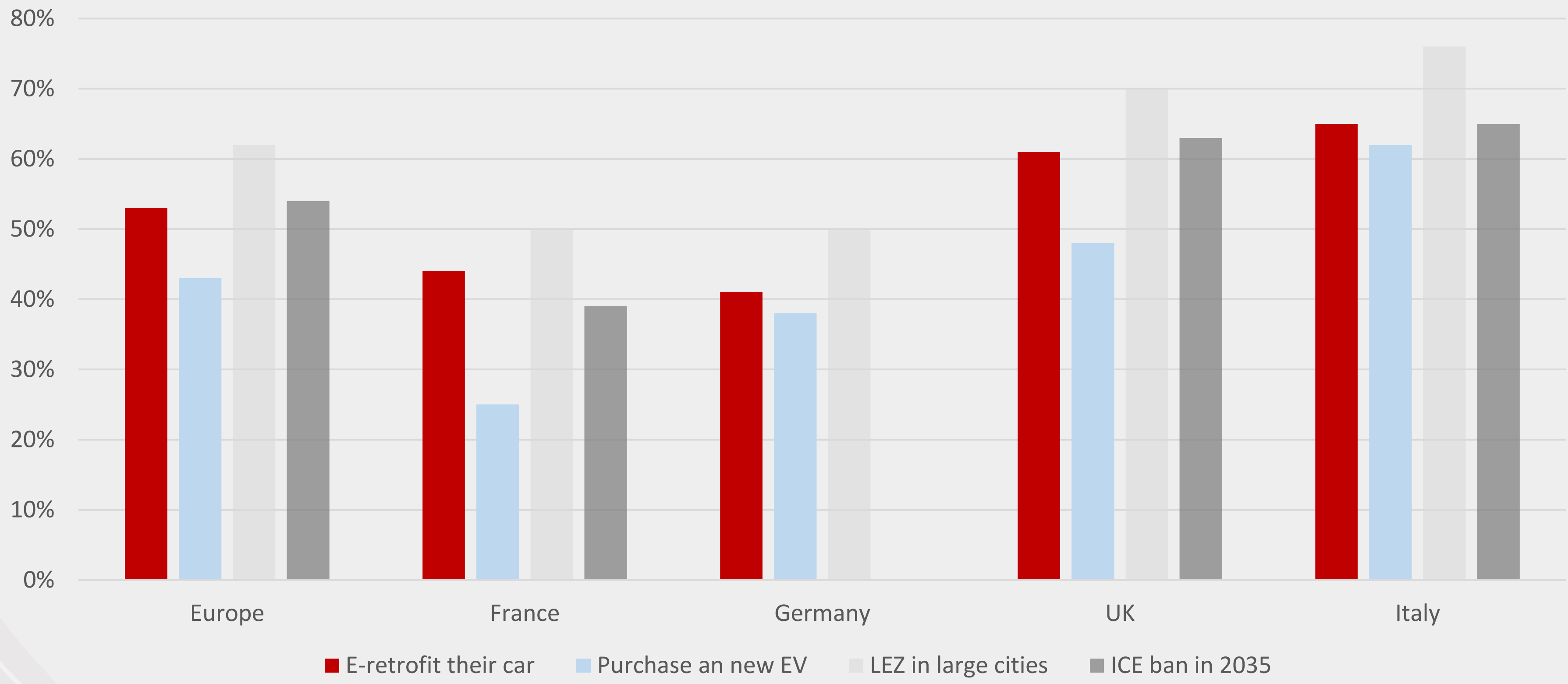
1. Zero & Low Emission Zones

2.Taxes

3. Subsidies

4. Consumer interest

Support expressed for solutions at individual level and collective levels



Source: IPSOS (2022)

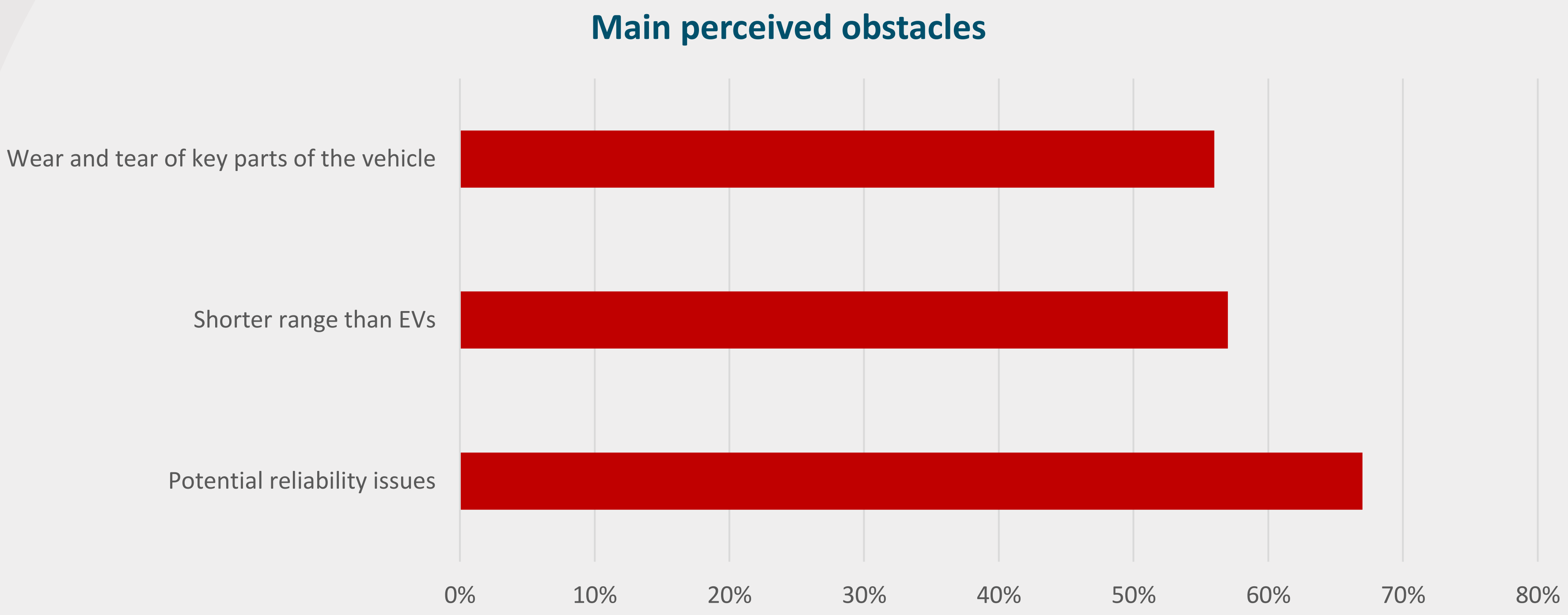
Passer à l'électrique ou privilégier l'entretien durable (2022) IPSOS/Equip Auto 2022.

1. Zero & Low Emission Zones

2.Taxes

3. Subsidies

4. Consumer interest



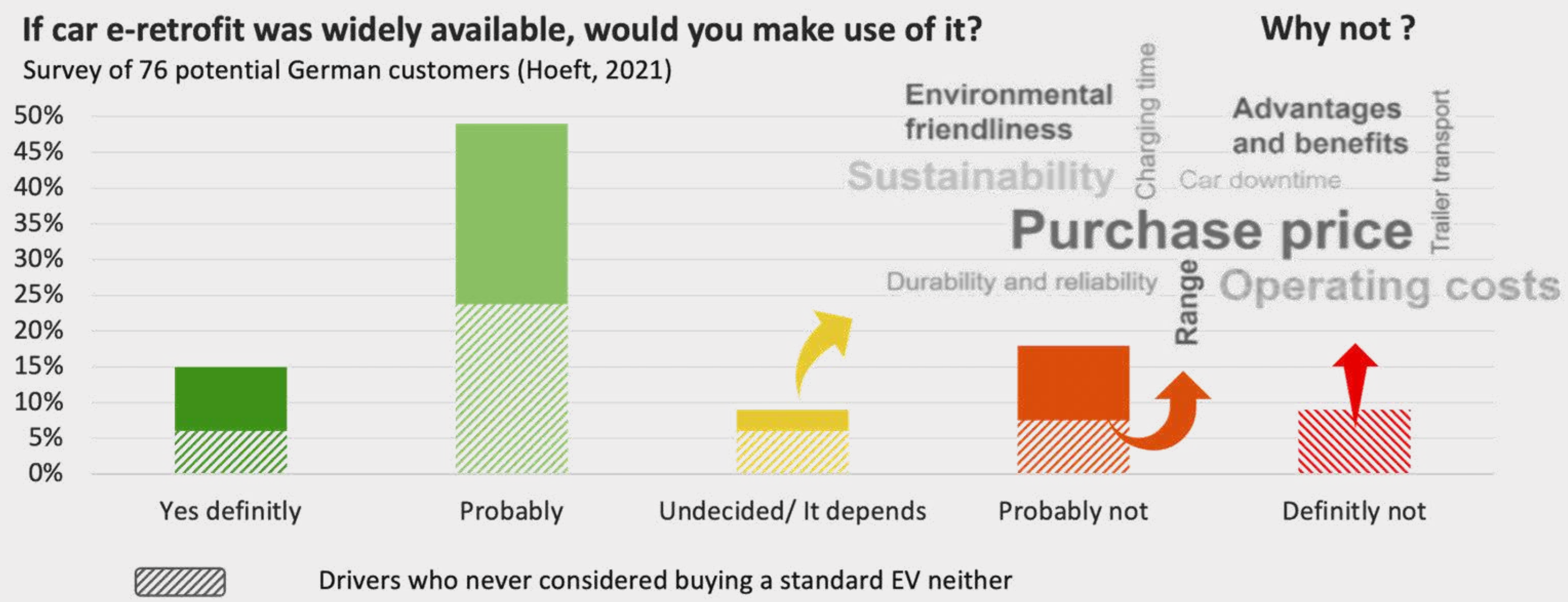
Source: IPSOS (2022)

1. Zero & Low Emission Zones

2.Taxes

3. Subsidies

4. Consumer interest

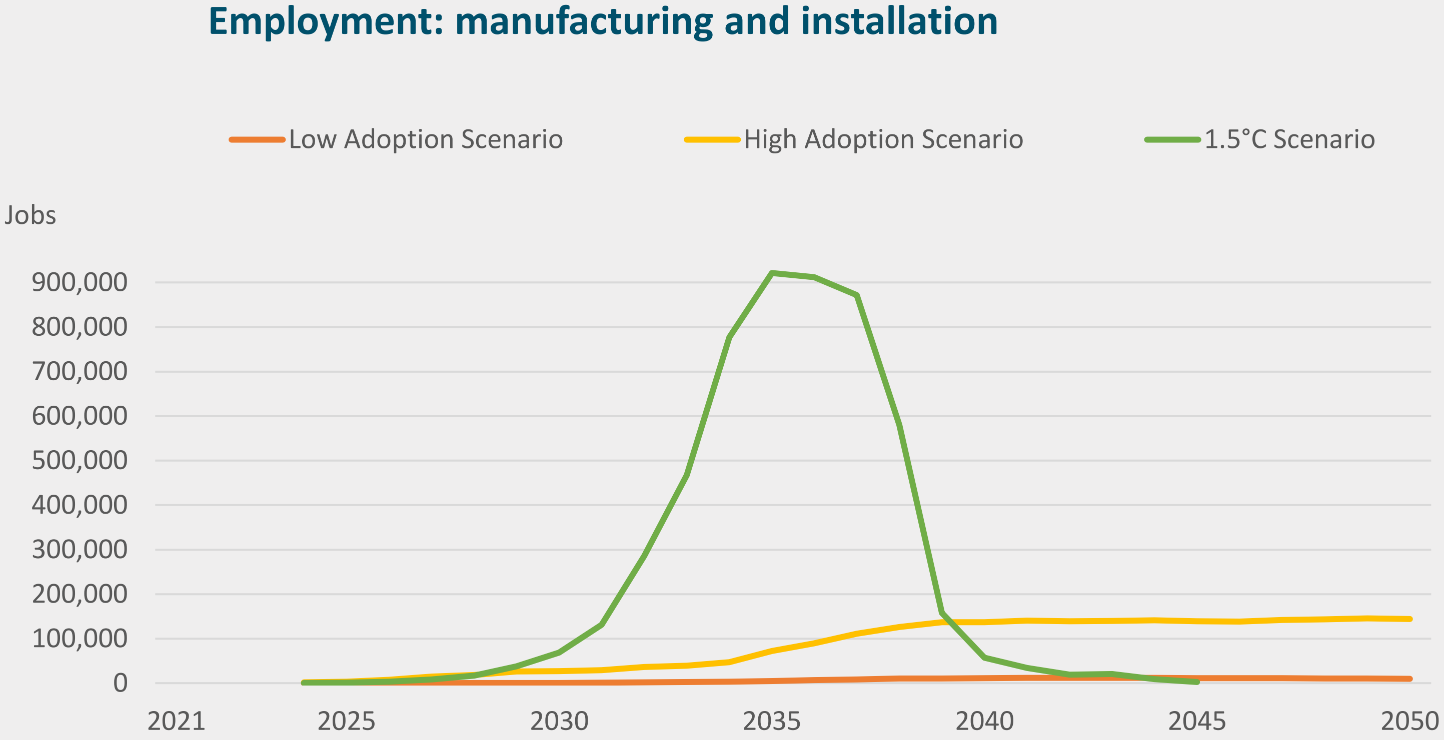


Source: Hoeft (2021)

Internal combustion engine to electric vehicle retrofitting: Potential customer's needs, public perception and business model implications

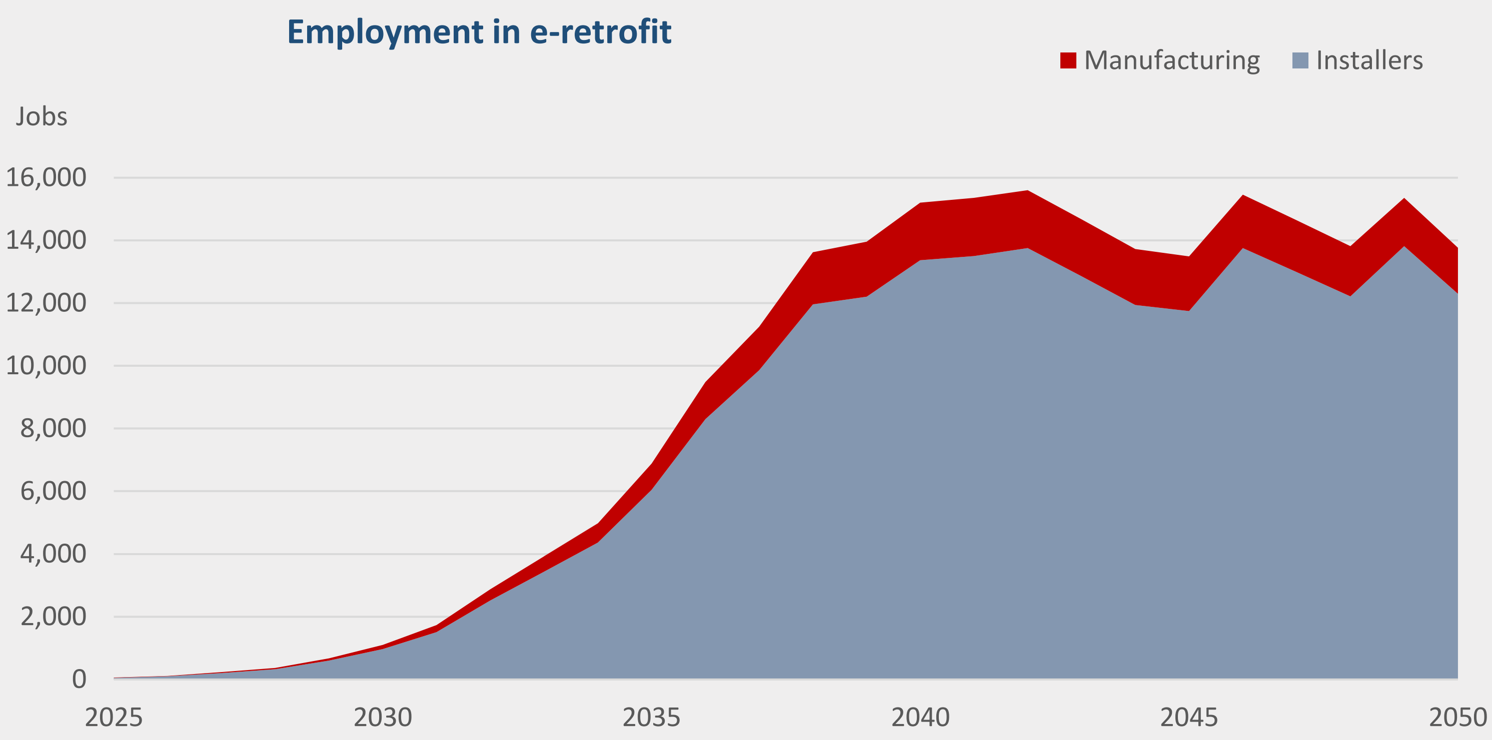
Low Adoption Scenario

Direct job creation



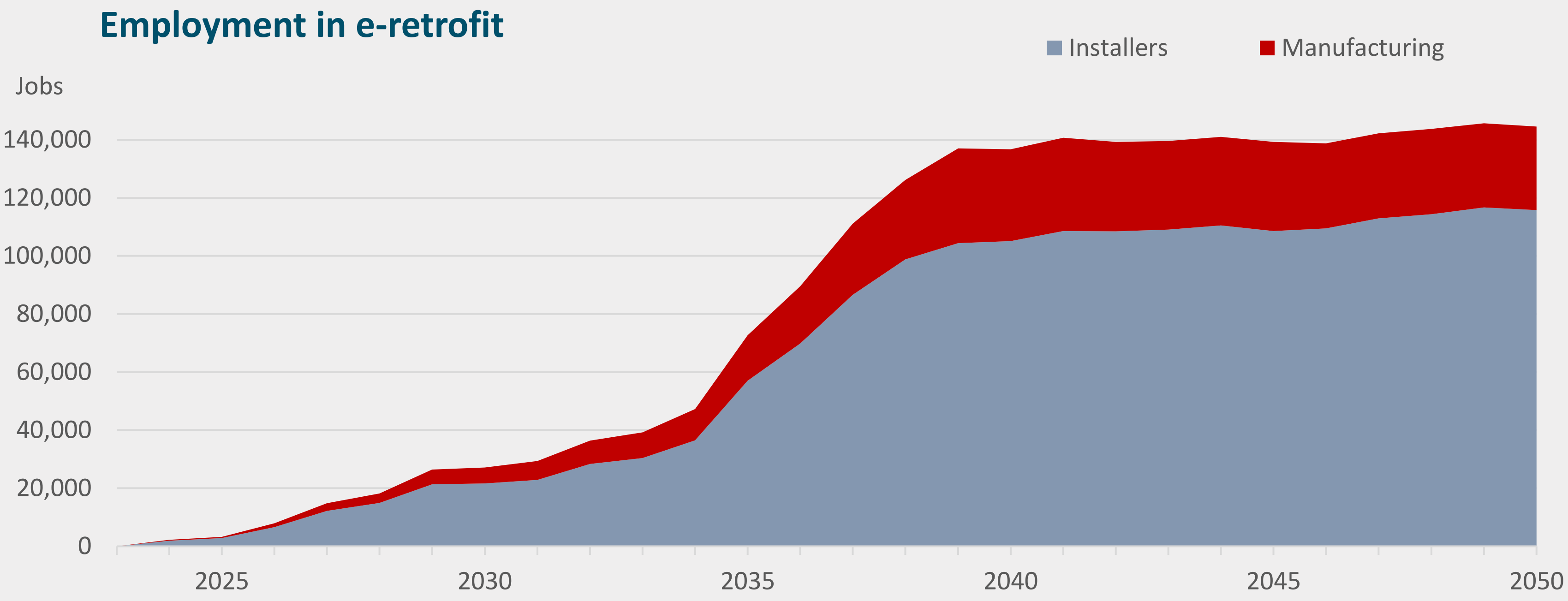
Source: model output

Low Adoption Scenario



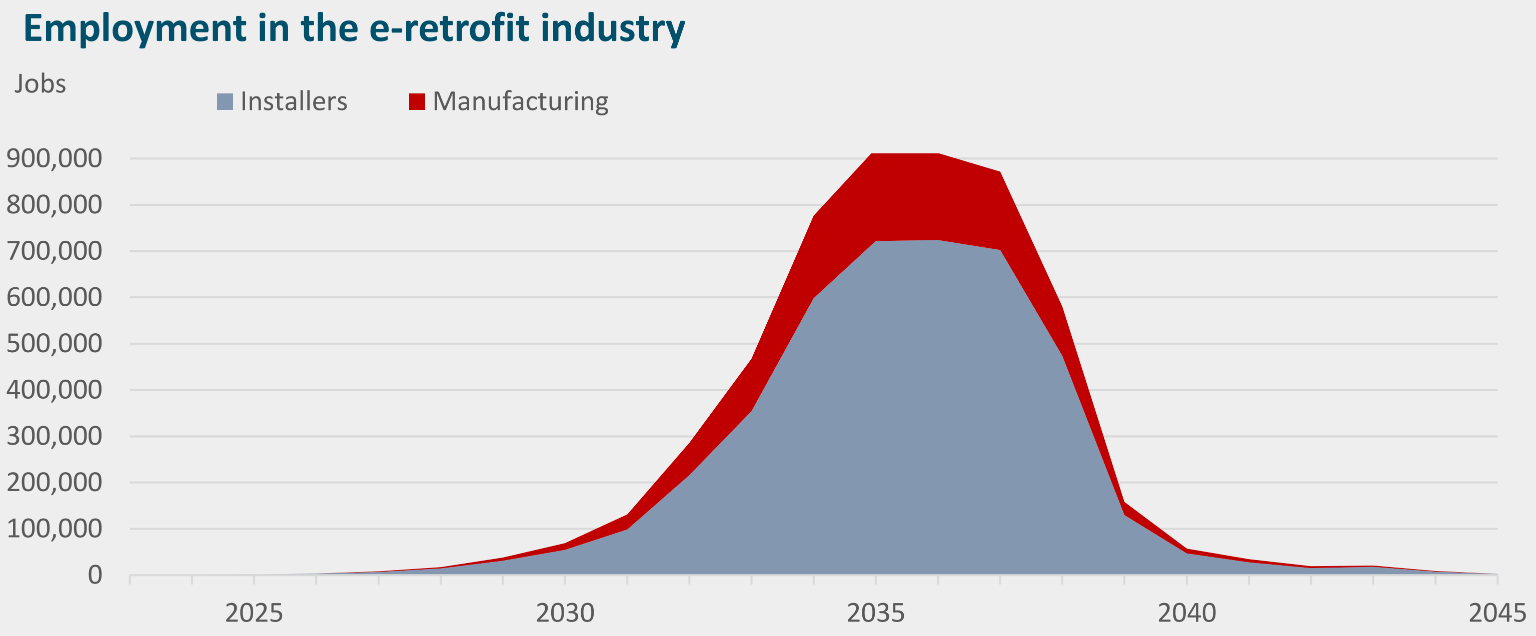
Source: model output

High Adoption Scenario



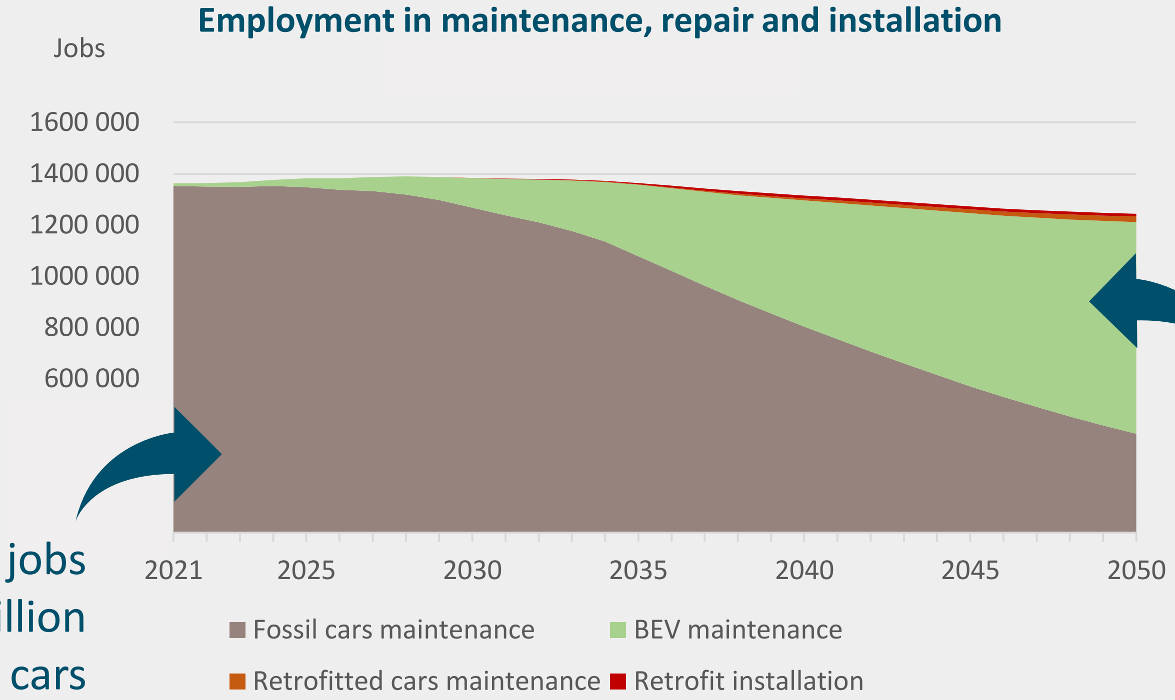
Source: model output

1.5°C Scenario



Source: model output

Low Adoption Scenario



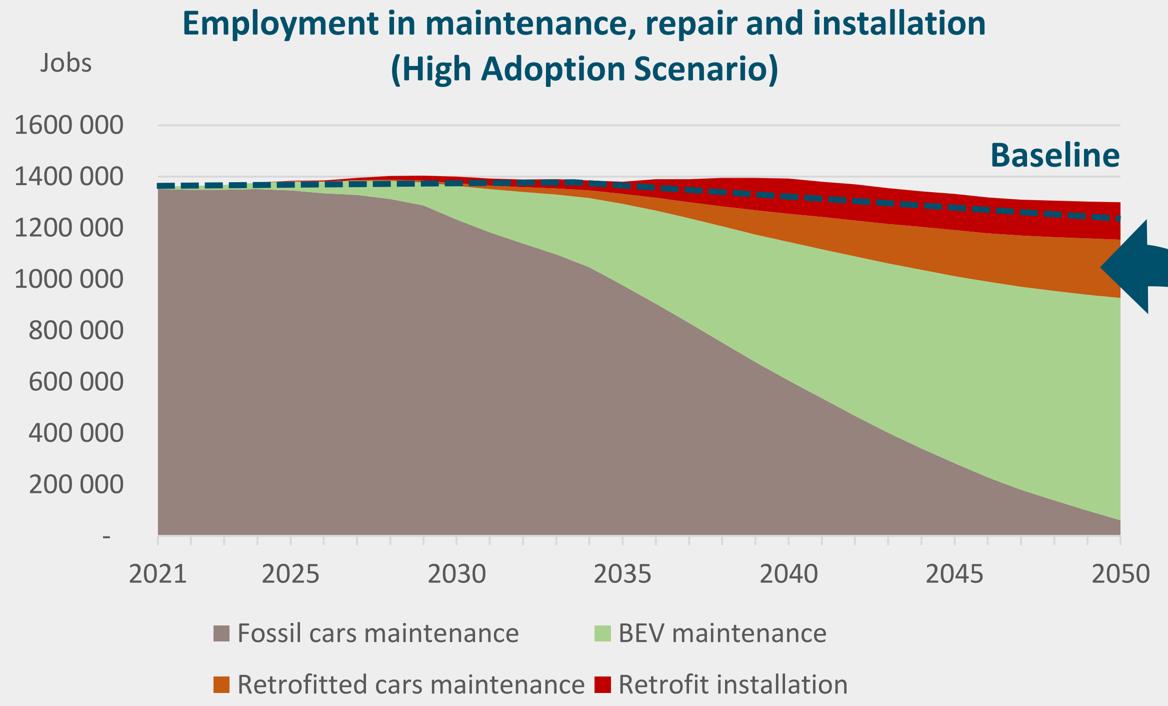
4,612 jobs per million cars

We assume -30% jobs in repairs and maintenance of EV (3,228 jobs per million cars)

Source: model output

- **ACEA (2032)** reports 1.35 million jobs in repair & maintenance in Europe.
- **Lease Plan** (2022) estimates that the maintenance cost is 23% cheaper for EVs in Europe. The study focuses on first-hand cars though.
- **Consumer Reports** (2020) estimate the cost savings at 50% based on an owner survey in the US for vehicles > 200,000 total miles.
- **BEUC** (2021) estimates that the lower maintenance burden for EVs is offset by their higher purchase price, which increased the maintenance average cost.

High Adoption Scenario



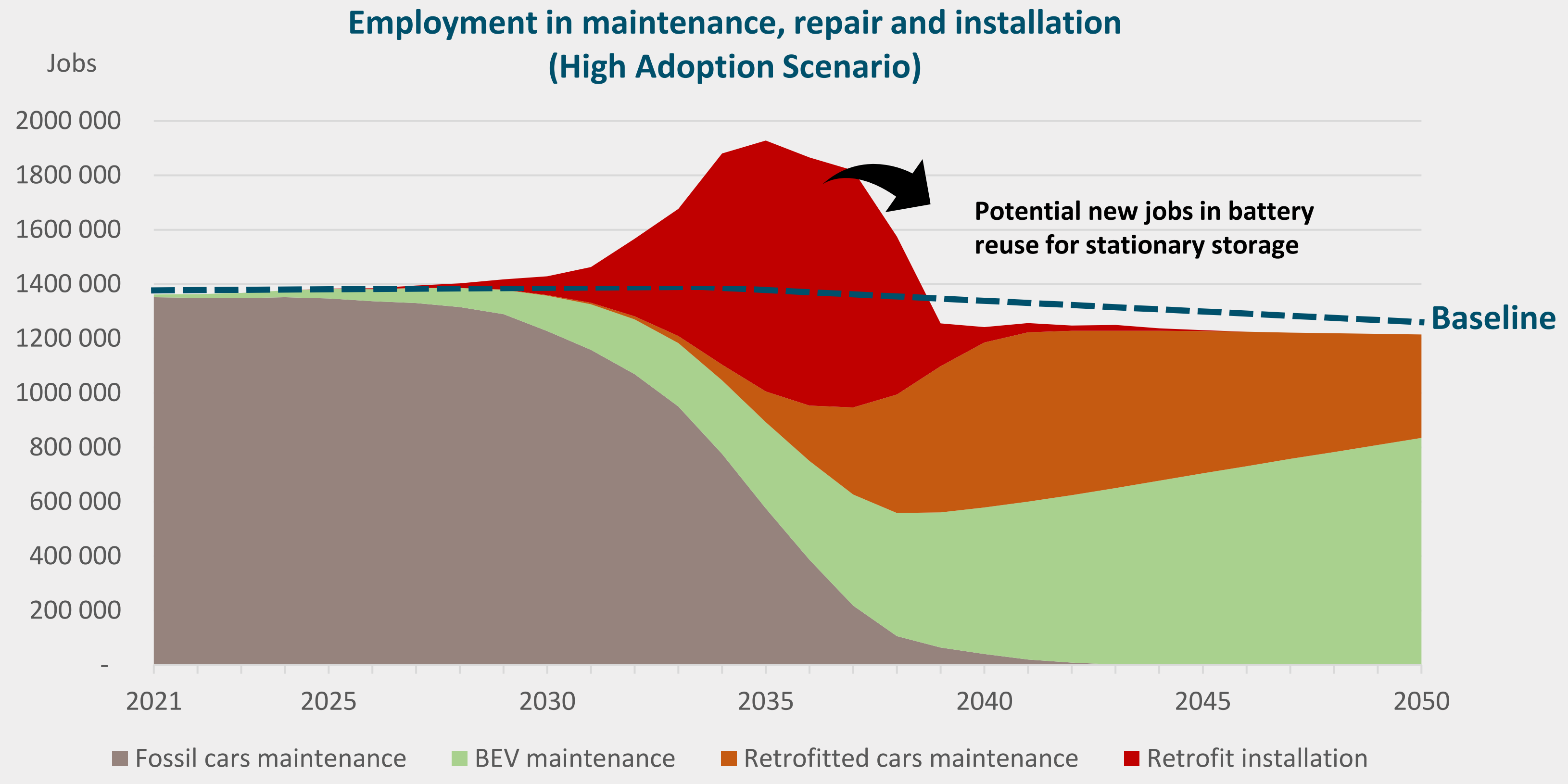
We assume 3,920 jobs per million cars (between ICE & EV) in the maintenance & repair of e-retrofitted cars.

Source: model output

In this scenario, e-retrofit is expected to slightly increase the employment level in maintenance and repair, relative to the baseline.

It is to be noted that the uncertainty around job intensity ratios is high. This topic would require further analysis.

1.5°C Scenario

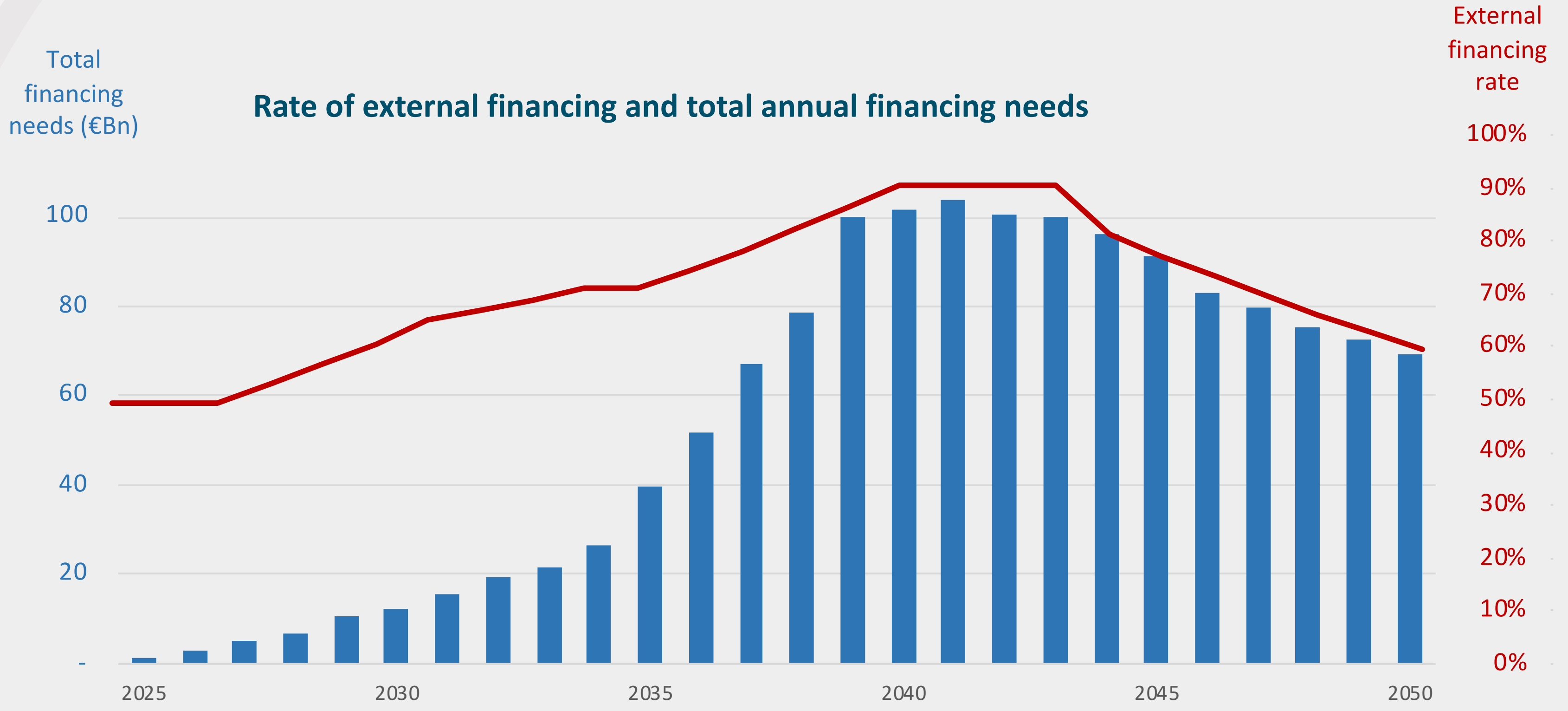


In this scenario, e-retrofit generates a sharp increase in employment between 2035 and 2038 and slightly reduces the level of employment at the end of the period due to the lower maintenance costs assumed for e-retrofitted cars.

These estimates do not factor in potential additional services (refit, additional repairs) that might come with retrofit operations (which might amplify the peak) and the potential jobs created after the peak associated with the reuse of batteries for stationary storage purposes (see discussion in the report).

Source: model output

High Adoption Scenario



Formula

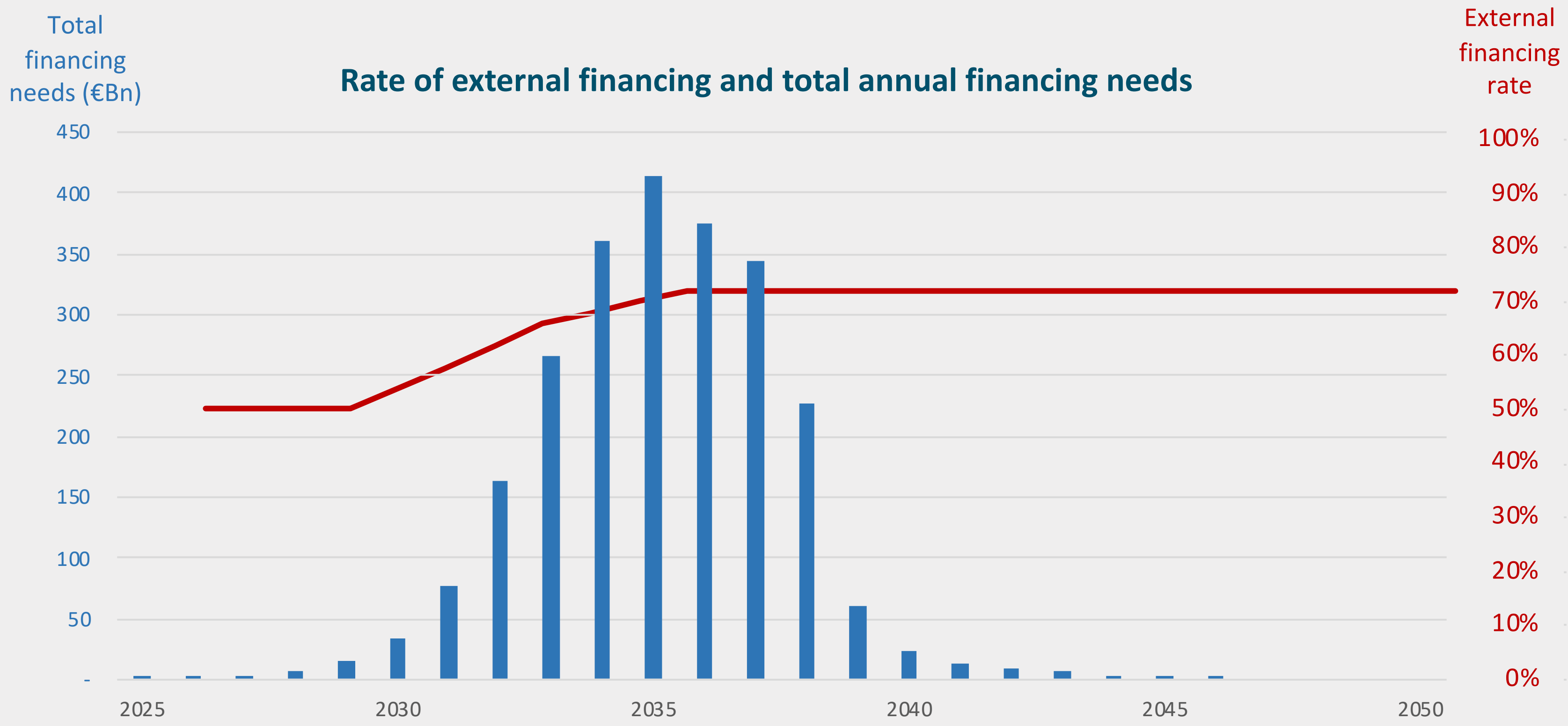
Financing needs

=

(Number of cars x Average net price paid by consumers + Average cost of a glider – Subsidies) x External financing rate

Source: model output

1.5°C Scenario



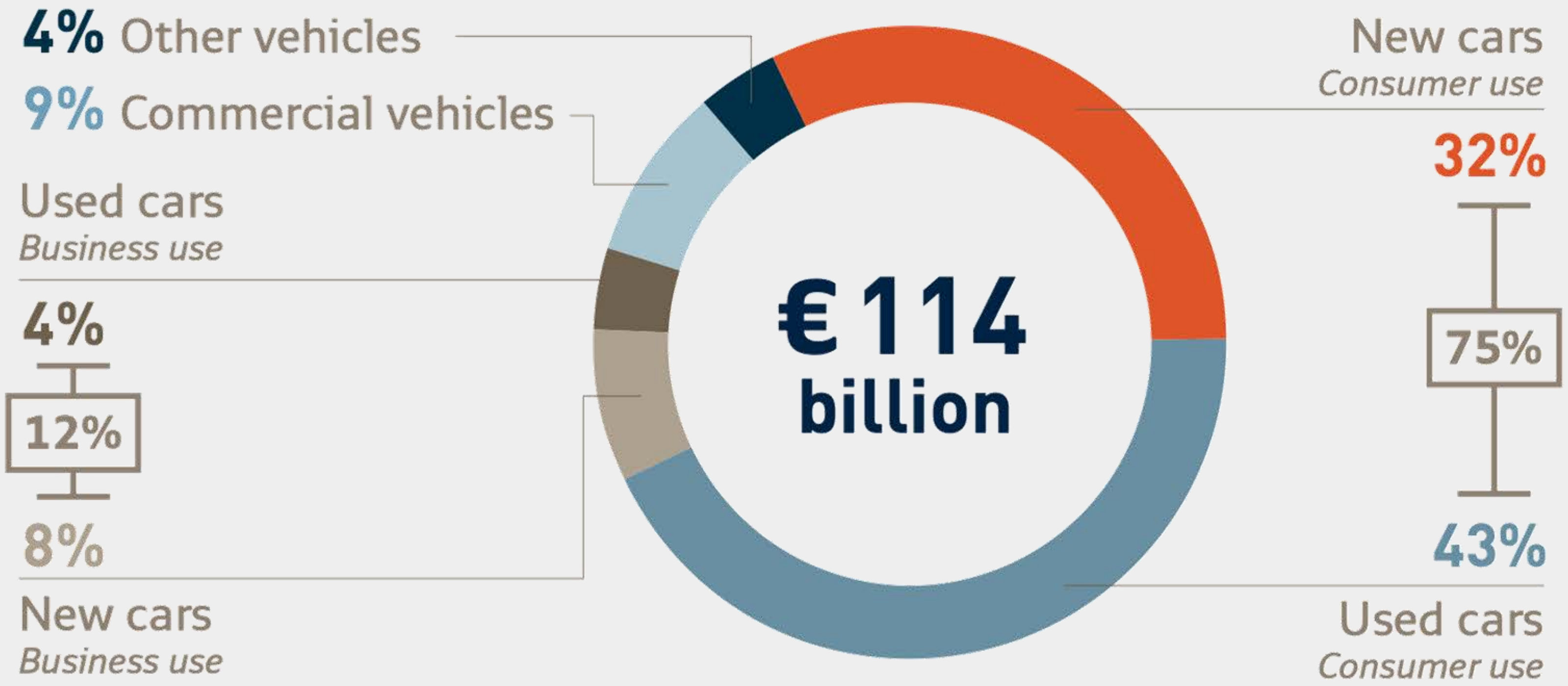
Formula

Financing needs

=

(Number of cars x Average net price paid by consumers + Average cost of a glider – Subsidies) x External financing rate

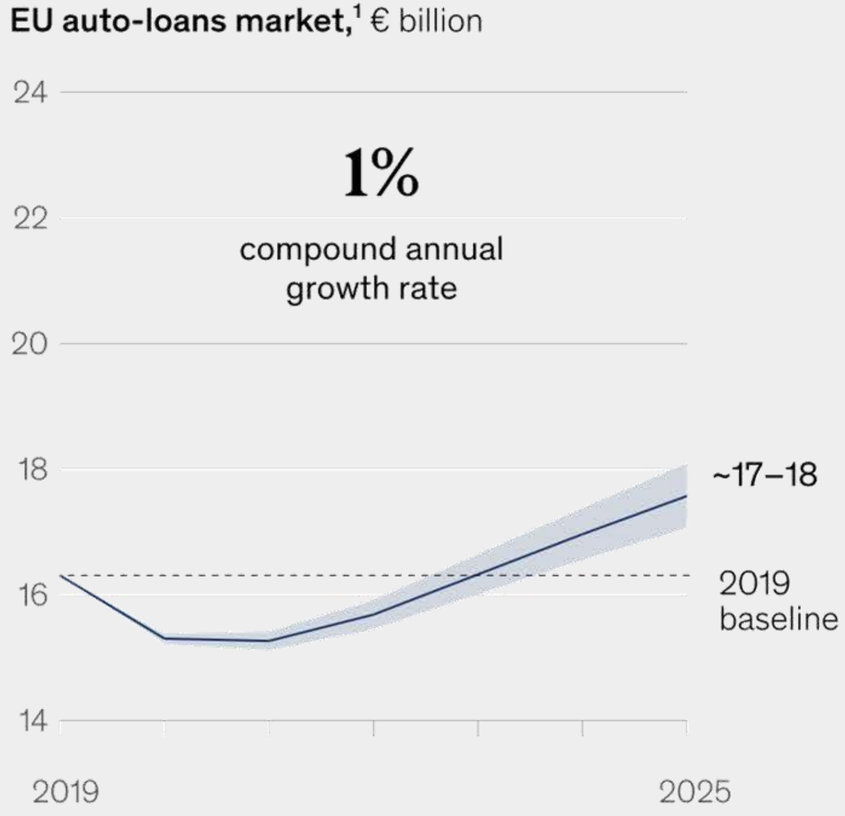
Source: model output

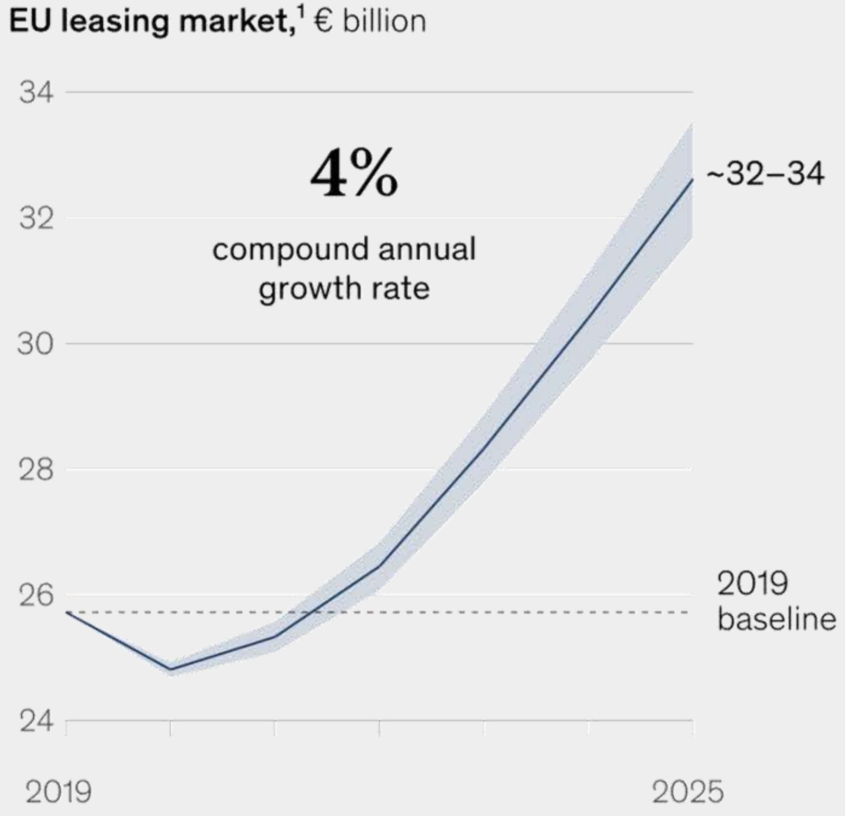


Eurofinas is the European federation of the specialized consumer credit industry. During 2021, Eurofinas members granted loans to consumers to finance some 1.8 million new cars and 3.2 million used cars.

Source: Eurofinas(2021)

European auto financing market (interest + provision results)





[1]Growth rates with sensitives of +/– 0.5%.
Source: McKinsey European Auto Finance Survey 2020

Source: McKinsey & Company (2020)

CHAPTER III
TECHNICAL & ECONOMIC ROADBLOCKS

1. Fossil fleet eligibility for e-retrofit

2. Cost of electric retrofit

2.1. Model description

2.2. Key parameters

2.3. Results in Low Adoption Scenario

2.4. Results in High Adoption Scenario

2.5. Results in 1.5°C Scenario

Starting point: eligibility criteria

AGE

The donor car must be recent enough to remain roadworthy for its second life in order to increase the amortization period and reduce maintenance costs.

RESIDUAL VALUE

The donor car must have a low residual value to make the the e-retrofit economically viable

MECHATRONICS

Recent cars tend to be equipped with complex electronics systems that make the e-retrofit more complex

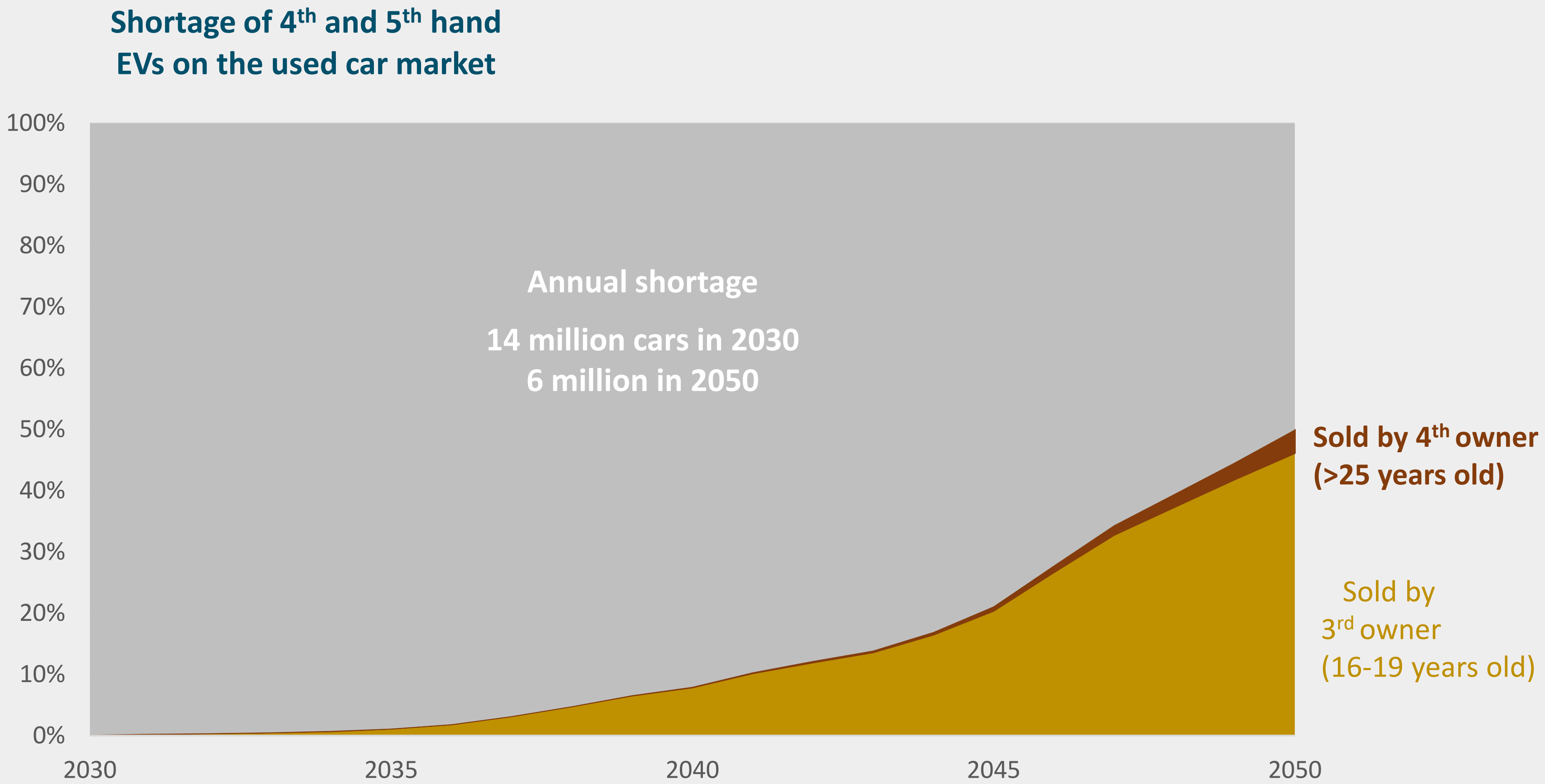
ADAS

Advanced driver assistance systems increase the complexity of the mechatronics challenge for e-retrofit. Keeping them on retrofitted cars would require the collaboration of manufacturers

POWERTRAIN

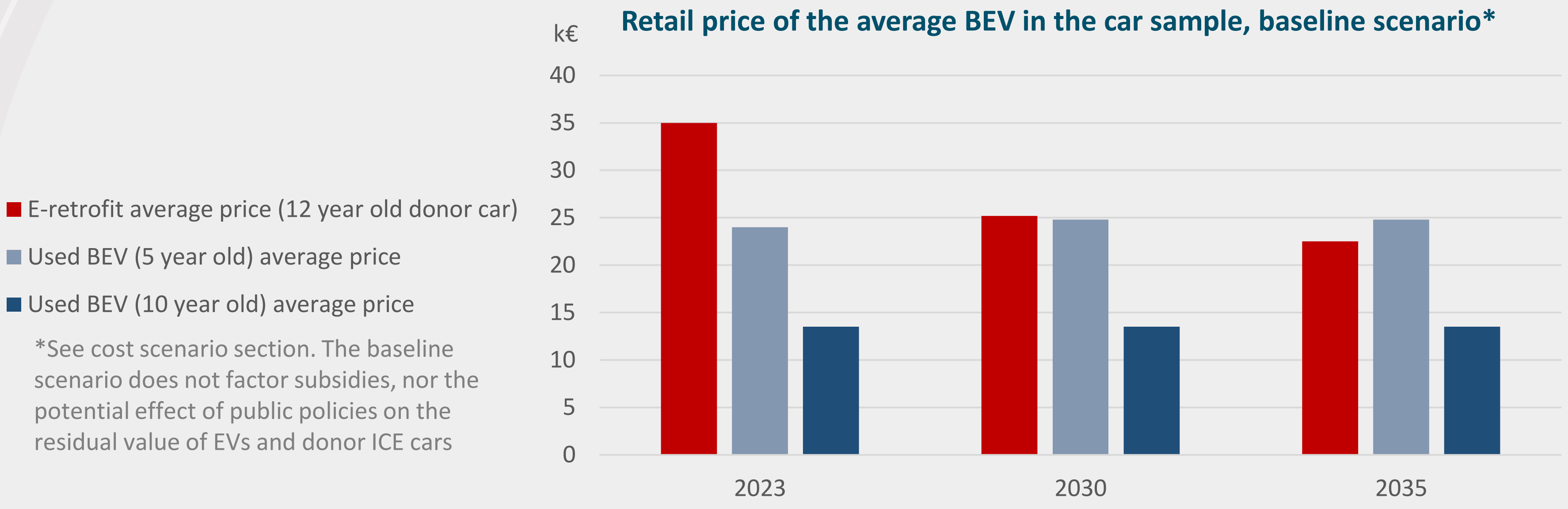
Hydrids and Plug-in-hybrids tend to be more fuel-efficient than ICE cars and also add complexity to the e-retrofit. They are not a priority today.

Step 1: Defining the time window for retrofit



The shortage of very affordable used BEVs (> 10 or 20 year old) is strong between 2030 and 2045. If ICE cars become uneconomic to operate during this period (due to policy, taxes or fuel prices), low-income households might be priced out of car ownership without an affordable zero emission solution. NB: the demand for old used cars is estimated based on the share of old cars in the fleet and used car market today.

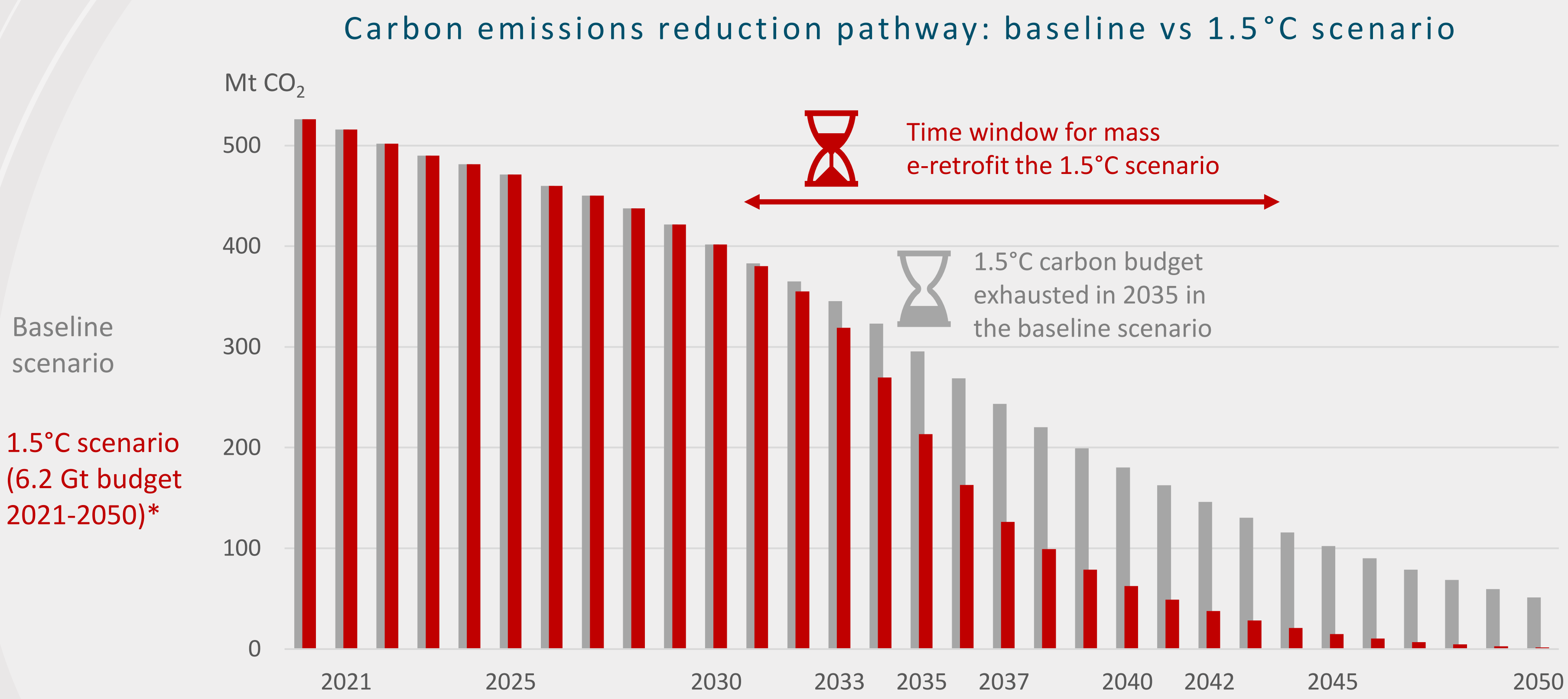
Step 1: Defining the time window for retrofit



*See cost scenario section. The baseline scenario does not factor subsidies, nor the potential effect of public policies on the residual value of EVs and donor ICE cars

Without policy intervention, e-retrofit does not reach price parity with used BEVs of the same age (10 year-old), but it becomes cost competitive with more recent used BEVs (5 year-old or less) from 2030 onwards.

Step 1: Defining the time window for retrofit

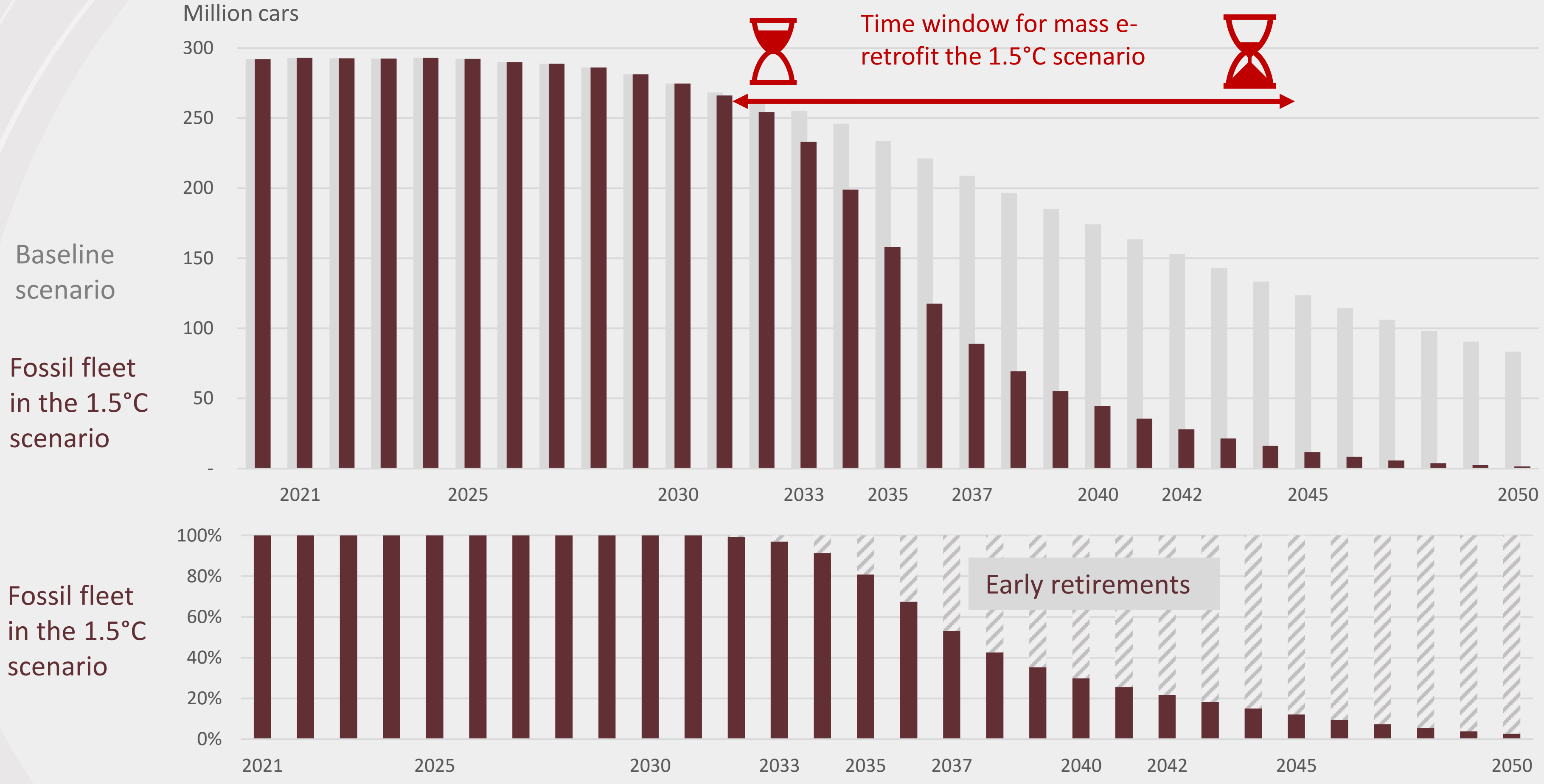


E-retrofit (or any other solution to reduce the emissions of the existing fossil car fleet at scale) is unlikely to be deployed massively before 2030. From there, the time window is very limited not to overshoot the 1.5°C carbon budget.

*High estimate, see related section

Step 1: Defining the time window for retrofit

Fossil car fleet: baseline vs 1.5°C scenario



In the 1.5°C scenario, 90% of the necessary early retirements (additional scrapping or e-retrofit, relative to the baseline scenario) must occur before 2043.

Step 2.1. Eligibility criteria: Age

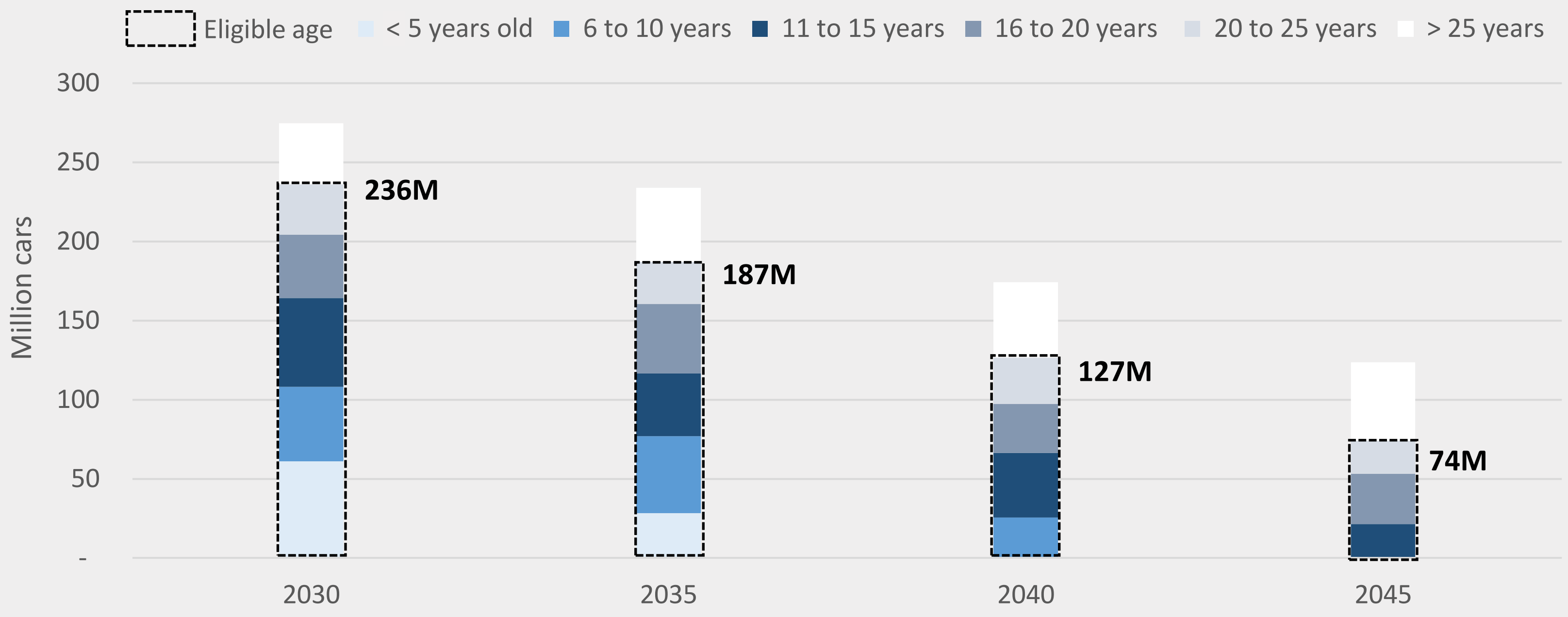
A triple dynamic is at play:

1. The stock of recent cars will naturally shrink during the time window,
2. Policy priorities for e-retrofit might shift: recent cars not prioritize in 2030* could be prioritized at a later stage over old cars,
3. Retrofits performed in 2030 will alter the age structure for the fleet for the following years (effect not featured on the charts)

*The French regulation only applies to e-retrofit of donor cars older than 5 years. However, younger cars lock-in more lifetime CO_2 emissions.

Step 2.1 Eligibility criteria: age

Evolution of the donor car pool: all fossil cars (baseline assuming no early retirement)

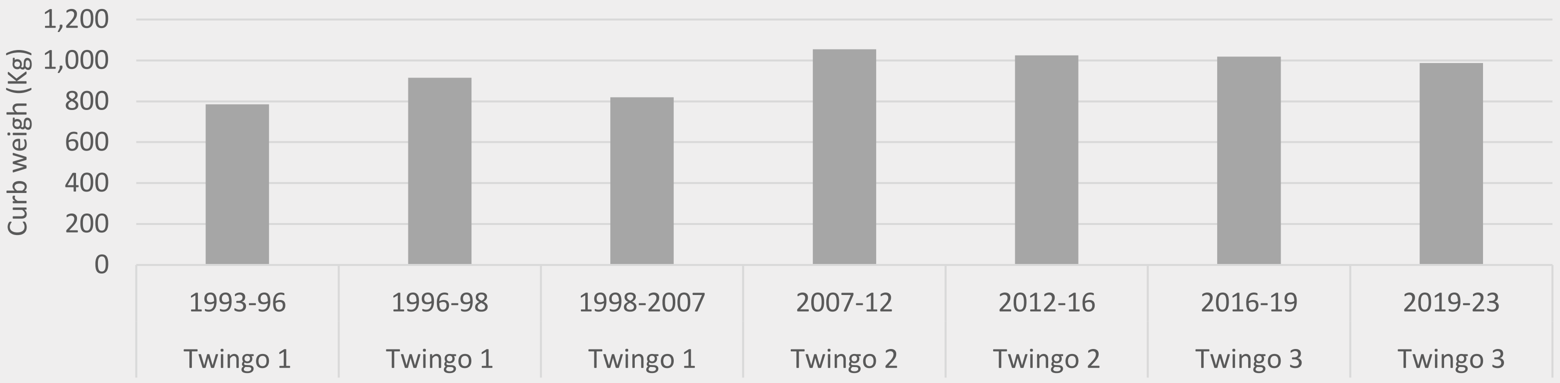


As a result of the natural aging of the fleet, the pool of age-eligible cars shrinks from 250 million cars today to 236 million cars in 2030 to 74 millions in 2045 (baseline scenario assuming no early retirement).

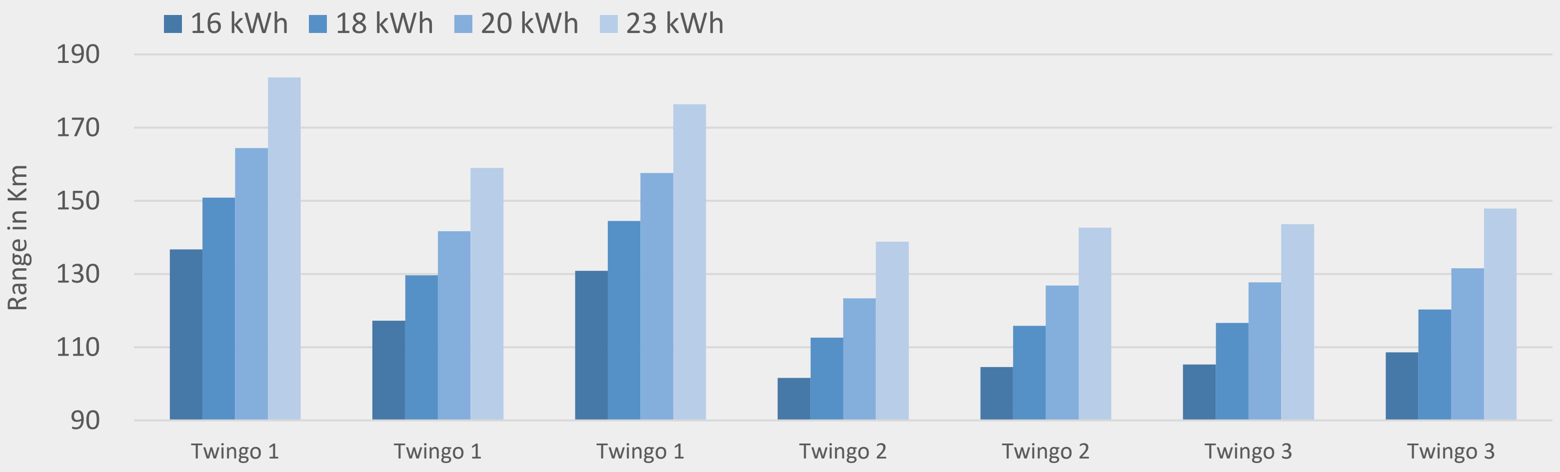
These results are calculated using the aging matrix described in the “Car Fleet Aging” section.

Step 2.2 Eligibility criteria: Weight

Donor car weight

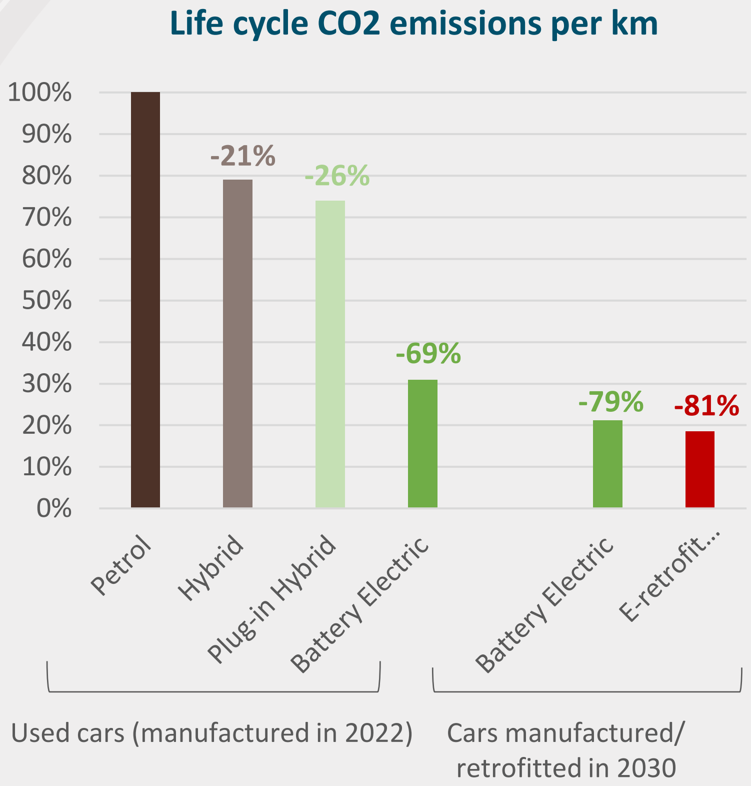


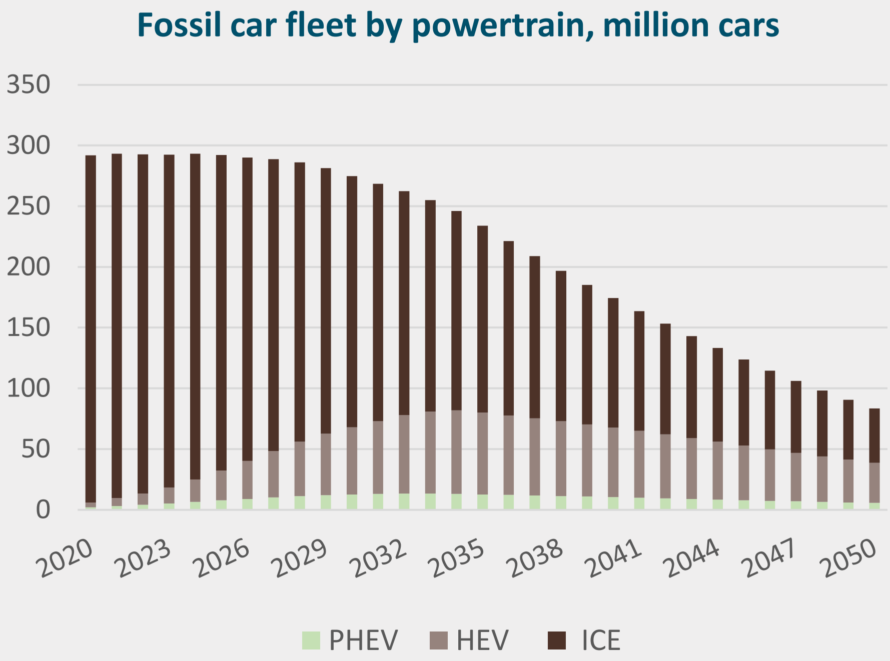
Maximum range of retrofited cars, for different battery capacities (estimates)



The estimates for Twingo are based on the application of a 100*1000/15 ratio: 15 kWh needed for 100 km of range for a one-ton donor car (original curb weight including ICE). This ratio is derived from the analysis of the claimed range of different small cars by e-retrofitters and interviews with them. Sources: ultimatespecs.com (weights), EV-database.org (e-Twingo range for a mild weather, in city and combined use).

Step 2.3. Eligibility criteria: powertrain

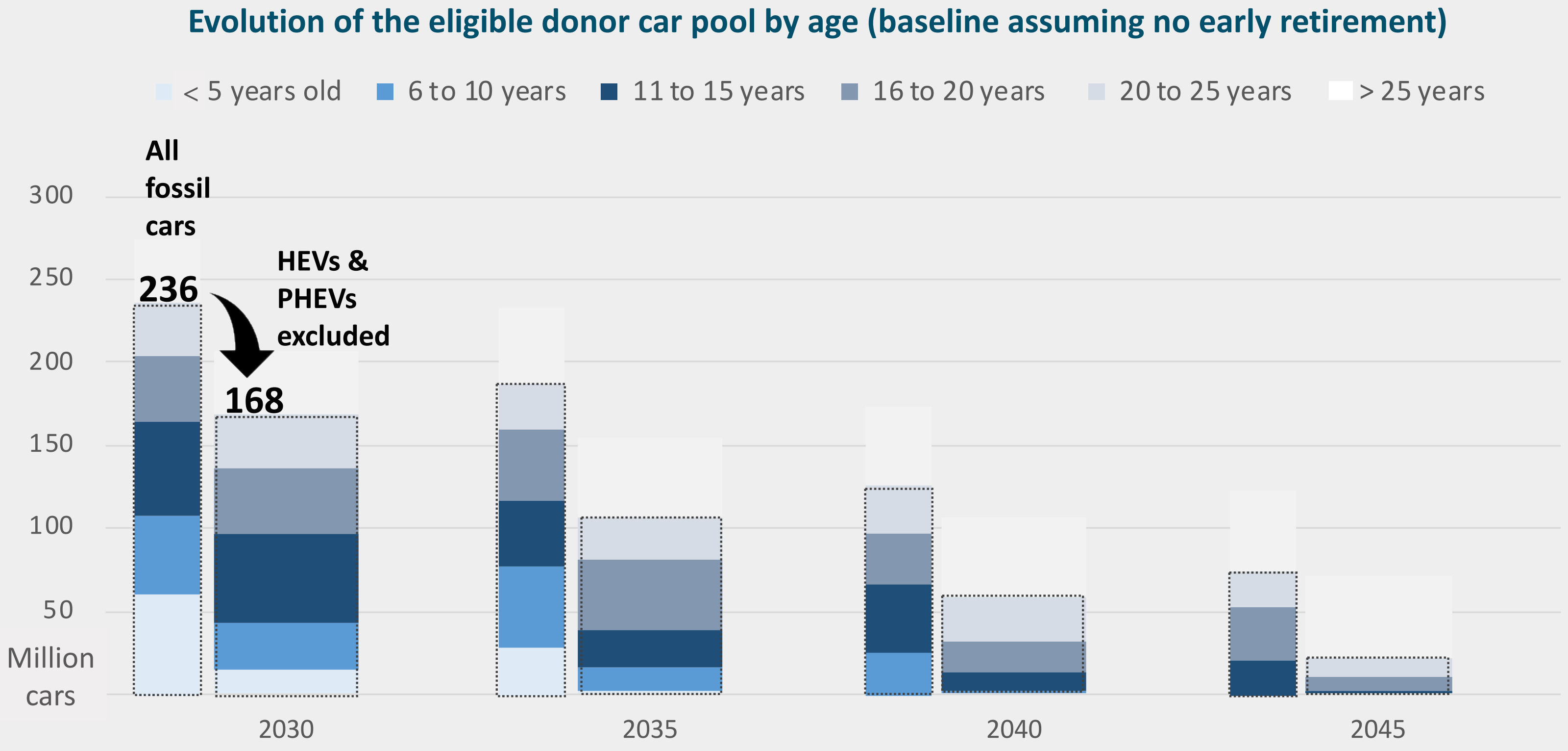




Currently, e-retrofit solutions are not designed for hybrid (HEV) and plug-in hybrid (PHEV) vehicles and the series regulation (in France) is not even explicit on whether these vehicles are concerned or not.
Another potential hurdle is the fact that the environmental benefits of e-retrofit are slightly limited compared to the conversion from a standard ICE vehicle (first chart).

As shown on the second chart, HEVs and PHEVs will represent a significant share of the fossil car fleet post 2030 although not the majority.

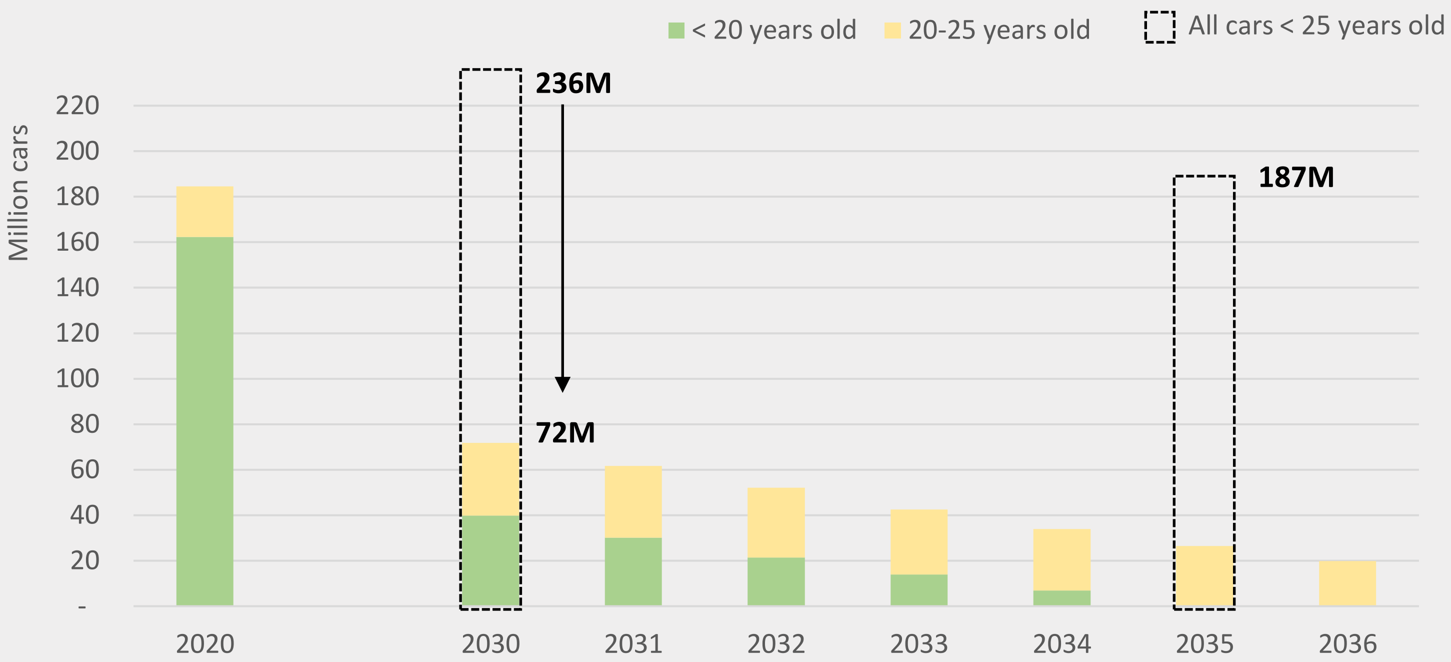
Step 2.3. Eligibility criteria: powertrain



The analysis of the fleet (using the aging matrix) shows that not retrofitting PHEVs and HEVs would have a significant impact on the size of the eligible fleet in 2030, which would increase in the following 15 years.

Step 2.4. Eligibility criteria: Mechatronics

Fossil cars registered before 2015



Sophisticated mechatronics systems have been more systematically integrated after 2015, which implies that most cars in the good age range for e-retrofit in 2030 and 2035 will be equipped with such systems.

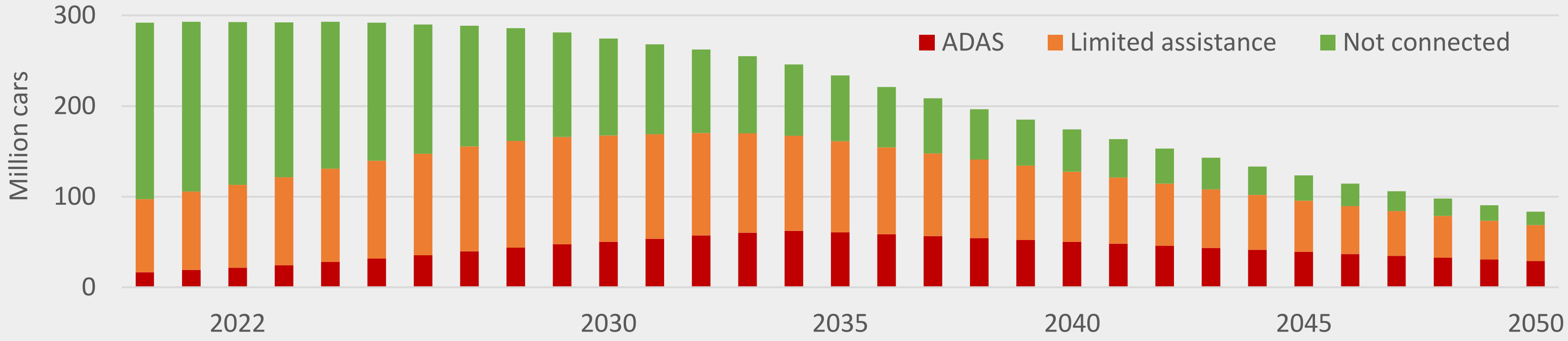
The chart shows that 70-80% of the cars produced before 2015 will be already retired or too old for e-retrofit in 2030, and the remaining pool quickly shrinks during the time window.

It makes dealing with mechatronics the single biggest technical hurdle for scaling-up e-retrofit.

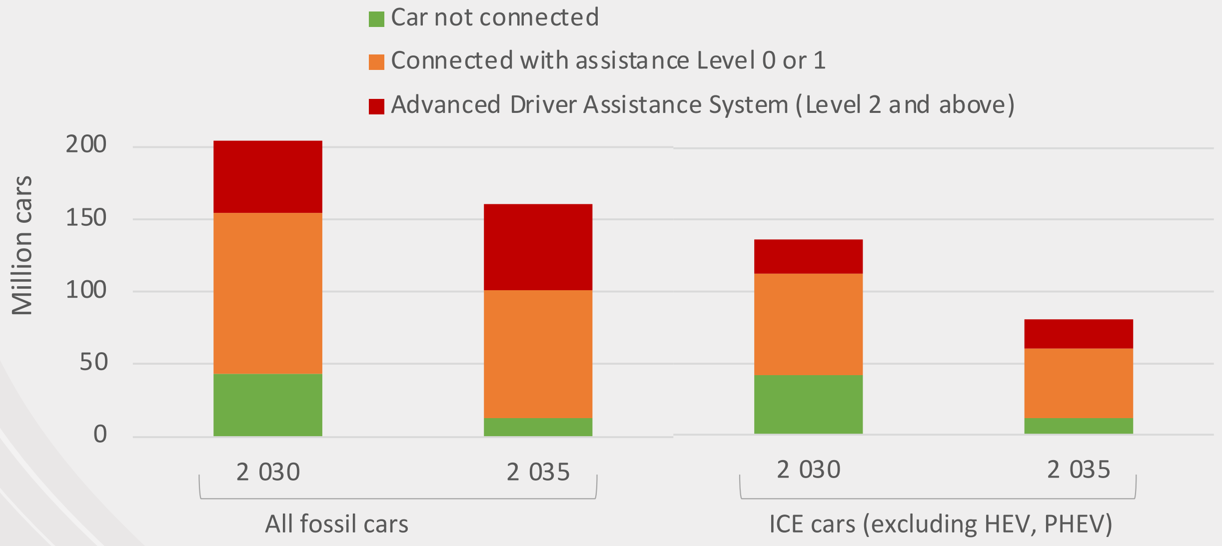
NB: The share of HEVs and PHEVs in the pool of cars manufactured before 2015 is negligeable.

Step 2.5. Eligibility criteria: ADAS

Onboard electronics equipment rate forecast (all cars in the fleet)



Fossil cars fleet <20 years old: sophistication of the onboard electronic system

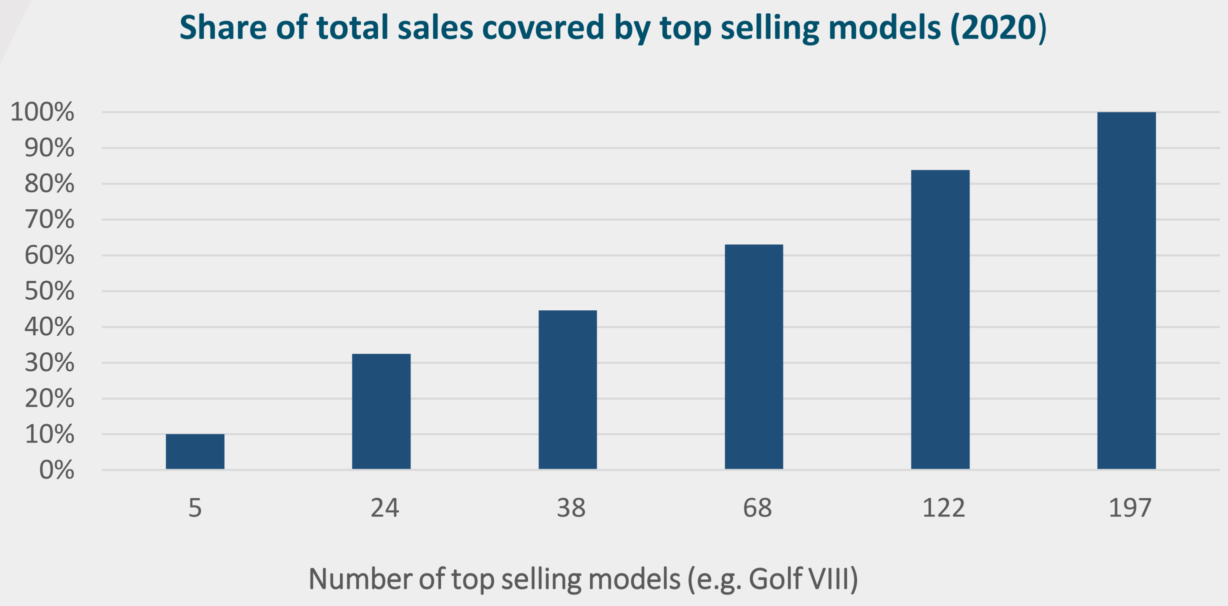


If the Mechatronics challenge is addressed, a subproblem will rise: ADAS.

A majority of car drivers tend to disable the first generation of assistance (level 1), to avoid being annoyed by alarms and signals, so it might not be a major obstacle. The issue is different for Level 2 and above. The problem is significant (about 50 million cars), but not as critical as the overall mechatronics retrofit challenge.

Source: Statista

Step 2.6.
Series size

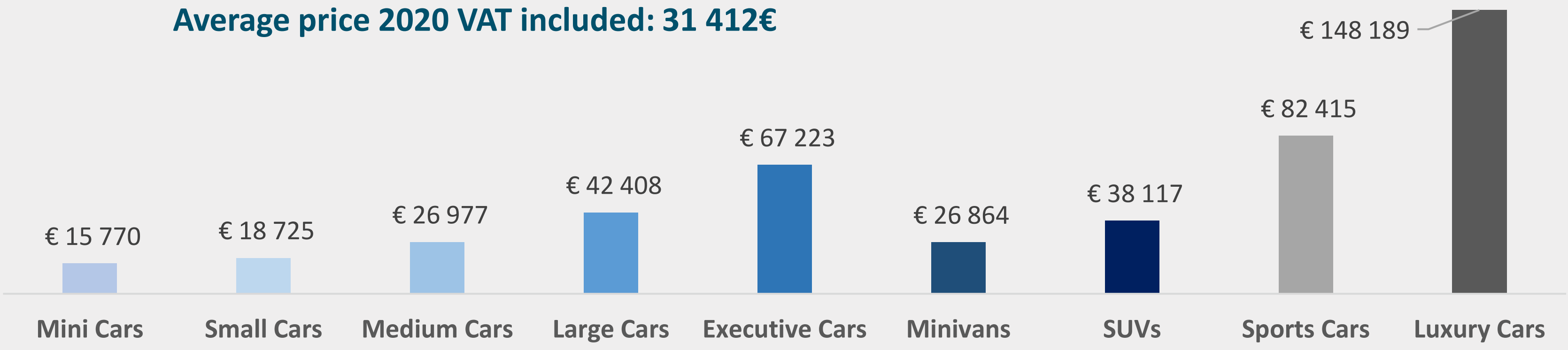


To limit the R&D investment required, especially in the early stages of deployment, e-retrofit manufacturers will likely only offer affordable retrofit for top selling models. A typical series e-retrofitter plan to introduce 6-8 models in the first batch and about 30 models in the following couple of years.

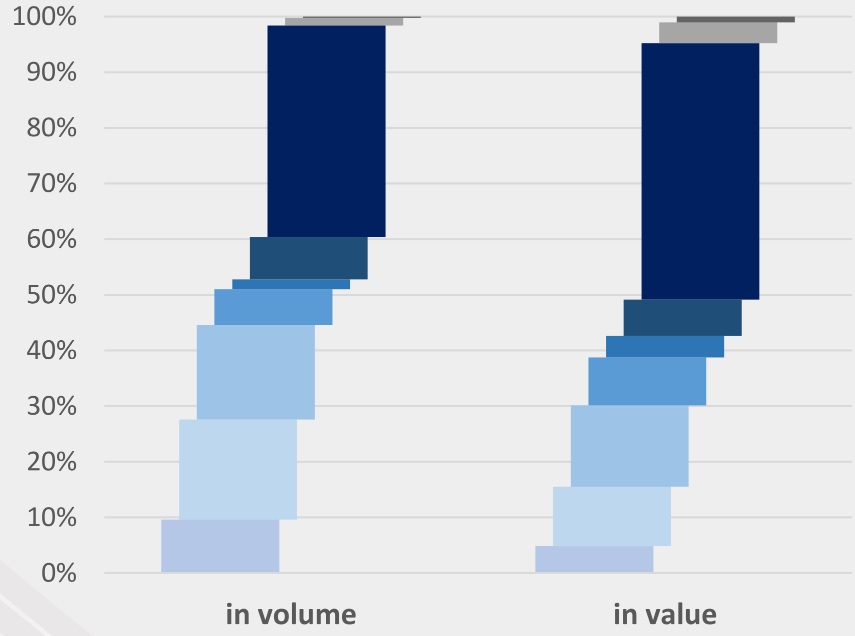
The chart is based on the analysis of the sales by model for January 2022 (source: ACEA).
NB: the analysis underestimates the potential for economies of scale, several models being built on the same platform, thus requiring an extension rather than a new approval.

Step 3: Residual value of donor cars

Average price 2020 VAT included: 31 412€



Market share by segment



The analysis for Step 3 starts with a calculation of the average price of a new car based on market data (Statista 2022) for the EU-27+UK+NO+CH market.

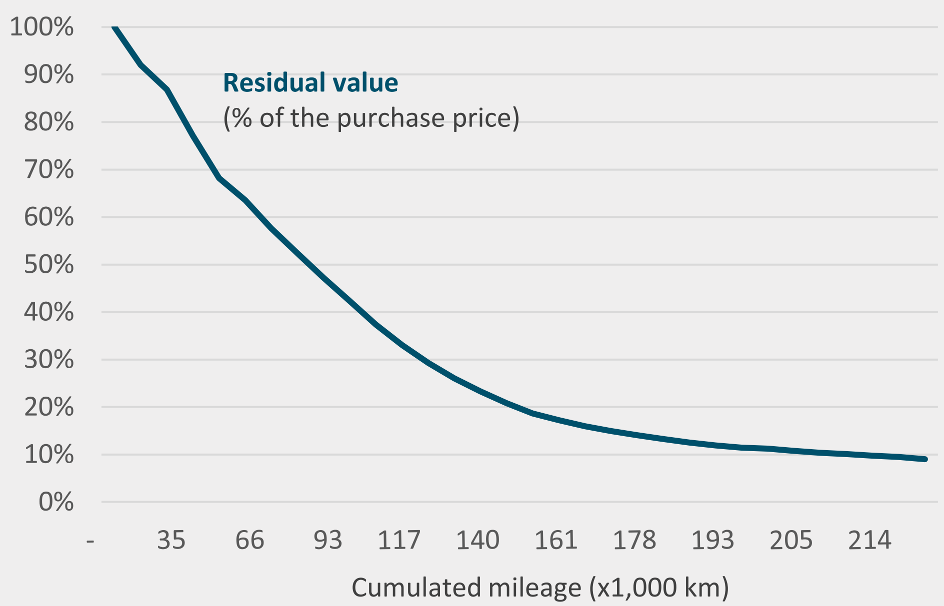
We assume a VAT rate of 20%.

We assume that the price of a new ICE car over the forecast period remains constant in $€_{2020}$.

Sources: Statista (2022)

Step 3: Residual value of donor cars

Default Depreciation curve - *assumption*



Most studies conclude that the residual value is primarily based on total mileage.

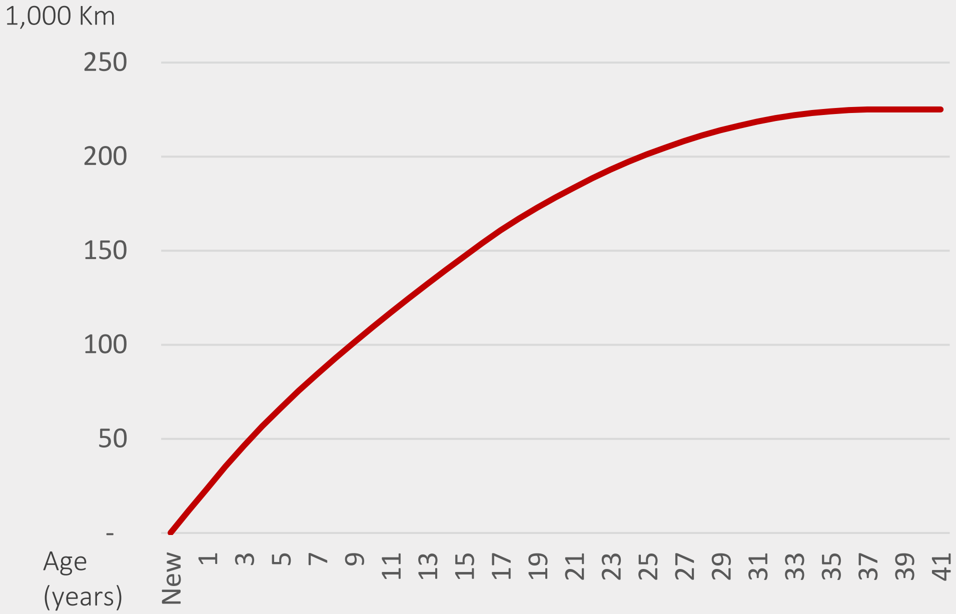
For our default curve, we have assumed a total cumulated mileage of **225,000 km** over the lifetime of the car. To ensure consistency of the results across the study, we have applied the assumption used by T&E in the life cycle analysis and in the calculation of average annual CO_2 emission per car (based on Ricardo, 2013).

For the first 220,000 km the annual depreciation rate is roughly aligned with the assumptions used in *"Study on the implications of EU policies for the affordability of car use in the future"* page 34 (Transport & Mobility Leuven Nov. 2022). The assumption is also informed by the results of the study *"Electric Cars: Calculating the Total Cost of Ownership for Consumers"* (BEUC, April 2021). We slightly adjusted the curve based on a review of depreciation per category on French (La Central) and German (ADAC) car websites, and recent studies of absolute residual values (Car Vertical).

Main sources: Transport & Mobility Leuven (2016), BEUC (2021)

Step 3: Residual value of donor cars

Average car's cumulated mileage *assumption* (all categories, Europe)

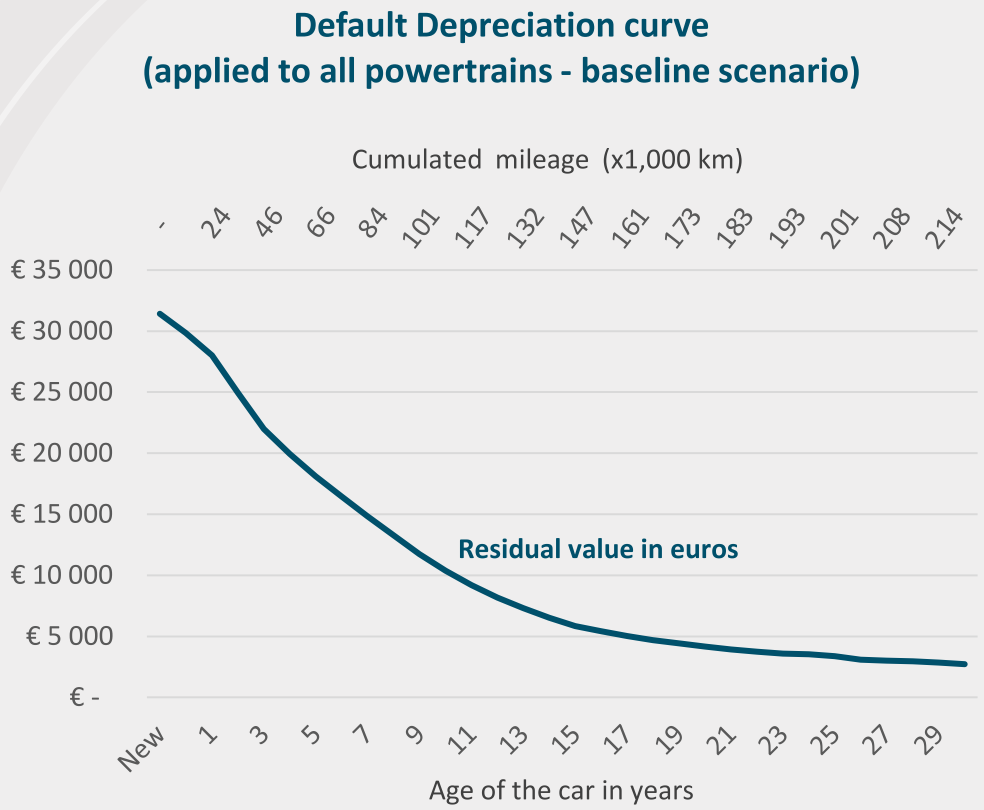


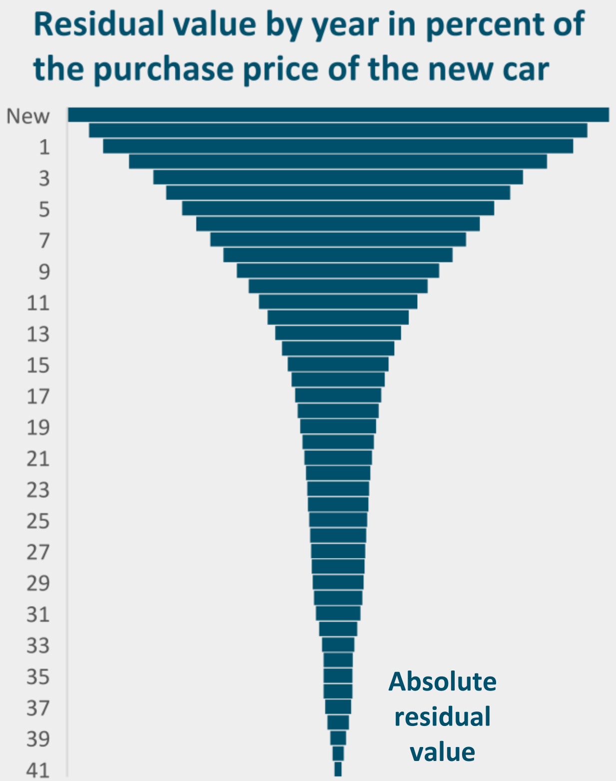
Most studies conclude that the residual value is primarily based on total mileage, while professional calculators factor mileage and age.

For our default curve, we assume 225,000 km over 40 years, with a decreasing annual mileage (illustrated by the flattening of the curve on the cumulated mileage chart).

The maximum age is derived from the cumulated survival probability from Held et al (2021), and the annual mileage is derived from Transport & Mobility Leuven 2022. It is to be noted that Transport & Mobility Leuven assumes an average 265,000 km cumulated mileage over a lifetime in their study of the used car market. However, studying old cars involves a "survival bias", a percentage of the cars being exported before the end of their lifetime and therefore reducing the average mileage of the fleet.

Source CSP: Lifespan of passenger cars in Europe: empirical modelling of fleet turnover dynamic (Held, 2021)





Step 3: Residual value of donor cars

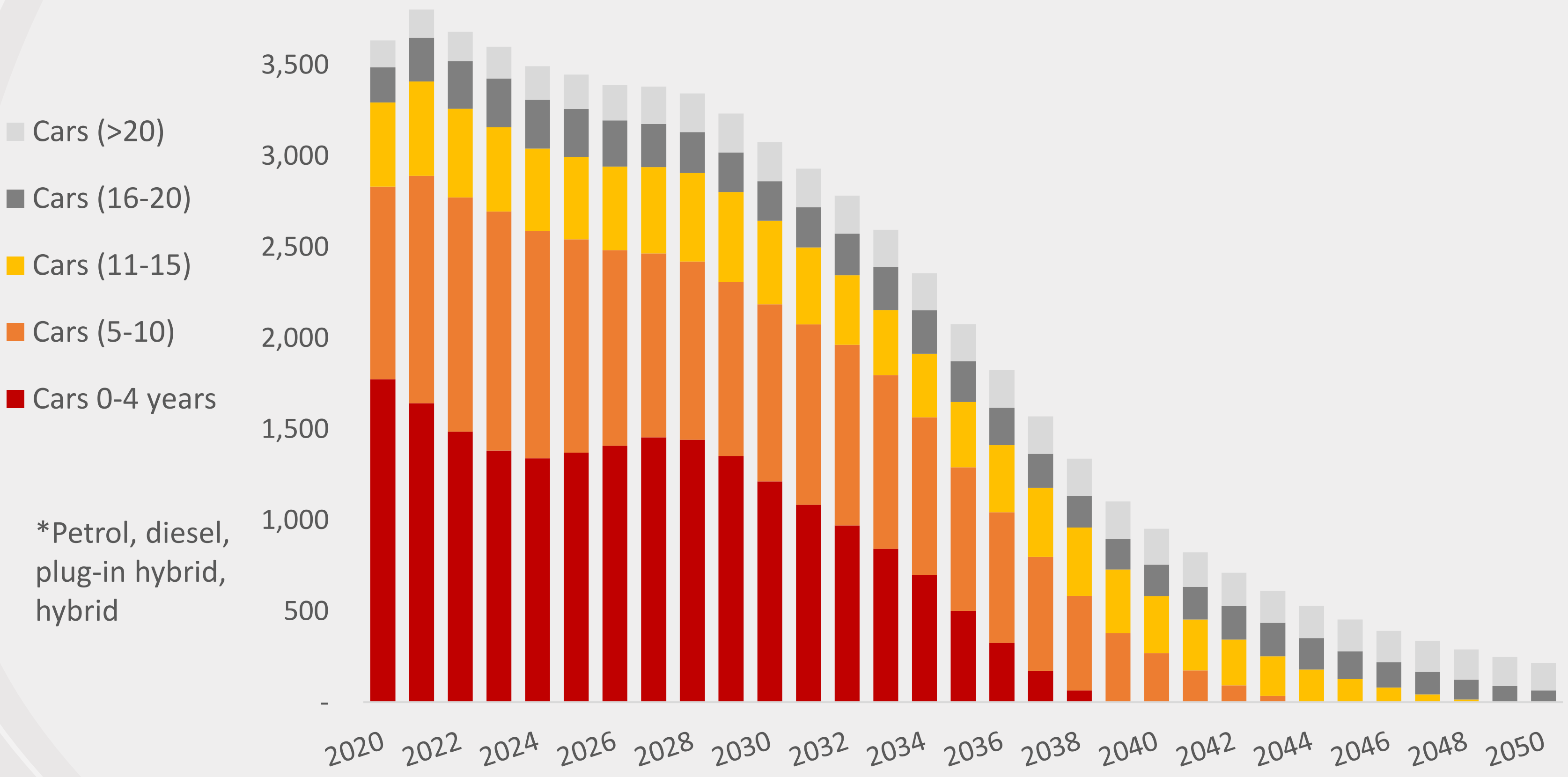
Based on the two figures above (depreciation based on mileage and mileage per age), the depreciation curve has been applied by age – which is the main unit used in our overall model.

After 25 years, we assume that the average annual mileage declines and the car reaches its absolute residual value (between 5 and *33%* of the original price depending on the brand and category, according to CarVertical), declining slowly from 10% to 1.5% over 15 years.

After 40 years, we assume that the car reaches its “scrapping” value which 1.5% of the original price on average, or 50€ to 500€ depending on the car category.

Step 3: Residual value of the donor cars fleet

Residual value of the fossil fleet* in billion euros, by age category



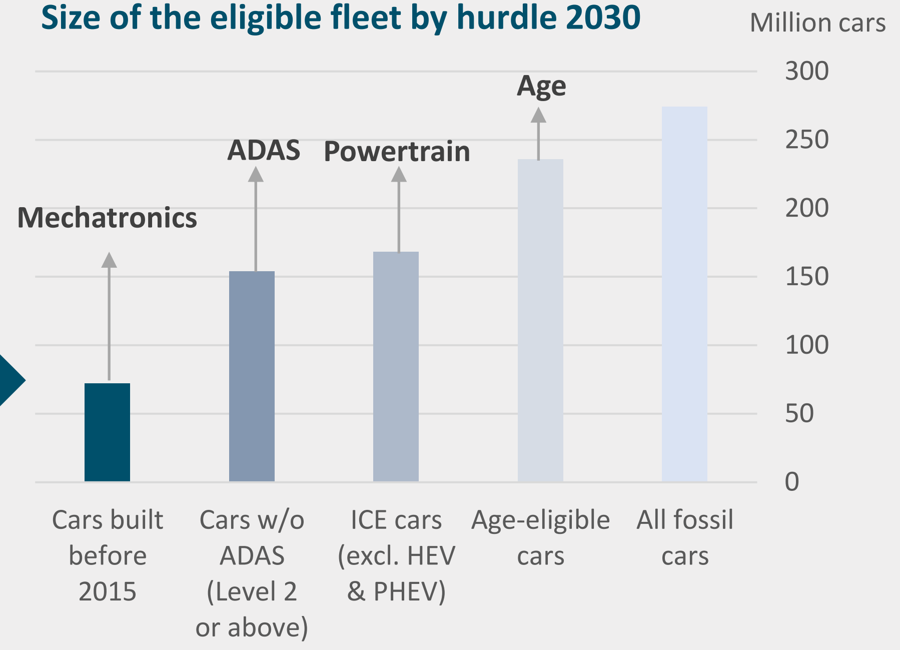
*Petrol, diesel, plug-in hybrid, hybrid

Based on the application of the above-described default depreciation curve, the fossil fleet will still be worth €2tn when the 1.5°C carbon budget will be exhausted (2033 to 2035)

The comparison of the different technical hurdles shows that the top first challenge for e-retrofitters is to demonstrate the applicability to more recent cars equipped with more complex mechatronics.

If this challenge is not addressed, the number of cars eligible for retrofit will be limited to 60 million cars in 2030.

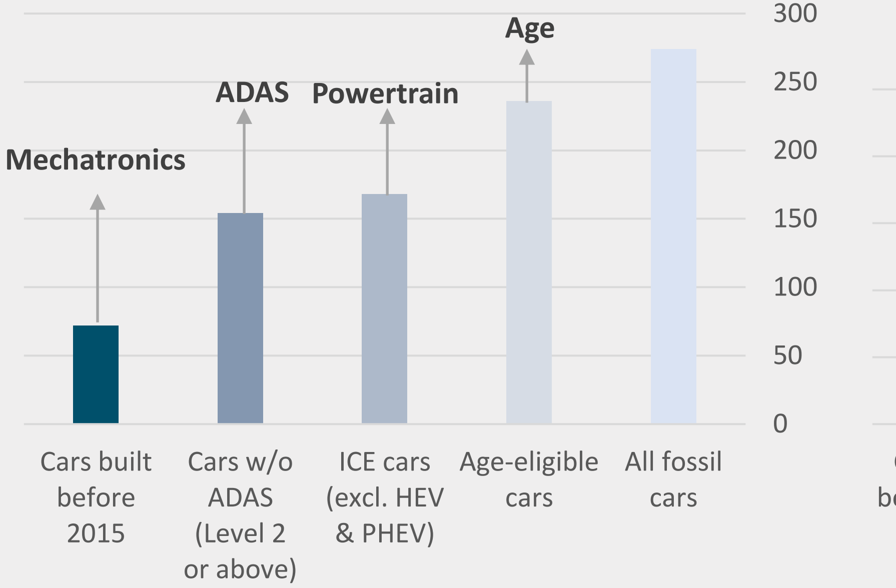
Size of the eligible fleet by hurdle 2030



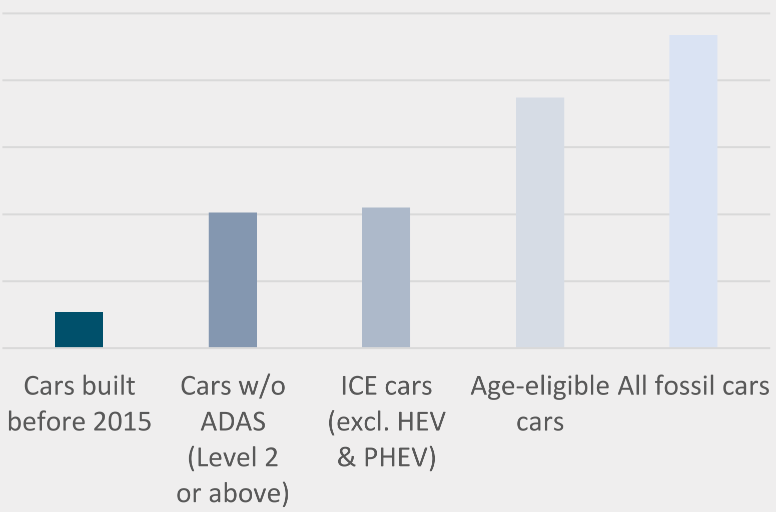
If the mechatronics challenge is addressed, e-retrofit companies will then have to solve the difficulties related to ADAS and hybridization. Finally, the eligible fleet can be slightly increased by finding a way to extend the lifetime of very old cars (>25 years) during the retrofit process.

Step 4: Summary of technical hurdles

Size of the eligible fleet by hurdle 2030



Size of the eligible fleet in 2035 assuming no early retirement



The size of the fleet eligible to e-retrofit is time sensitive: in just five years (2030-35), it will be reduced significantly due to aging.

Step 4: Summary of technical hurdles

Starting price

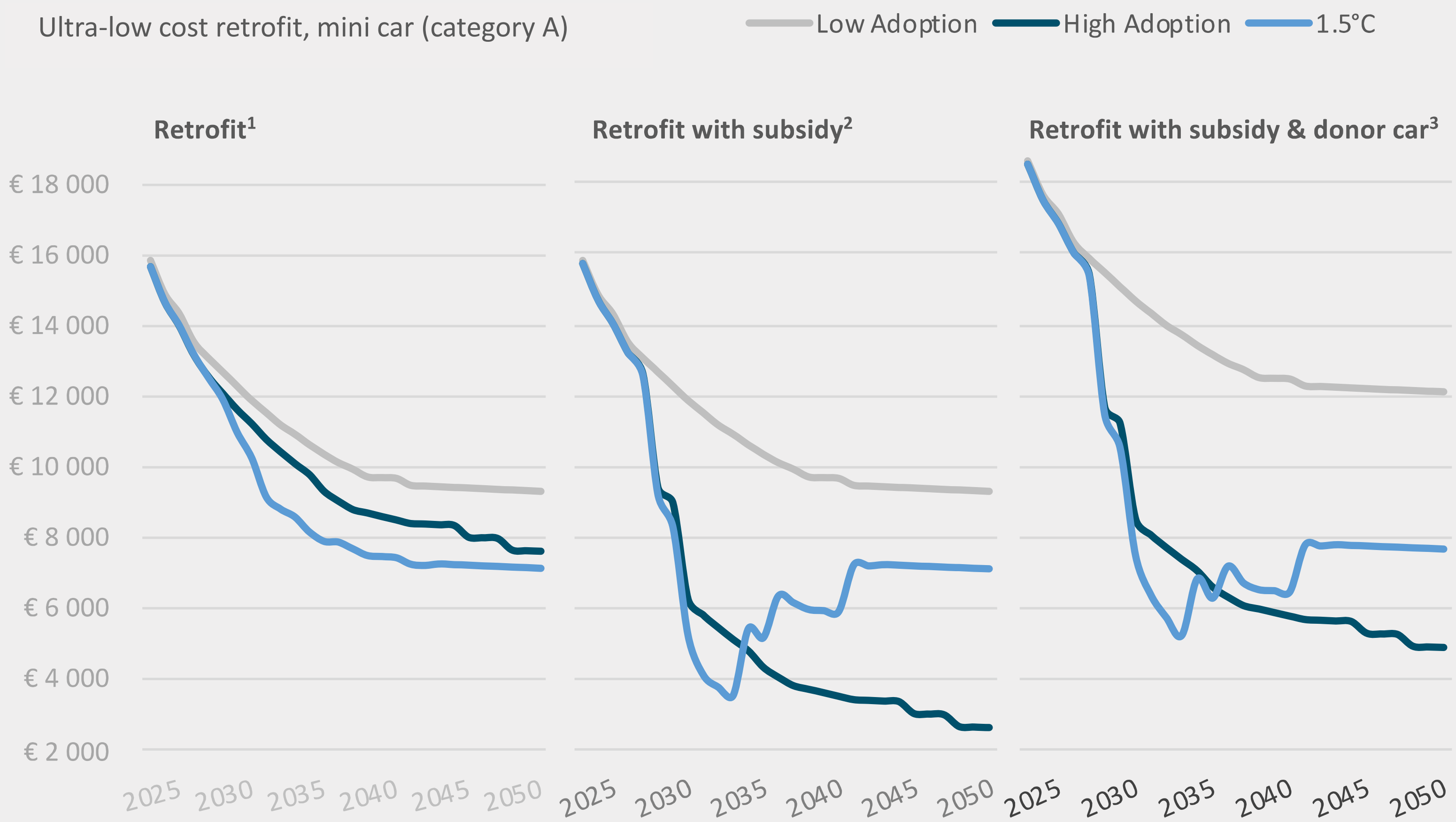
Evolution of the starting retail prices across scenarios

Ultra-low cost retrofit, with 16 kWh battery, for a 15-year-old mini car (category A)

Date	Scenario	Retrofit (Kit, battery, installation)		Retrofitted car (donor car included)	
		Without subsidy	*With subsidy*	*Without subsidy*	*With subsidy*
2023	**Baseline**	**€15,700**	**-**	**€18,500**	**-**
2030	Low adoption	€11,900	-	€14,700	-
	High adoption	€11,300	€6,248	€13,500	€8,500
	1.5°C scenario	€10,300	€5,251	€12,500	€7,500
2035	Low adoption	€10,400	-	€13,200	-
	High adoption	€9,400	€4,400	€11,600	€6,600
	1.5°C scenario	€7,900	€5,200	€9,000	€6,300
2050	Low adoption	€9,300	-	€12,100	-
	High adoption	€7,600	€2,600	€9,900	€4,900
	1.5°C scenario	€7,100	€7,100	€7,700	€7,700

Starting price

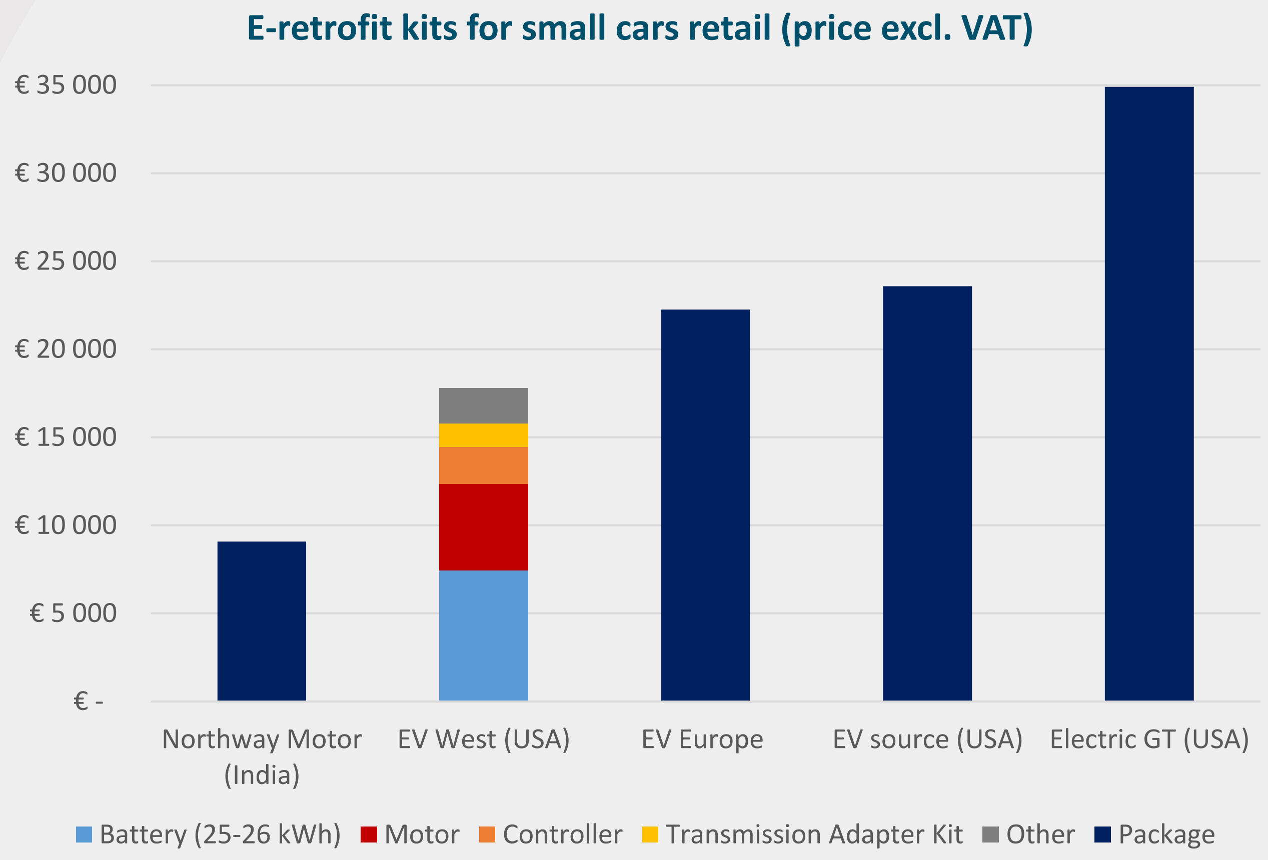
Evolution of the starting retail prices across scenarios



(1) Kit, 16 kWh battery, Installation, VAT (2) Level of subsidies changes by scenario (3) 15-year-old donor car

The rise observed in the light blue price curve (1.5°C scenario) in 2035 correspond to a reduction of subsidies. At this date, the necessary stock of affordable used EVs is already built and remaining fossil cars approach their mandatory expiration date.

Starting point:
a) Public data on e-retrofit kit prices



The public retail prices for generic e-retrofit kits (excluding installation cost) range from €9 000 to €35 000 for a small car with a 25-26 kWh battery.

Source: e-retrofit retailers public prices (websites, Dec 2022)

New BEV
Used BEV
E-retrofited car

Starting point: b) public data on e-retrofitted cars prices

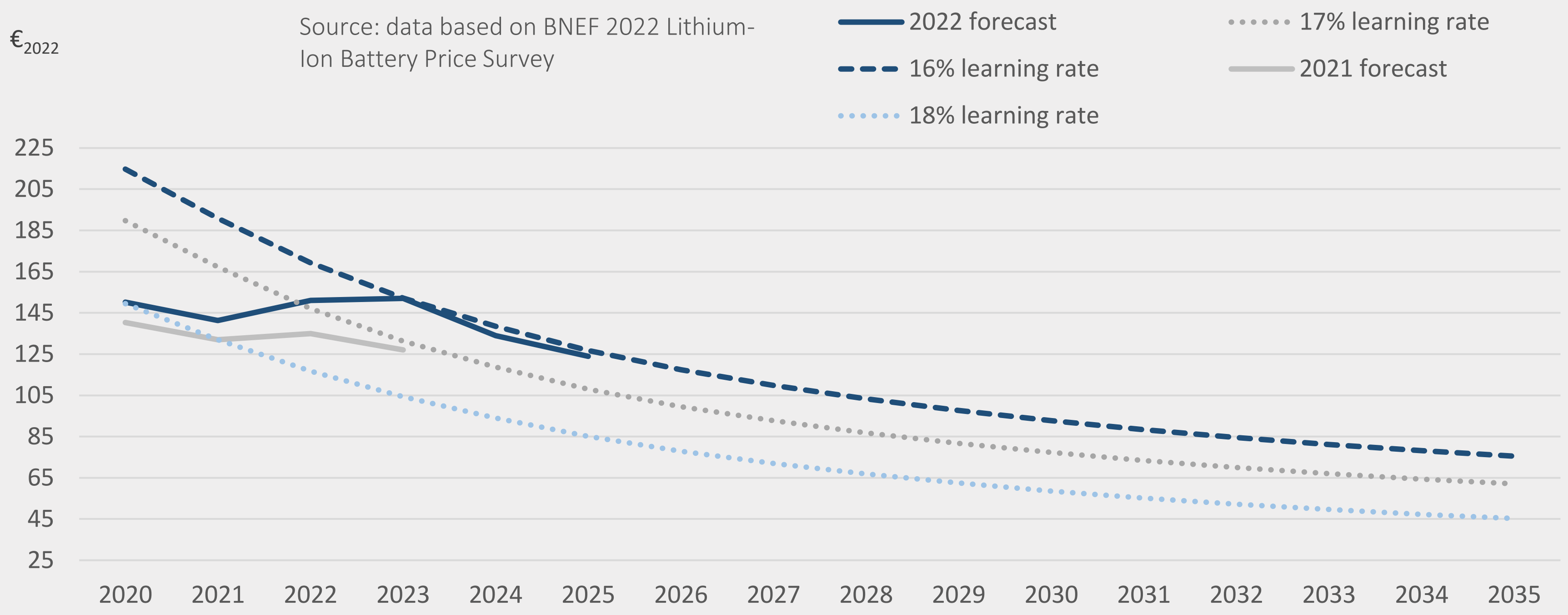
Approach: comparing e-retrofit passenger cars available for sale with the cheapest new and used EVs comparable.

Sources: Manufacturers websites, la Centrale (France) for used cars, EV-database.org for maximum range. Dec 2022.

Segment	Model	Price (incl. VAT)	
Mini (A)	Dacia Spring 27 kWh (new)	€	20 800
	FreZe Nikrob (new)	€	16 000
	Twingo Electric 22 kWh (new)	€	25 250
	Peugeot Ion 2013 16 kWh (75000km)	€	6 700
	Vintage Mini 20 kWh Retrofuture	€	22 000
	Twingo 2 16 kWh (Transition One), base Twingo 2 2012	€	17 833
Small (B)	New Energy Mobility JAC iEV7s	€	29 500
	Fiat 500e	€	29 500
	Fiat 500e 2021 (100 000 km)	€	20 592
	Renault Zoe 26 kWh 2013 (100 000 km)	€	7 200
	Citroen 2CV (R-Fit) 10 kWh	€	21 400
	FIat 500 15 kWh (Transition One), Base Fiat 500 2012 (100 000 km)	€	18 800
Medium (C)	MG G4 2022 51 kWh (new)	€	29 000
	Nissan Leaf 40 kWh (new)	€	37 000
	Nissan Leaf 2013 24 kWh (10000km)	€	9 219
	Renault Kangooo 2 Express 15 kWh (Transition One) base 100 000km	€	18 445
	Renault Kangooo Express 34 kWh (REV) base 100 000km	€	32 445
Medium SUV (JC)	Renault Megane E-Tech 40 kWh (new)	€	39 300
	Mazda MX-30 30 kWh (new)	€	37 500
	Land Rover Defender 40 kWh (Retrofuture)	€	57 000
	Land Rover Series III 100 kWh (London Electric cars)	€	196 000
Large Sedan (D)	Hyundai IONIQ 6 Standard Range 2WD	€	52 200
	Tesla Model 3 60 kWh 2022 (new)	€	53 390
	Tesla Model 3 52 kWh 2018 (100 000km)	€	44 542
	Tesla Model S 60 kWh 2013 (100 000km)	€	36 400
	Peugeot 505 35 kWh (Retrofuture)	€	37 000
	Jaguar 50 kWh (Retrofuture)	€	53 000
Large SUV/Minivan	Tesla Model Y 60 kWh 2022 (new)	€	50 000
	Mustang Mach E (New)	€	61 700
	Combi VW (Retrofuture)	€	34 000
	Range Rover 40 kWh (Retrofuture)	€	60 000
	Range Rover 50 kWh (Retrofuture)	€	66 000

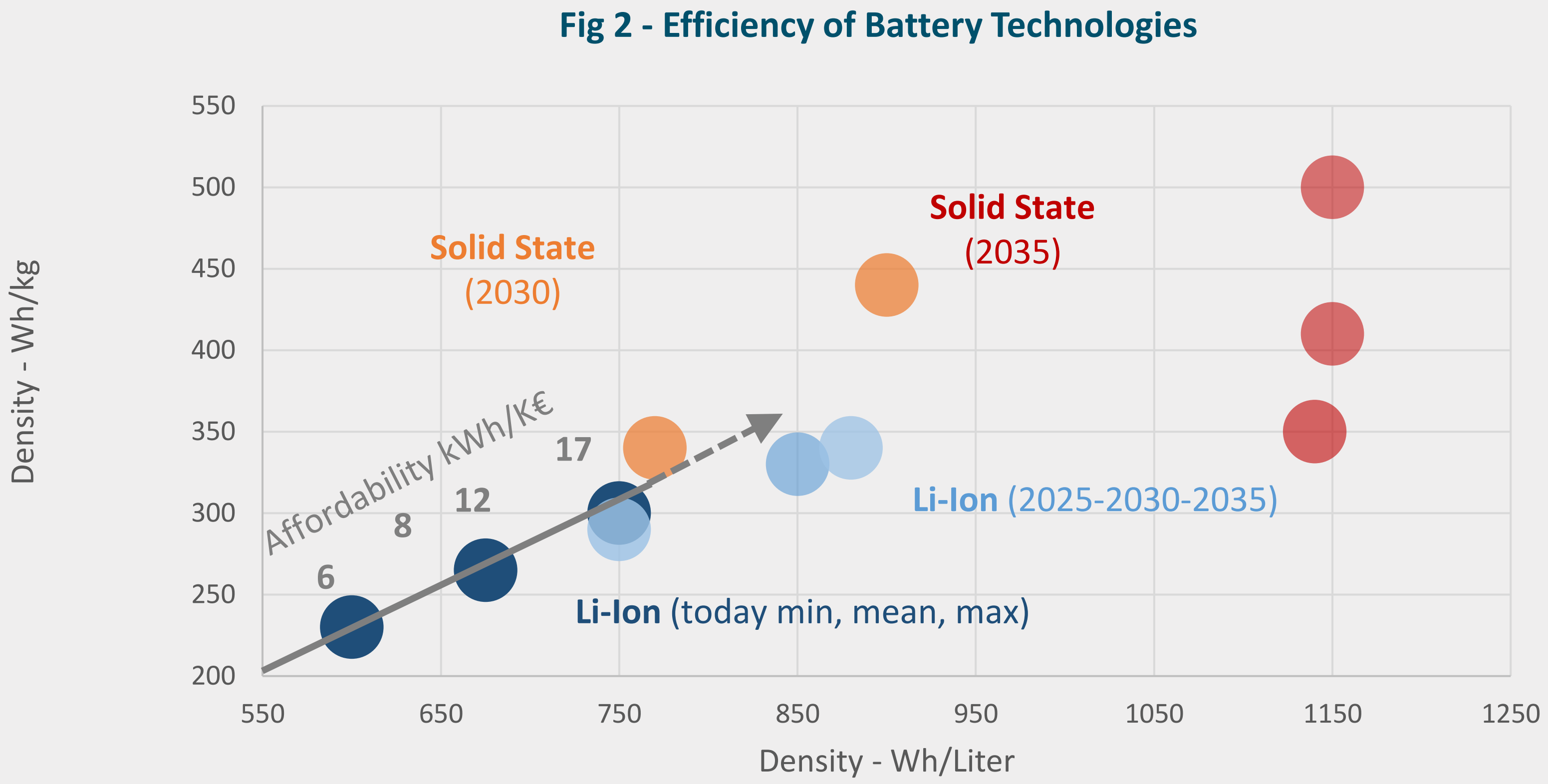
Starting point:
c) Battery pack price and efficiency forecast

Fig 1 - Bloomberg NEF battery pack prices forecast & scenarios



Sources: Bloomberg/NEF 2021/2022

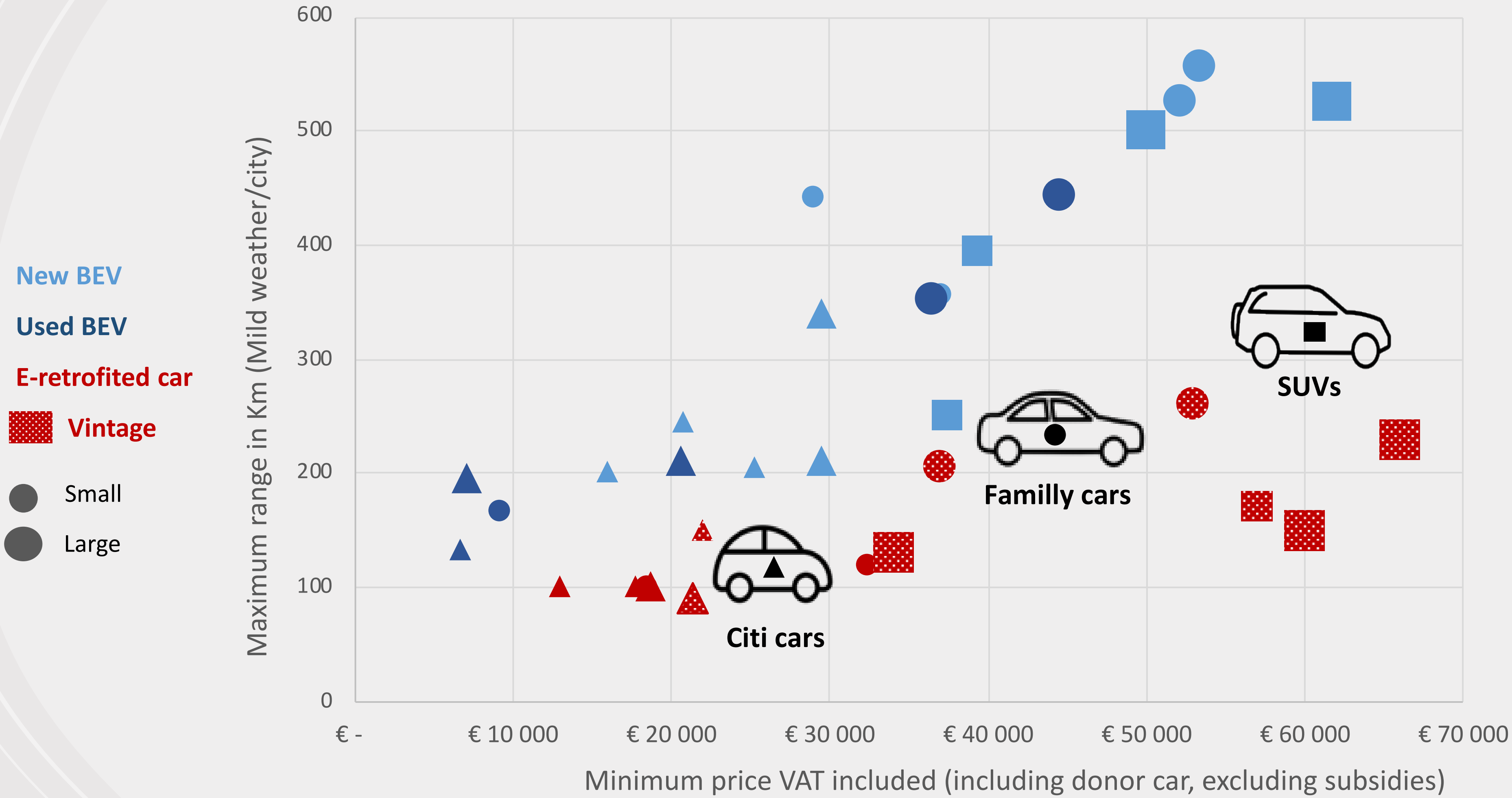
Starting point:
c) Battery pack price and efficiency forecast



Sources: Fraunhofer 2022

Step 1: Competitiveness of e-retrofitted passenger cars today

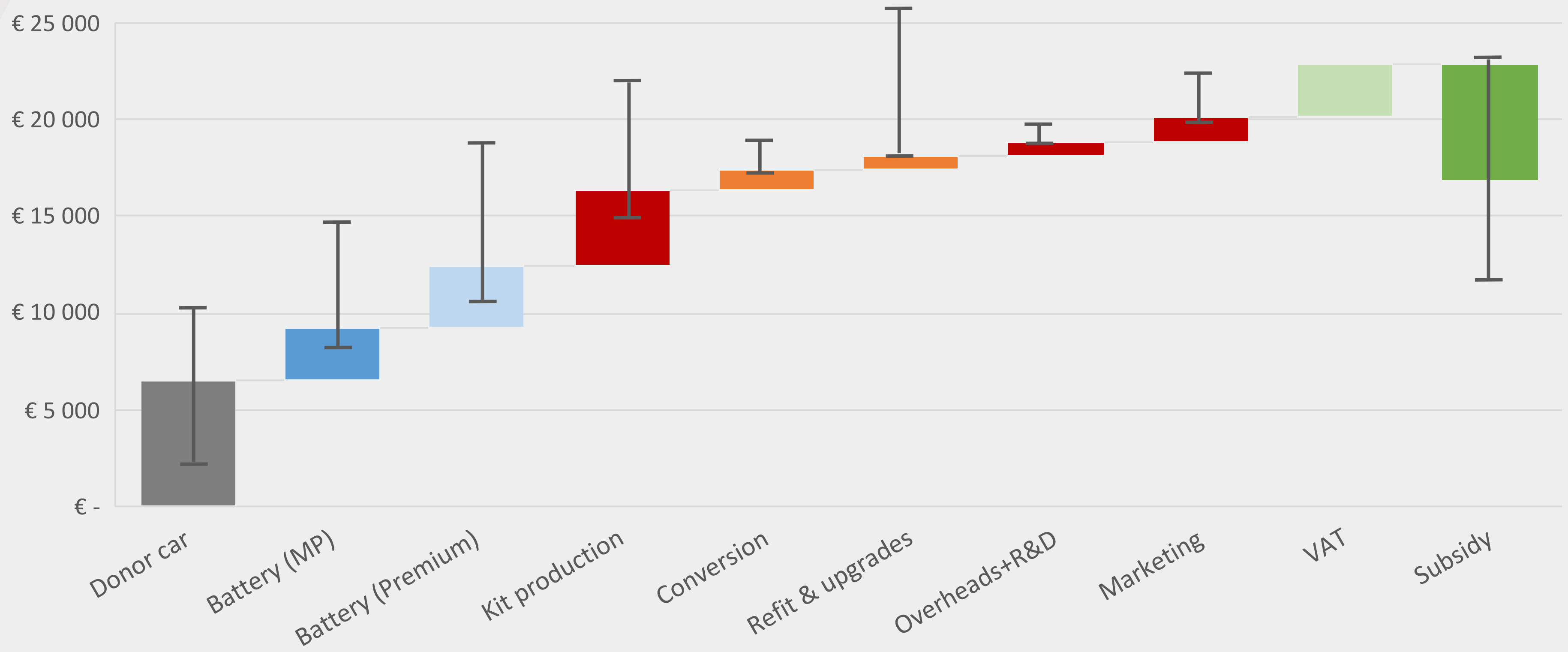
Fig 3. Price vs range comparison for a selection of cars



Today, e-retrofitted cars are more expensive and have a lower range than used EVs and many new EVs for every category of passenger car

Step 2: Analyzing the cost structure of e-retrofit today

Fig 4. Cost structure of series low cost e-retrofit (10-year-old small car, 20 kWh battery, excl. financing)



Sources: Algoé 2020 study for France, interviews with manufacturers, public prices.

The baseline assumption corresponds to a retrofitted car sold €16,000 and factors economies of scale compared to current public prices. The estimates for a small car range from €10,000 to €30,000, depending on the sophistication and complexity of the retrofit and economies of scale factored in the calculation.

Model for simulating the evolution of price and range of a selection of cars

We assume that the battery capacity will increase with lower prices and higher energy density. Scenarios based on Fig 1 and Fig 2 data

Comparable cars in each category

New BEV
Used BEV
E-retrofited

Category	Share	Car	Size battery (kWh) Today	Size battery (kWh) Scenario	Range (Km) Today	Range (Km) Scenario	Battery cost (€2023) Today	Battery cost (€2023) Scenario
Mini (A)		FreZe Nikrob	14	15	200	201	€ 1 967	€ 916,0
		Dacia Spring	27	29	245	246	€ 3 849	€ 1 792,1
	10%	Renault Twingo	22	24	205	206	€ 3 136	€ 1 460,2
		FreZe Nikrob (new)	14	14	190	175	€ 1 967	€ 840,3
	5%	Dacia Spring	27	27	233	214	€ 3 849	€ 1 644,1
		Renault Twingo	22	22	195	179	€ 3 136	€ 1 339,7
		Citroen C1 (entry)	16	16	110	101	€ 5 702	€ 1 267
		Renault Twingo (premium)	18	18	140	129	€ 6 414	€ 1 425
Small (B)		JAC iEV7s	43,5	47	340	341	€ 6 200	€ 2 887,3
	23%	Fiat 500e	24	26	210	211	€ 3 421	€ 1 593,0
	11%	JAC iEV7s	44	44	323	297	€ 6 200	€ 2 648,9
		Fiat 500e	24	24	200	184	€ 3 421	€ 1 461,5
		Clio (entry)	16	16	100	92	€ 5 702	€ 1 267
		Fiat 500 (premium)	20	20	135	124	€ 7 127	€ 1 583
Mid Size (C)		MG G4	51	56	442	443	€ 7 269	€ 3 385,1
	24%	Mazda MX-30 (SUV)	40	44	250	251	€ 5 702	€ 2 655,0
	14%	MG G4	51	51	420	386	€ 7 269	€ 3 105,6
		Mazda MX-30	40	40	238	219	€ 5 702	€ 2 435,8
		Nissan Juke (entry)	20	20	90	83	€ 7 127	€ 1 583
		Renault Kangoo (larger)	34	34	130	120	€ 12 116	€ 2 692
Large Size (D)		Tesla Model 3 60 kWh	60	65	555	557	€ 8 552	€ 3 982,5
	43%	Mustang Match E (SUV)	75	82	525	526	€ 10 690	€ 4 978,1
	64%	Tesla Model 3 60 kWh	60	60	527	485	€ 8 552	€ 3 653,6
		Mustang Match E	75	75	499	459	€ 10 690	€ 4 567,1
		Peugeot 508 (sedan)	40	40	180	166	€ 14 254	€ 3 166
		Citroen C4 space tourer (mini van)	50	50	230	212	€ 17 817	€ 3 958

Share of EU 2023 (9 years) sales in Value and Volume (source: Statista)

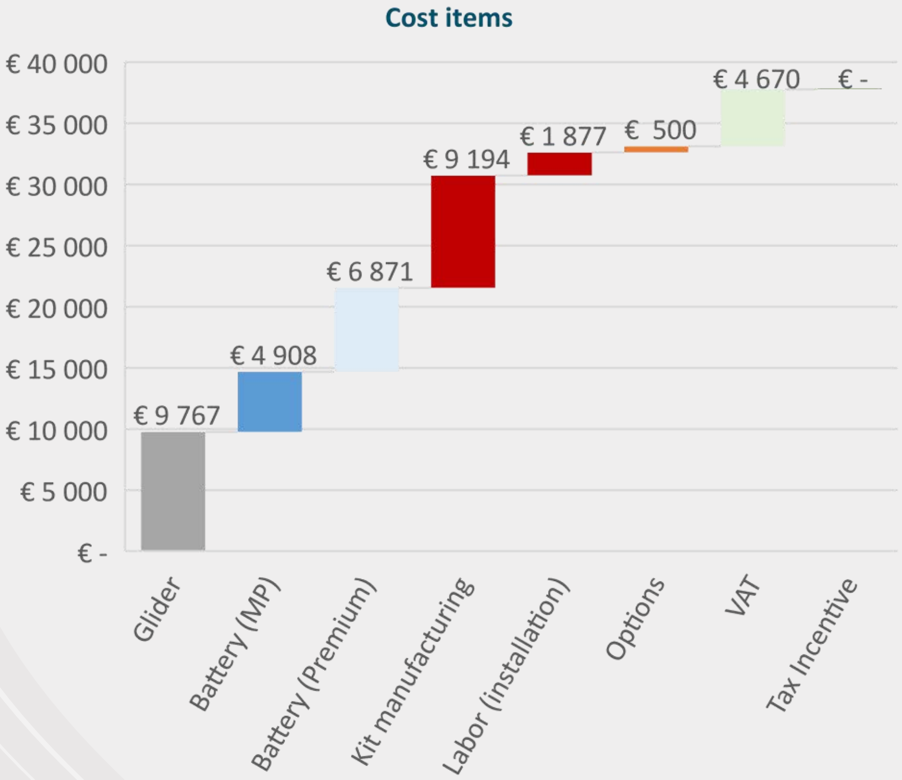
Step 3:
Cost scenario analysis/Model

Cost optimization simulation module for e-retrofit operations

	Year
Baseline	2021
Scenario	2030

Cost simulation

For each item of the cost structure, the model simulates the evolution over time.



Cost of e-retrofit					
Glider	Battery	Kit	Labor	Options	Tax incentive
9767	3470	8120	1877	500	0

Average

Weight in the average

Mini

6804	1623	5144	1700	500	0
7144	1826	5144	1700	500	0
10%		7344			

Small

6547	1623	5658	1700	500	0
7124	2029	5658	1700	500	0
19%		7858			0

Mid-size

10373	2029	7201	1840	500	0
9712	3450	7201	1840	500	0
16%		8086			0

Large

13493	4059	9773	1980	500	0
8904	5073	9773	1980	500	0
55%		10330			0

The weighted average price is calculated based on the market share of each category

Step 3: Cost scenario analysis/Settings

Cost optimization simulation module for e-retrofit operations

	Year
Baseline	2021
Scenario	2030

Scenario parameters

Cost simulation

Donor ICE age
10

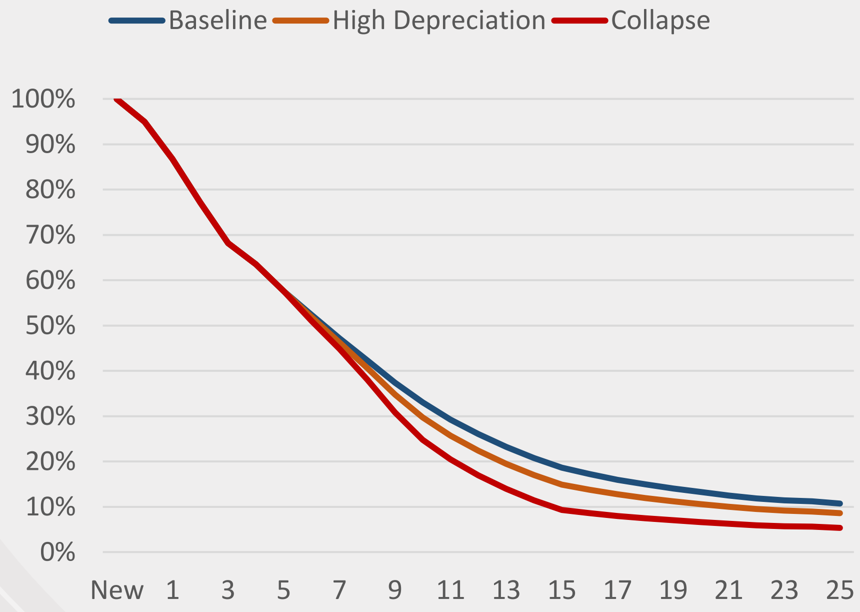
Residual value maximal correction	
Baseline	-0%
High Depreciation	-20%
Collapse	-80%

Glider	Cost of e-retrofit Battery	Kit	Labor	Options	Tax incentive
9767	3470	8120	1877	500	0
Average					

Weight in the average

Mini					
6804	1623	5144	1700	500	0
7144	1826	5144	1700	500	0
10%		7344			
Small					
6547	1623	5658	1700	500	0
7124	2029	5658	1700	500	0
19%		7858			0
Mid-size					
10373	2029	7201	1840	500	0
9712	3450	7201	1840	500	0
16%		8086			0
Large					
13493	4059	9773	1980	500	0
8904	5073	9773	1980	500	0
55%		10330			0

Variable: residual value of donor cars



Step 3: Cost scenario analysis/Settings

To determine the glider's price, the donor's typical age and the depreciation scenario for ICE cars can be adjusted. By default, the standard depreciation rate is applied.

Cost optimization simulation module for e-retrofit operations

	Year
Baseline	2021
Scenario	2030

Scenario parameters

Cost simulation

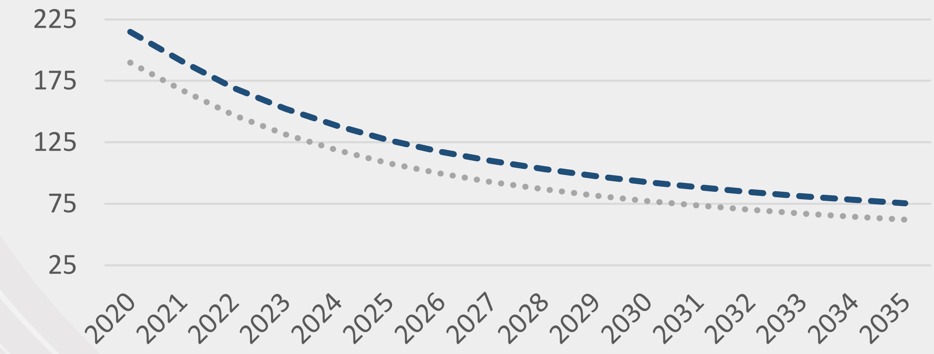
Battery pack price scenario €/kWh (Fig 5)

Optimistic BNEF 2022 forecast

Price in the selected scenario (Battery pack per kWh)

	Year	Market price/kWh	E-retrofiter price/KWh	Premium paid
Baseline	2021	€ 127	€ 357	€ 230
Scenario	2030	€ 69	€ 167	€ 97

Battery pack prices scenarios (€/kWh)



	Cost of e-retrofit					
	Glider	Battery	Kit	Labor	Options	Tax incentive
	9767	3470	8120	1877	500	0
	Average					
Weight in the average						
Mini						
	6804	1623	5144	1700	500	0
	7144	1826	5144	1700	500	0
	10%		7344			
Small						
	6547	1623	5658	1700	500	0
	7124	2029	5658	1700	500	0
	19%		7858			0
Mid-size						
	10373	2029	7201	1840	500	0
	9712	3450	7201	1840	500	0
	16%		8086			0
Large						
	13493	4059	9773	1980	500	0
	8904	5073	9773	1980	500	0
	55%		10330			0

Step 3: Cost scenario analysis/Settings

The market price of the batteries drops (for new EVs and e-retrofit) in line with BNEF 2022 forecast, with two options: "optimistic" = 17% learning rate), "pessimistic" (= 16% learning rate).

Step 3: Cost scenario analysis/Settings

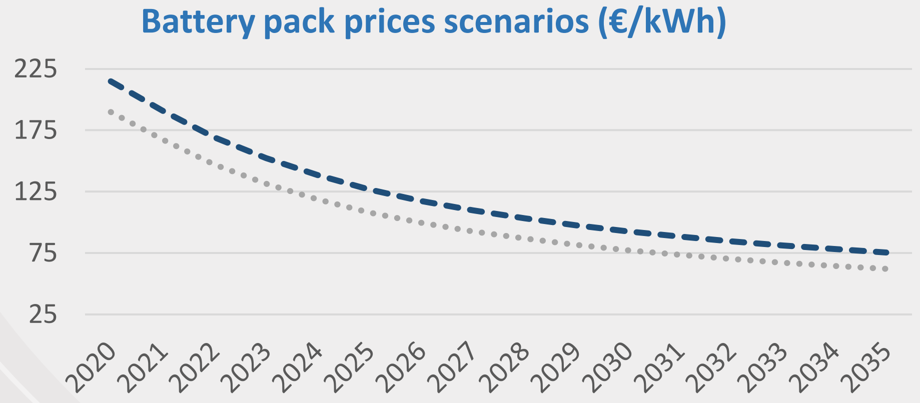
The premium paid by manufacturers on top of the average market price drops with the volume of cars retrofitted, which scale up at different speed in different scenarios.

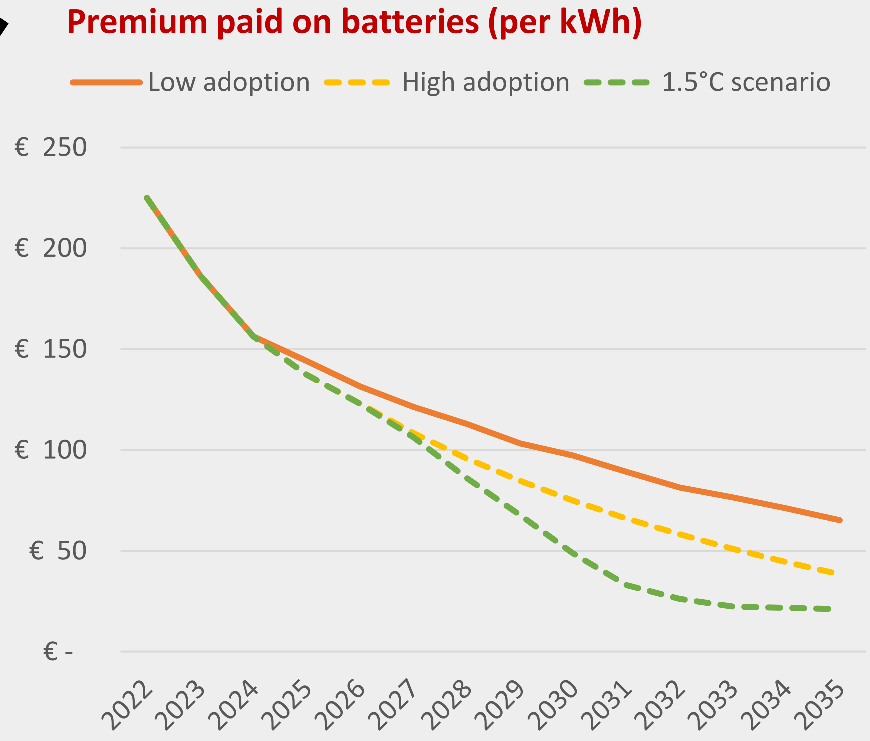
Battery pack price scenario €/kWh (Fig 5)

Optimistic BNEF 2022 forecast

Price in the selected scenario (Battery pack per kWh)

	Year	Market price/kWh	E-retrofiter price/KWh	Premium paid
Baseline	2021	€ 127	€ 357	€ 230
Scenario	2030	€ 69	€ 167	€ 97





Cost optimization simulation module for e-retrofit operations

Step 3: Cost scenario analysis/Settings

Scenario parameters

COST OF E-RETROFIT

Retrofit standards	Ultra-Low cost
Average cost labor	€ 58,2
Cost efficiency: kit	12%

	Kit	Labor	Options
Ultra-Low cost	100%	0	0
Low-cost	100%	€ 861	€ 200
Premium	100%	€ 2 044	€ 400

	Kit	Basic Labor
Mini	€ 5 079	€ 2 152
Small	€ 5 587	€ 2 152
Mid-Size	€ 7 111	€ 2 384
Large	€ 9 650	€ 2 453

excl VAT

Cost simulation

Weight in the average

	Glider	Battery	Cost of e-retrofit: Kit	Labor	Options	Tax incentive
Average	9767	3470	8120	1877	500	0
Mini						
	6804	1623	5144	1700	500	0
	7144	1826	5144	1700	500	0
	10%		7344			
Small						
	6547	1623	5658	1700	500	0
	7124	2029	5658	1700	500	0
	19%		7858			0
Mid-size						
	10373	2029	7201	1840	500	0
	9712	3450	7201	1840	500	0
	16%		8086			0
Large						
	13493	4059	9773	1980	500	0
	8904	5073	9773	1980	500	0
	55%		10330			0

Gains in efficiency for the selected scenario are applied to the cost of manufacturing ("Kit") and installing it ("Labor").

Scenario parameters

COST OF E-RETROFIT

Retrofit standards Ultra-Low cost

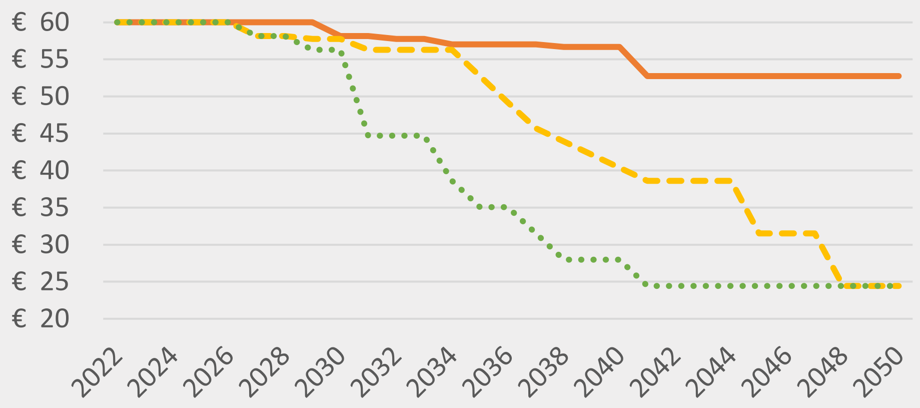
Average cost labor € 58,2

Cost efficiency: kit 12%

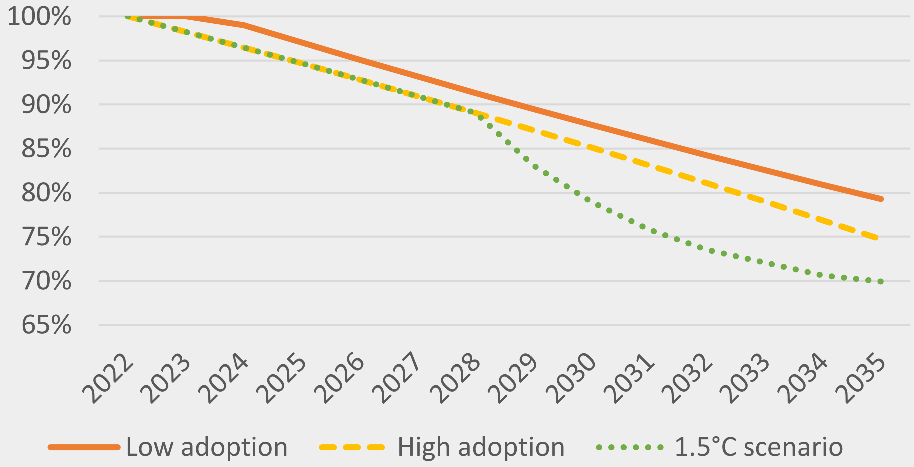
	Kit	Labor	Options
Ultra-Low cost	100%	0	0
Low-cost	100%	€ 861	€ 200
Premium	100%	€ 2 044	€ 400

	Kit	Basic Labor
Mini	€ 5 079	€ 2 152
Small	€ 5 587	€ 2 152
Mid-Size	€ 7 111	€ 2 384
Large	€ 9 650	€ 2 453
	excl VAT	

Average hourly LABOR cost for installation



Manufacturing cost of e-retrofit KIT



Step 3:
Cost scenario analysis/Settings

Cost optimization simulation module for e-retrofit operations

Step 3:
Cost scenario analysis/Settings

Tax incentives that benefit new EVs, used EVs and e-retrofit equally do not affect their relative competitiveness and are not reflected in the model.

In the default settings, there is no additional tax incentive for e-retrofit.

Two levels of "LCA-based" incentives can be added. They mirror the reduction of external costs associated with e-retrofit due to lower lifecycle emissions.

The "just transition" level also reflects an additional subsidy to support low-income households' transition to electric mobility.

Cost simulation

		Cost of e-retrofit			
Glider	Battery	Kit	Labor	Options	Tax incentive
9767	3470	8120	1877	500	0
Average					
6804	1623	5144	1700	500	0
7144	1826	5144	1700	500	0
10%		7344			
6547	1623	5658	1700	500	0
7124	2029	5658	1700	500	0
19%		7858			0
10373	2029	7201	1840	500	0
9712	3450	7201	1840	500	0
16%		8086			0
13493	4059	9773	1980	500	0
8904	5073	9773	1980	500	0
55%		10330			0

Scenario parameters

	Incentive
No	0
LCA-based moderate	-1500
LCA-based high	-2700
Just transition	-5000

Modification of residual value assumption for used EVs

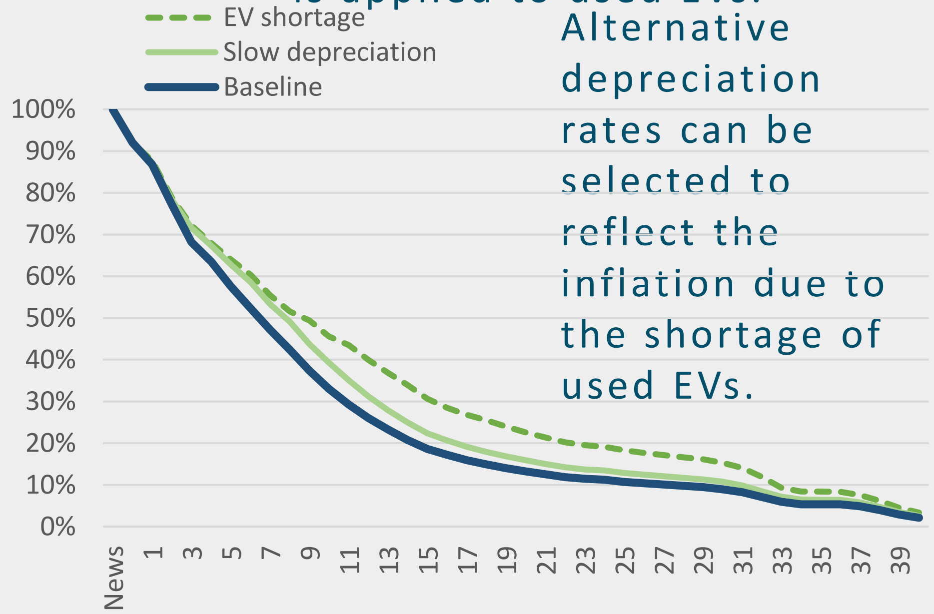
Segment	Share	Model		Price
Mini (A)		FreZe Nikrob	€	14 861
		Dacia Spring	€	18 571
	10%	Renault Twingo	€	23 433
		FreZe Nikrob (new)	€	7 257
	5%	Dacia Spring	€	9 435
		Renault Twingo	€	11 453
		Citroen C1 (entry)	€	17 564
		Renault Twingo (premium)	€	18 148
Small (B)		JAC iEV7s	€	25 908
	23%	Fiat 500e	€	27 518
	11%	JAC iEV7s	€	13 381
		Fiat 500e	€	13 381
		Clio (entry)	€	17 924
		Fiat 500 (premium)	€	18 989
Mid Size (C)		MG G4	€	24 789
	24%	Mazda MX-30 (SUV)	€	34 197
	14%	MG G4	€	13 154
		Mazda MX-30	€	17 009
		Nissan Juke (entry)	€	24 257
		Renault Kangoo (larger)	€	25 301
Large Size (D)		Tesla Model 3 60 kWh	€	48 436
	43%	Mustang Match E (SUV)	€	55 507
	64%	Tesla Model 3 60 kWh	€	24 217
		Mustang Match E	€	24 217
		Peugeot 508 (sedan)	€	33 066
		Citroen C4 (minivan)	€	29 695

Used EV age
10

By default, the model compares a retrofitted car based on a 10-year-old donor car with an EV of the same age. But theses settings can be changed.

EV Residual value
Baseline
EV shortage effect

By default, the standard depreciation curve (historical data for all cars) is applied to used EVs.



Alternative depreciation rates can be selected to reflect the inflation due to the shortage of used EVs.

Step 3: Cost scenario analysis/Settings

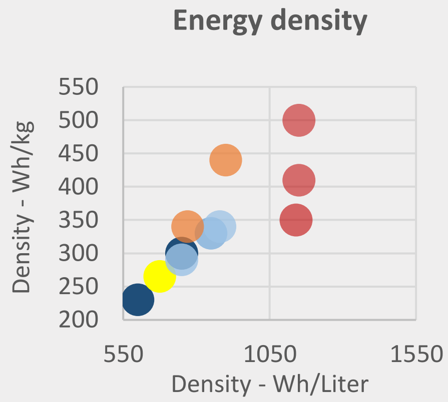
Step 3: Cost scenario analysis/Settings

Modification of energy density assumption (new EVs and e-retrofit)

		Capacity (kWh)		Range (Km)	
		Today	Scenario	Today	Scenario
Mini (A)	FreZe Nikrob	14	15	200	201
	Dacia Spring	27	29	245	246
10%	Renault Twingo	22	24	205	206
	FreZe Nikrob (new)	14	14	190	175
5%	Dacia Spring	27	27	233	214
	Renault Twingo	22	22	195	179
	Citroen C1 (entry)	16	16	110	101
	Renault Twingo (premium)	18	18	140	129
Small (B)	JAC iEV7s	43,5	47	340	341
23%	Fiat 500e	24	26	210	211
11%	JAC iEV7s	44	44	323	297
	Fiat 500e	24	24	200	184
	Clio (entry)	16	16	100	92
	Fiat 500 (premium)	20	20	135	124
Mid Size (C)	MG G4	51	56	442	443
24%	Mazda MX-30 (SUV)	40	44	250	251
14%	MG G4	51	51	420	386
	Mazda MX-30	40	40	238	219
	Nissan Juke (entry)	20	20	90	83
	Renault Kangoo (larger)	34	34	130	120
Large Size (D)	Tesla Model 3 60 kWh	60	65	555	557
43%	Mustang Match E (SUV)	75	82	525	526
64%	Tesla Model 3 60 kWh	60	60	527	485
	Mustang Match E	75	75	499	459
	Peugeot 508 (sedan)	40	40	180	166
	Citroen C4 (minivan)	50	50	230	212

Battery Technology Improvement

A -Li-Ion 2030 baseline	
New EVs	109%
E-retrofit	100%



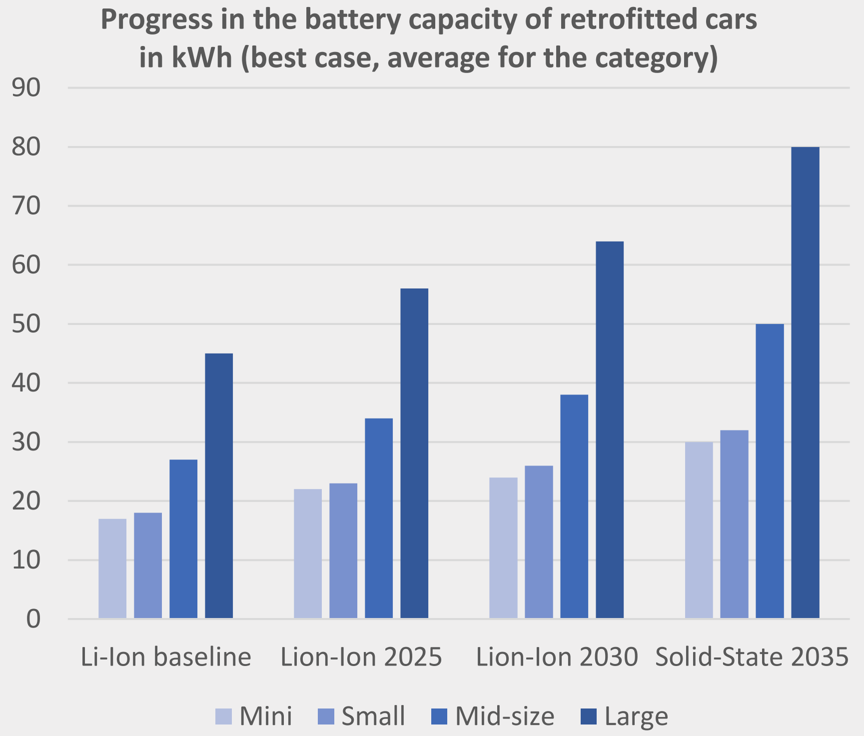
The weight and size of the battery limits the maximum capacity for e-retrofitted cars due to technical constraints. By default, the models assumes that cars are retrofitted with Lithium-Ion battery technology.

Poste 2030, the settings can be changed to reflect the use of better technologies. It automatically increases the capacity of the battery integrated in retrofitted cars and therefore the range (but also the cost).

Step 3: Cost scenario analysis/Settings

Modification of energy density assumption (new EVs and e-retrofit)

Category	Model	Capacity (kWh) Today	Capacity (kWh) Scenario	Range (Km) Today	Range (Km) Scenario
Mini (A)	FreZe Nikrob	14	15	200	201
	Dacia Spring	27	29	245	246
10%	Renault Twingo	22	24	205	206
	FreZe Nikrob (new)	14	14	190	175
5%	Dacia Spring	27	27	233	214
	Renault Twingo	22	22	195	179
	Citroen C1 (entry)	16	16	110	101
	Renault Twingo (premium)	18	18	140	129
Small (B)	JAC iEV7s	43,5	47	340	341
23%	Fiat 500e	24	26	210	211
11%	JAC iEV7s	44	44	323	297
	Fiat 500e	24	24	200	184
	Clio (entry)	16	16	100	92
	Fiat 500 (premium)	20	20	135	124
Mid Size (C)	MG G4	51	56	442	443
24%	Mazda MX-30 (SUV)	40	44	250	251
14%	MG G4	51	51	420	386
	Mazda MX-30	40	40	238	219
	Nissan Juke (entry)	20	20	90	83
	Renault Kangoo (larger)	34	34	130	120
Large Size (D)	Tesla Model 3 60 kWh	60	65	555	557
43%	Mustang Match E (SUV)	75	82	525	526
64%	Tesla Model 3 60 kWh	60	60	527	485
	Mustang Match E	75	75	499	459
	Peugeot 508 (sedan)	40	40	180	166
	Citroen C4 (minivan)	50	50	230	212

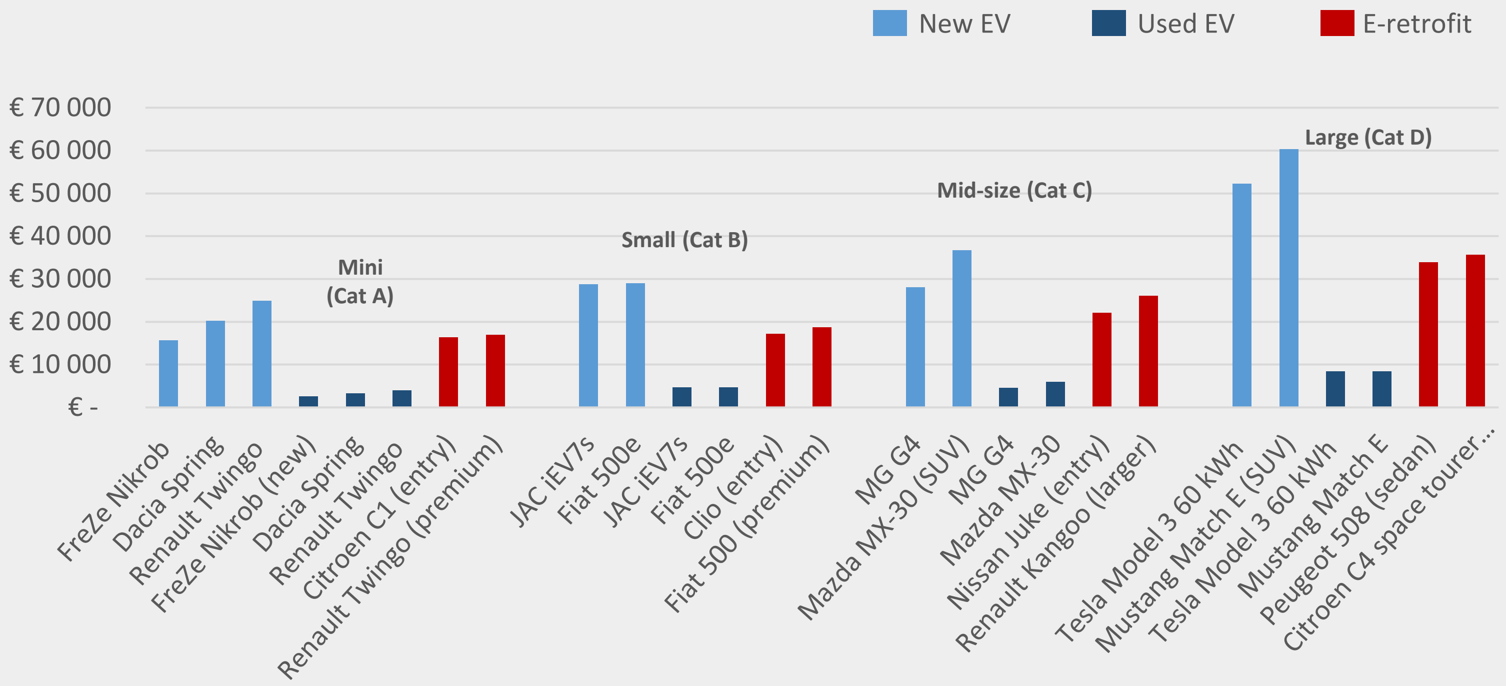


The "starting price" presented in the report is based on the capacity of the battery aligned with the "Li-Ion baseline".

However, the deployment scenarios including the total revenues of the sector are based on the assumption that some cars will be retrofitted with larger batteries.

Principle: Tracking the price of a representative market sample

The model compares the price of e-retrofit (including donor car), for each category with the equivalent new and used EV.



Scenario
Parameters

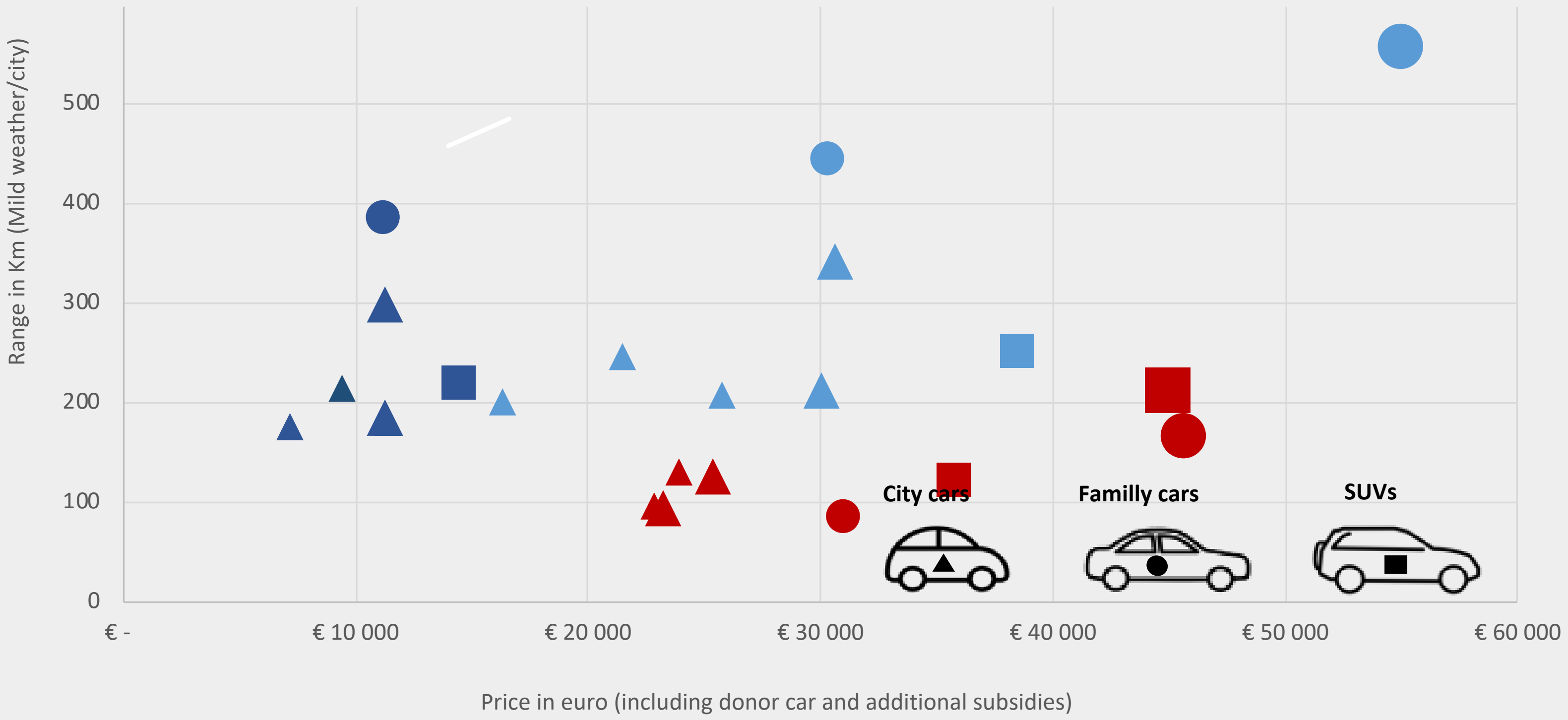
Year of the decision	2030	ICE donor age	10
Battery density scenario	A -Li-Ion 2020 baseline	ICE Residual value scenario	Scenario
Battery market price	€69	Premium on battery price	€97
E-retrofit specific subsidy	€0	Average retrofit price	€30 572
		Type of retrofit	Low-cost
Used EV age	10	Gain in efficiency Kit Prod.	12%
EV residual value scenario	Selected scenario	Labor cost	€58

Step 4: Output indicators

Principle: Comparing the maximum estimated range

The model provides estimates of the maximum range based on the battery size (that can be increased)

New BEV
Used BEV
E-retrofited car
Small
Large

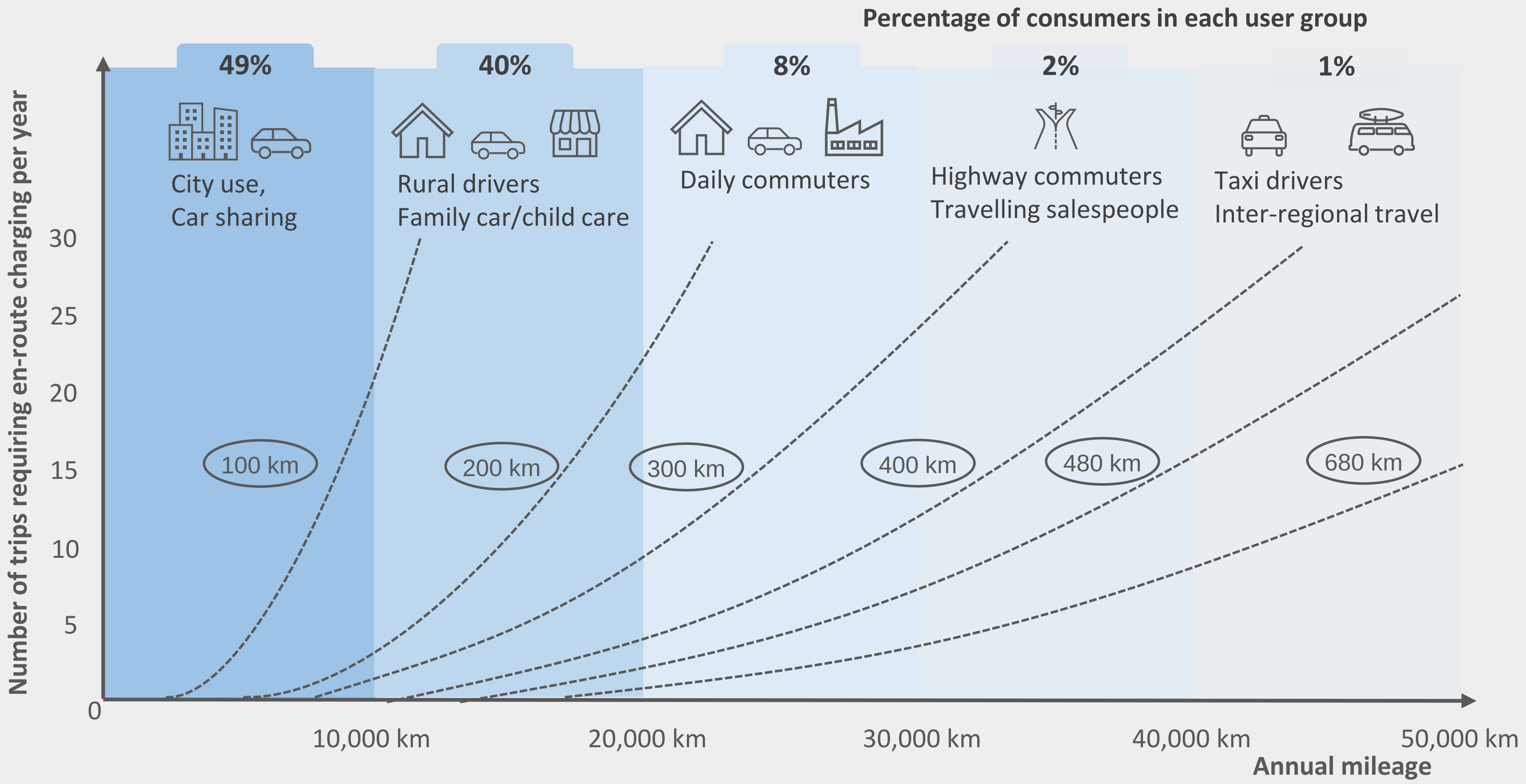


Scenario
Parameters

Year of the decision	2030	ICE donor age	15
Battery density scenario	C -Li-Ion 2030 scenario Moderate	ICE Residual value scenario	Scenario
Battery market price	€69	Premium on battery price	€97
E-retrofit specific subsidy	€0	Average retrofit price	€27 777
		Type of retrofit	Ultra-Low cost
Used EV age	10	Gain in efficiency Kit Prod.	12%
EV residual value scenario	EV shortage	Labor cost	€58

Step 4: Output indicators

Electric vehicle range vs typical use cases: trips requiring en-route charging



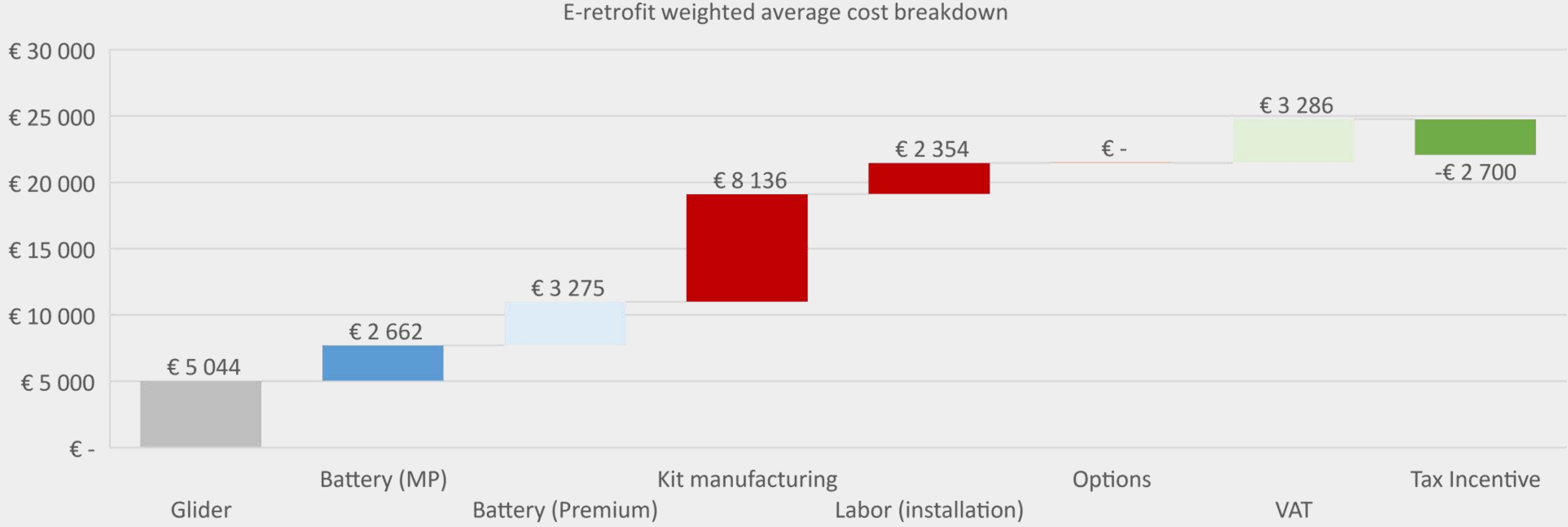
The chart above is derived from BEUC 2021 analysis. It shows that the current estimated range of e-retrofitted cars will make then suitable for the daily use of 50 to 90% of users, with daily destination charging but en-route charging limited to 10-30 trips per year.

Source: BEUC (2021)

Electric Cars: Calculating the Total Cost of Ownership for Consumers

Cost structure of e-retrofit

The model tracks the cost structure for the average car (all categories weighted by market share)



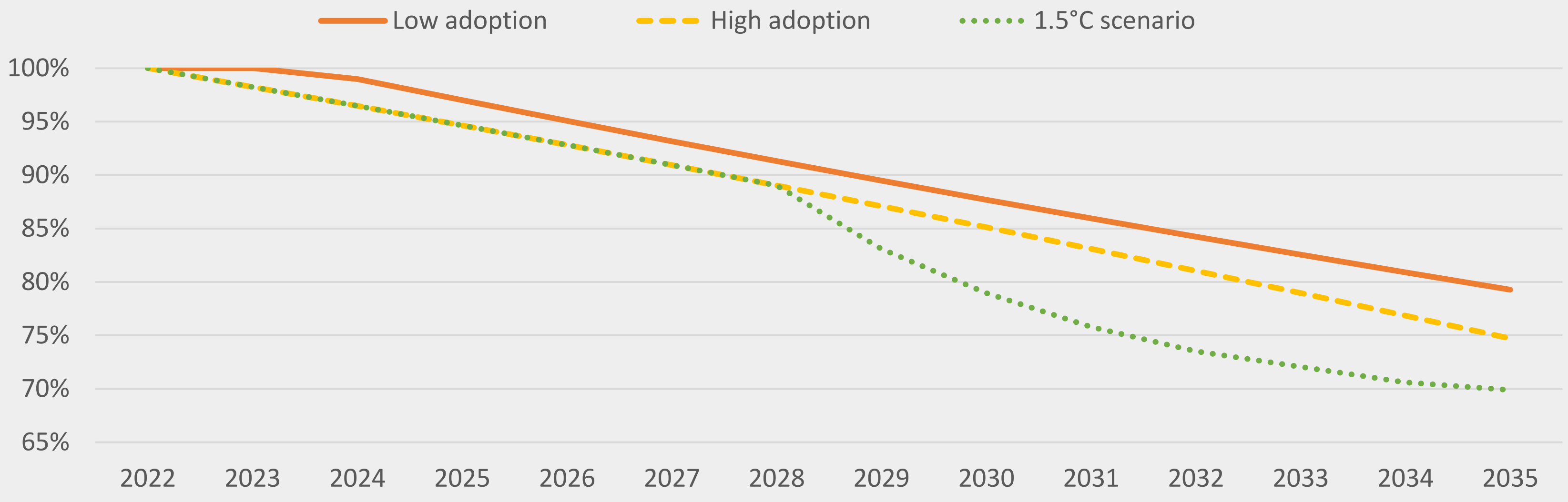
Scenario
Parameters

Year of the decision	2030	ICE donor age	15
Battery density scenario	C -Li-Ion 2030 scenario Moderate	ICE Residual value scenario	Scenario
Battery market price	€69	Premium on battery price	€75
E-retrofit specific subsidy	-€5 000	Average retrofit price	€20 040
		Type of retrofit	Ultra-Low cost
Used EV age	10	Gain in efficiency Kit Prod.	15%
EV residual value scenario	EV shortage	Labor cost	€58

Step 4: Output indicators

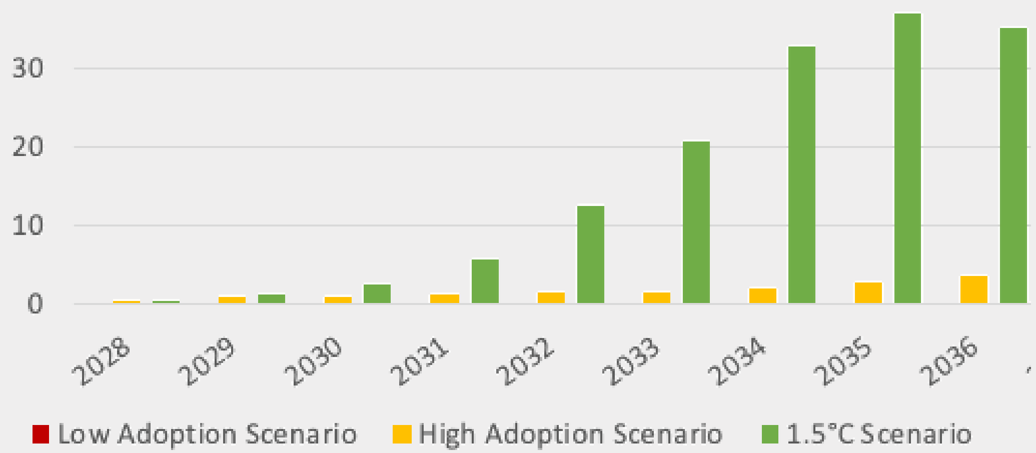
Manufacturing

Reduction of the manufacturing cost of e-retrofit kits

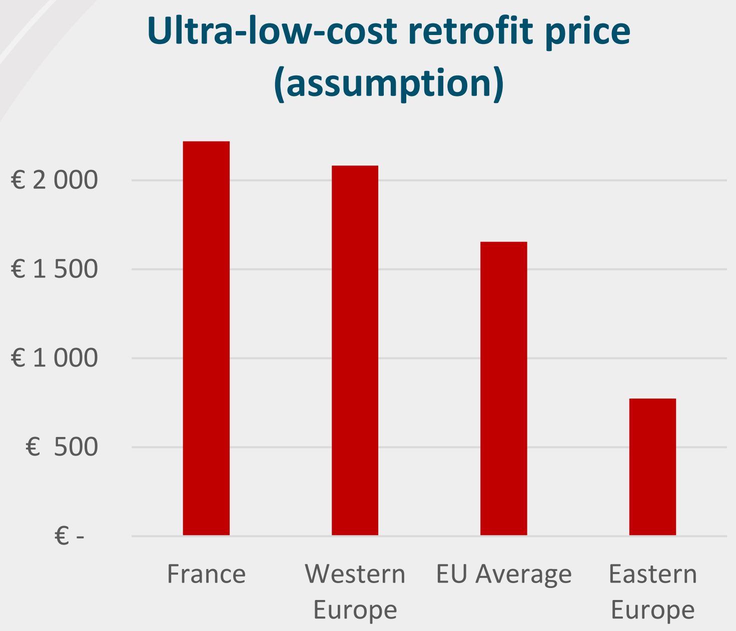


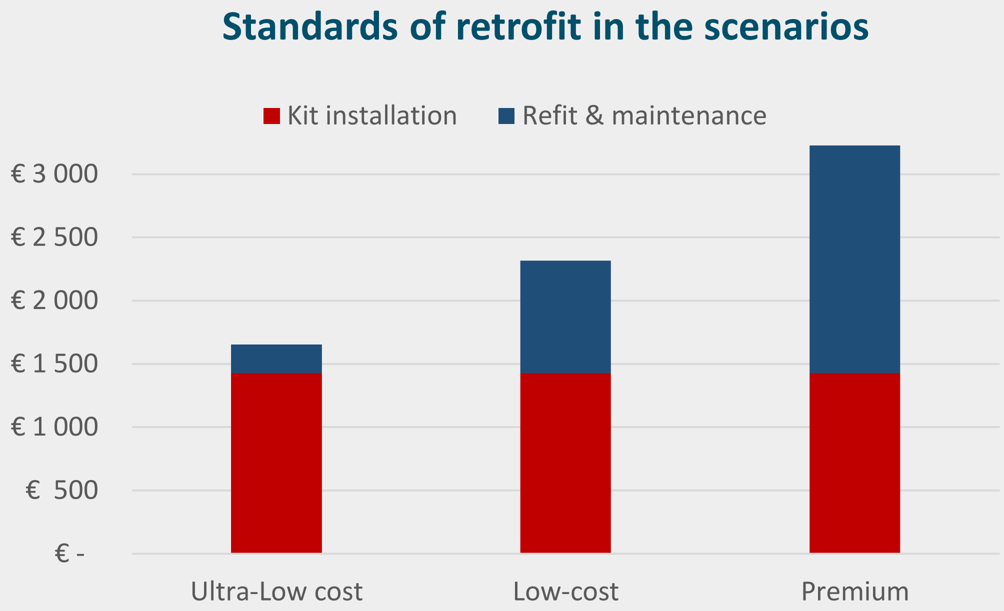
The cost of manufacturing drops in all scenarios, but at different speeds depending on how fast production scales up

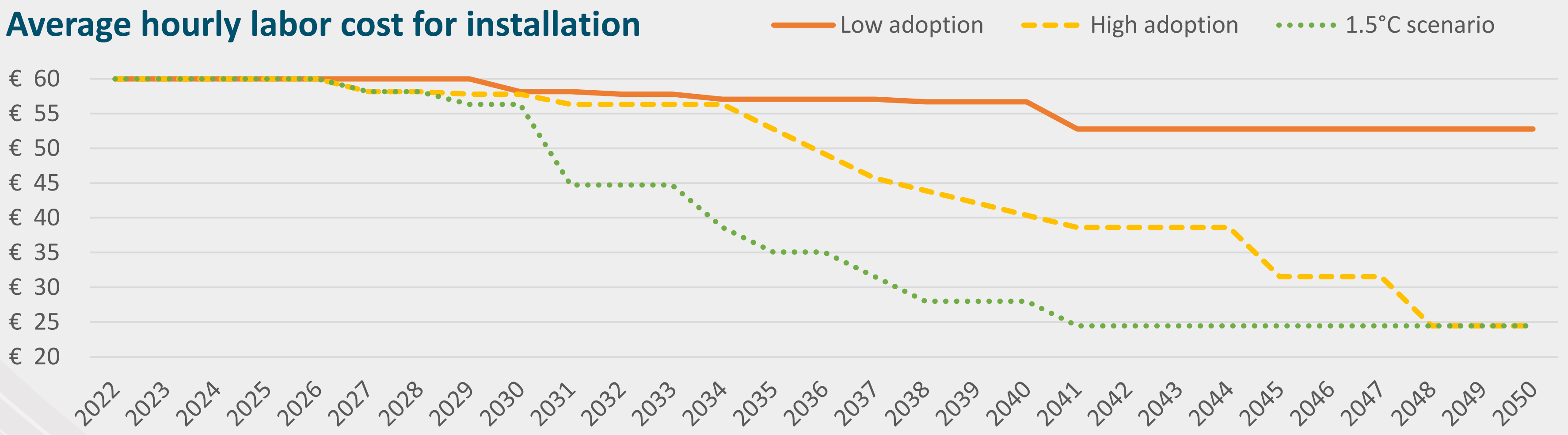
Number of cars retrofitted each year (million units)



Installation

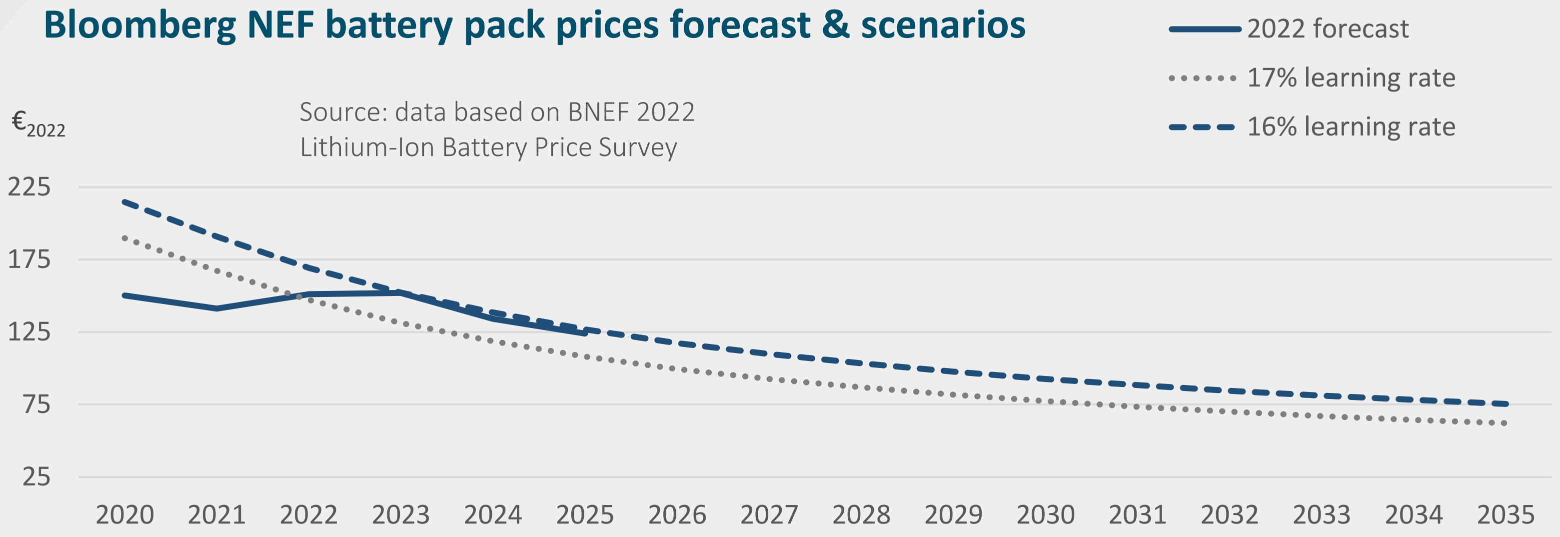




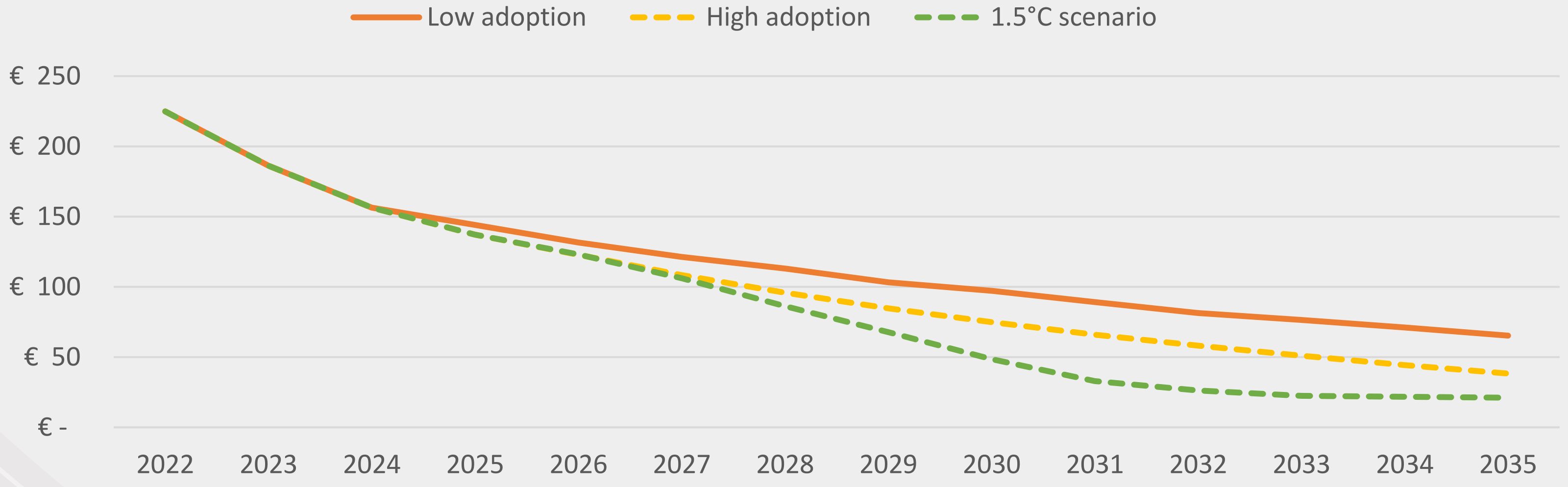


Battery prices

Bloomberg NEF battery pack prices forecast & scenarios

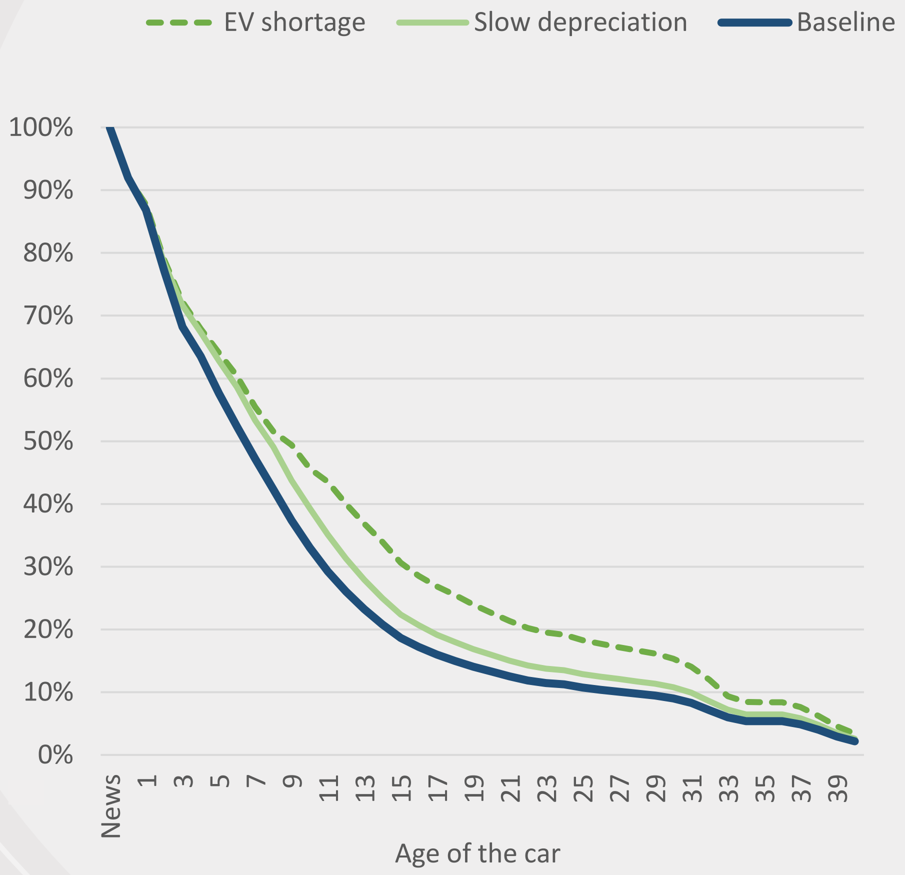


Premium paid on batteries (per kWh): scenarios

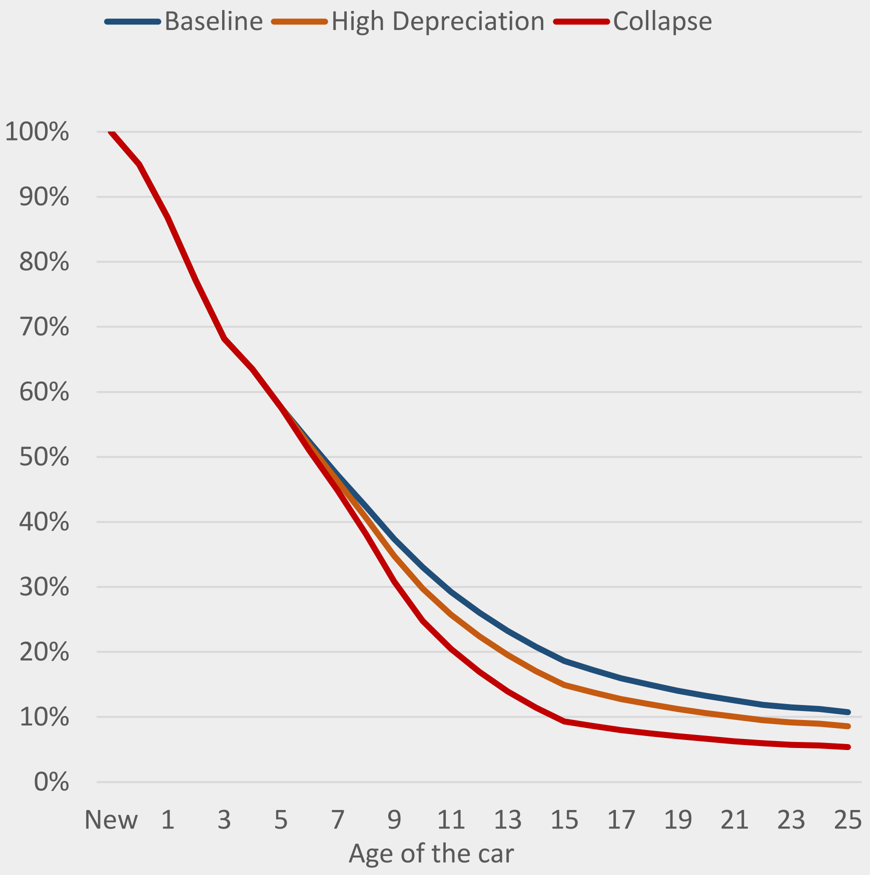


Residual value

Assumptions: residual value of used EVs



Assumptions: residual value of donor cars



Regulation & subsidies

High Adoption Scenario

Policy instruments	Implementation	Implications
Additional subsidies specific to e-retrofit	None until 2028 2,700€ from 2028 to 2030 5,000€ from 2030 to 2050	€495 Bn of public expenditures (assuming no subsidies for new EVs and limited to no subsidies for the purchase of an old EV).
Early retirement regulation and scrapping subsidies	Scrapping subsidy of: €1,000 from 2030 to 2035 and €300 from 2036 to 2050.	The program cost a maximum of €27Bn of public expenditure (which overlaps with existing scrapping schemes). 50 million cars are retired

1.5°C Scenario

Policy instruments	Implementation	Implications
Additional subsidies specific to e-retrofit	None until 2028 2,700€ from 2028 to 2030 5,000€ from 2030 to 2033 2,700€ from 3024 to 2035 1,500€ from 2036 to 2040	€545Bn of public expenditures (assuming no subsidies for new EVs and limited to no subsidies for the purchase of an old EV).
Scrapping program regulation	Scrapping subsidy of: €1,000 from 2030 to 2032, €500 from 2033 to 2035 and €300 from 2036 to 2040.	€17 Bn of public expenditure (which overlaps with existing scrapping schemes).

Low Adoption Scenario

Parameters settings

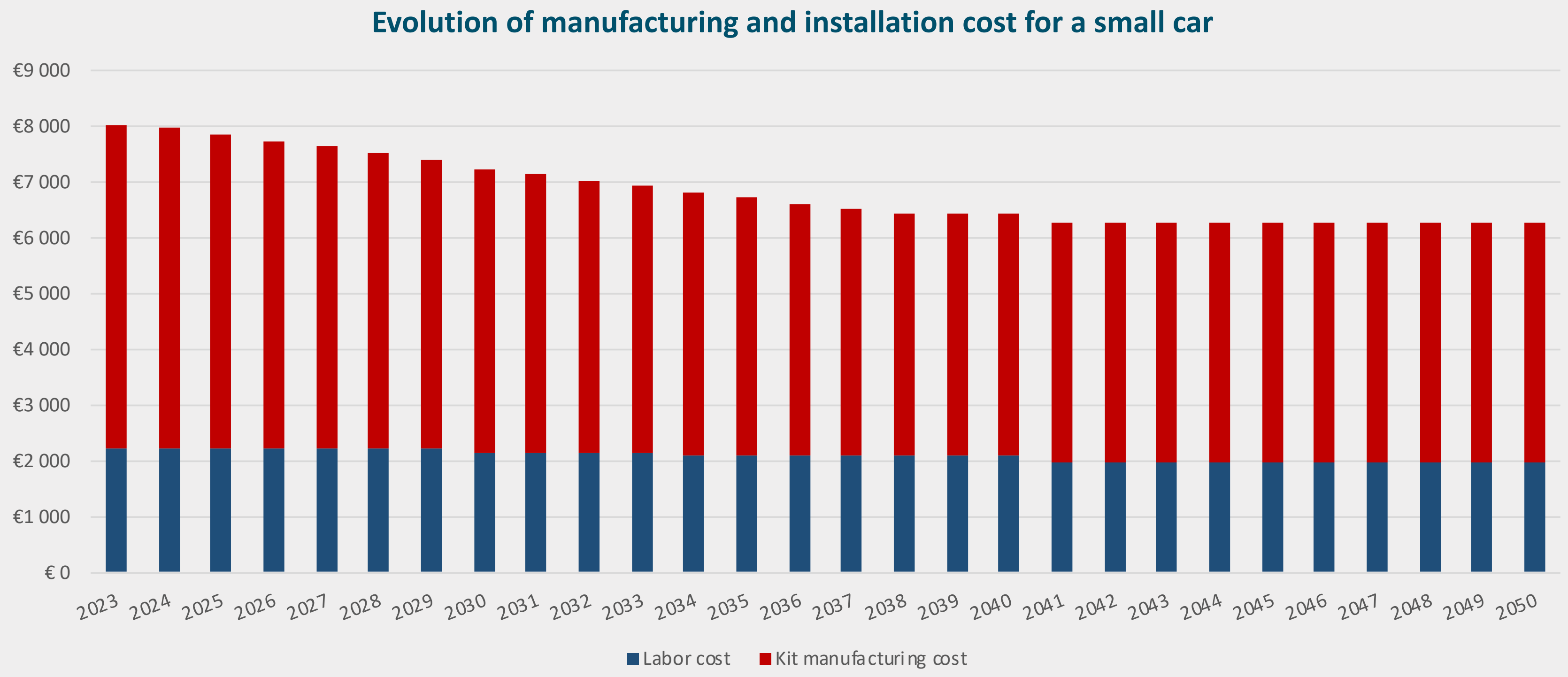
Settings of the key parameters in the scenario. The settings migh change from one year to the next.

Certain advanced settings might not appear on this slide. Access the model itself for details.

Parameter	Settings in the scenario
Batteries market price	BNEF 2022 forecast/16% learning rate
Batteries energy density	Adoption of best available Li-on tech
Premium paid above market price	The premium paid drops to +100% in 2050.
Kit manufacturing cost	-25% over 2022-2038 then stagnates
Labor cost	Drops from €60/h in 2023 to €53/h after 2040
Average type of retrofit	'Premium', including basic refit and tablet
Subsidies	No retrofit-specific subsidy
Fossil cars resale value	Aligned with the baseline curve
EV resale value	Aligned with the baseline curve

Low Adoption Scenario

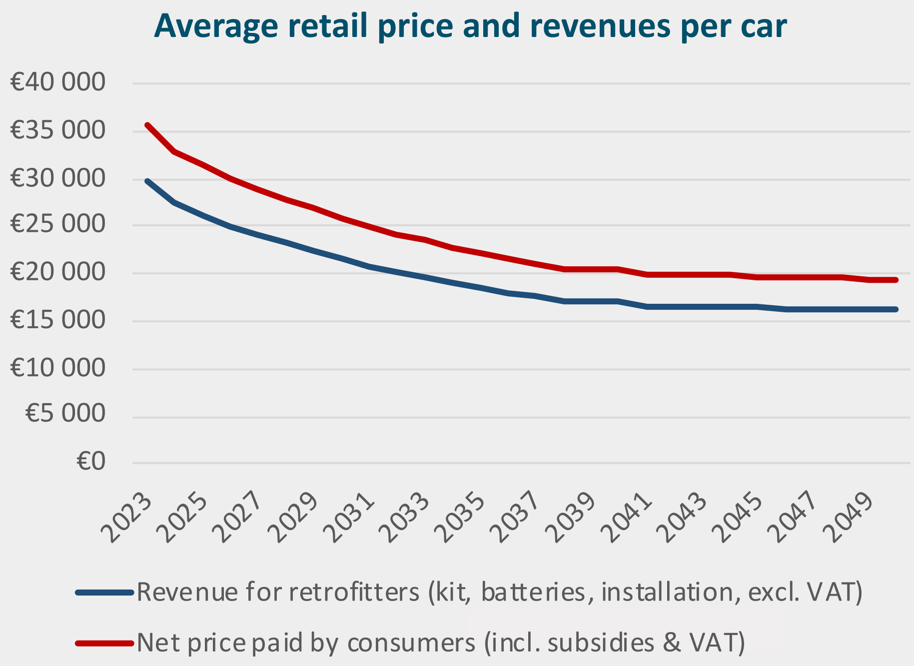
Cost reduction



Low Adoption Scenario

Cost reduction

Exclusing cost of the donor car, and subsidies.



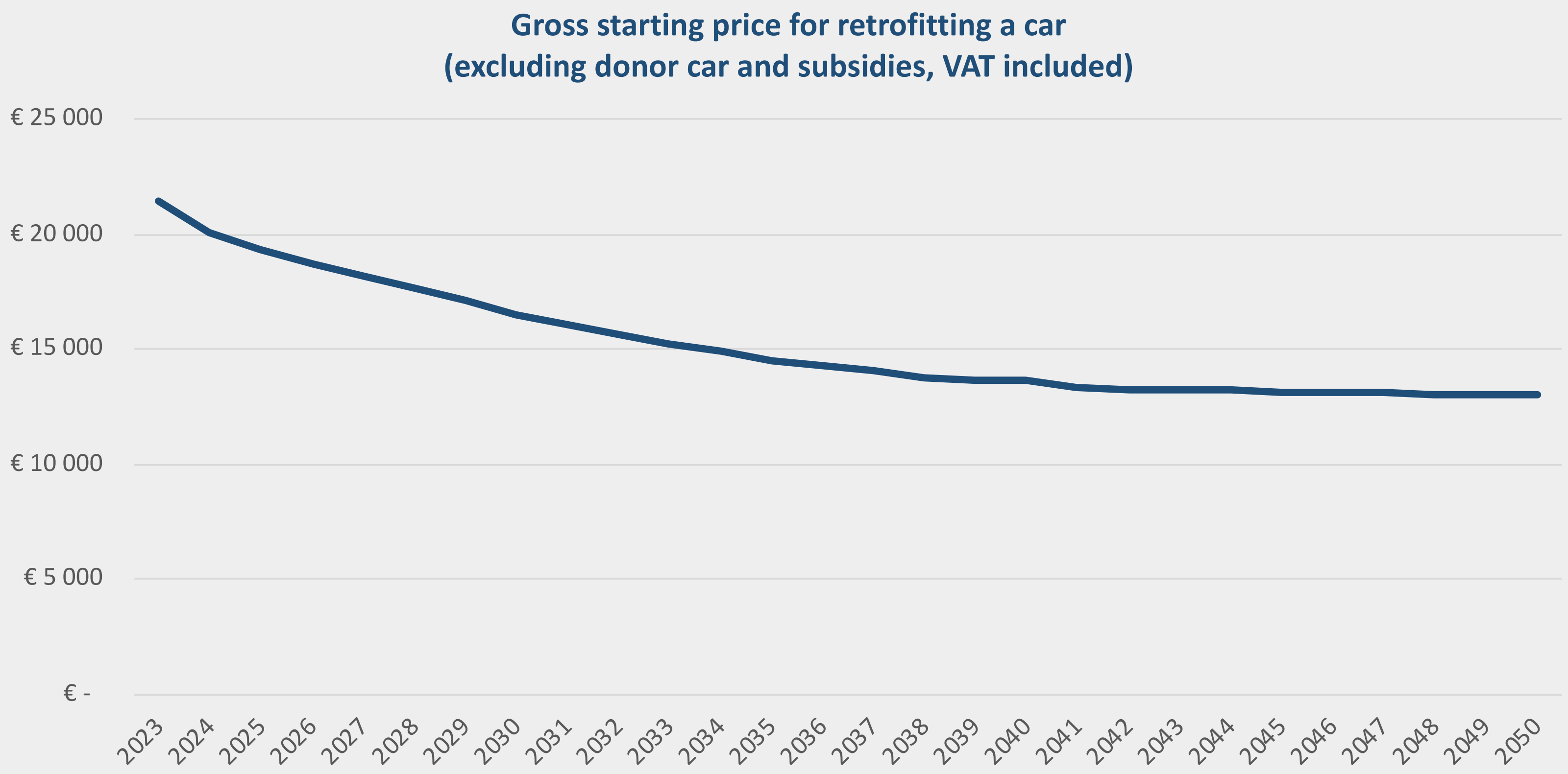
In this scenario there is no subsidies specific to e-retrofit, by subsidies applicable to all electric cars and scrapping might be applicable. They do not increase the competitivity of e-retrofit against used EVs though.

Low Adoption Scenario

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

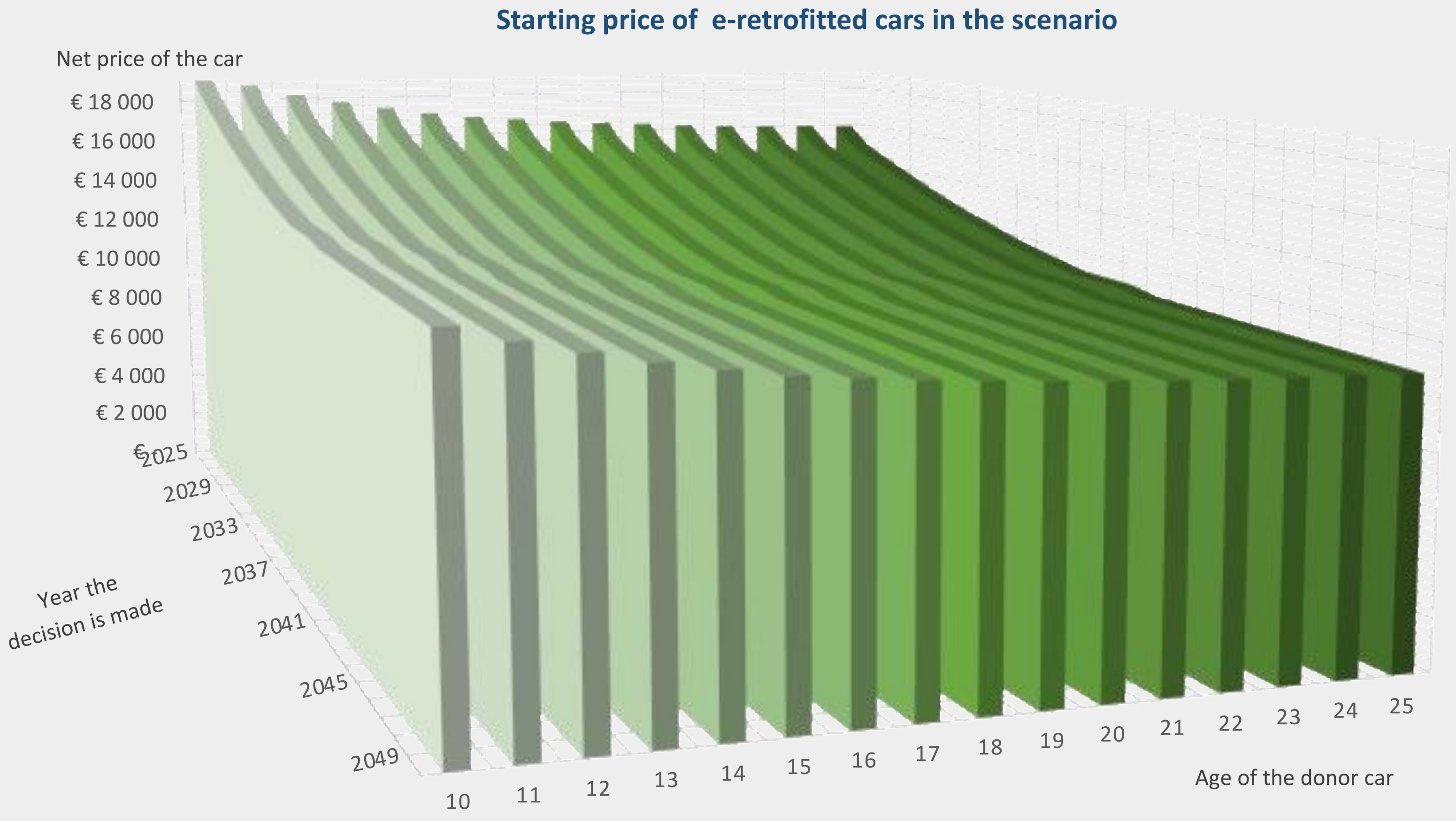


Low Adoption Scenario

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars



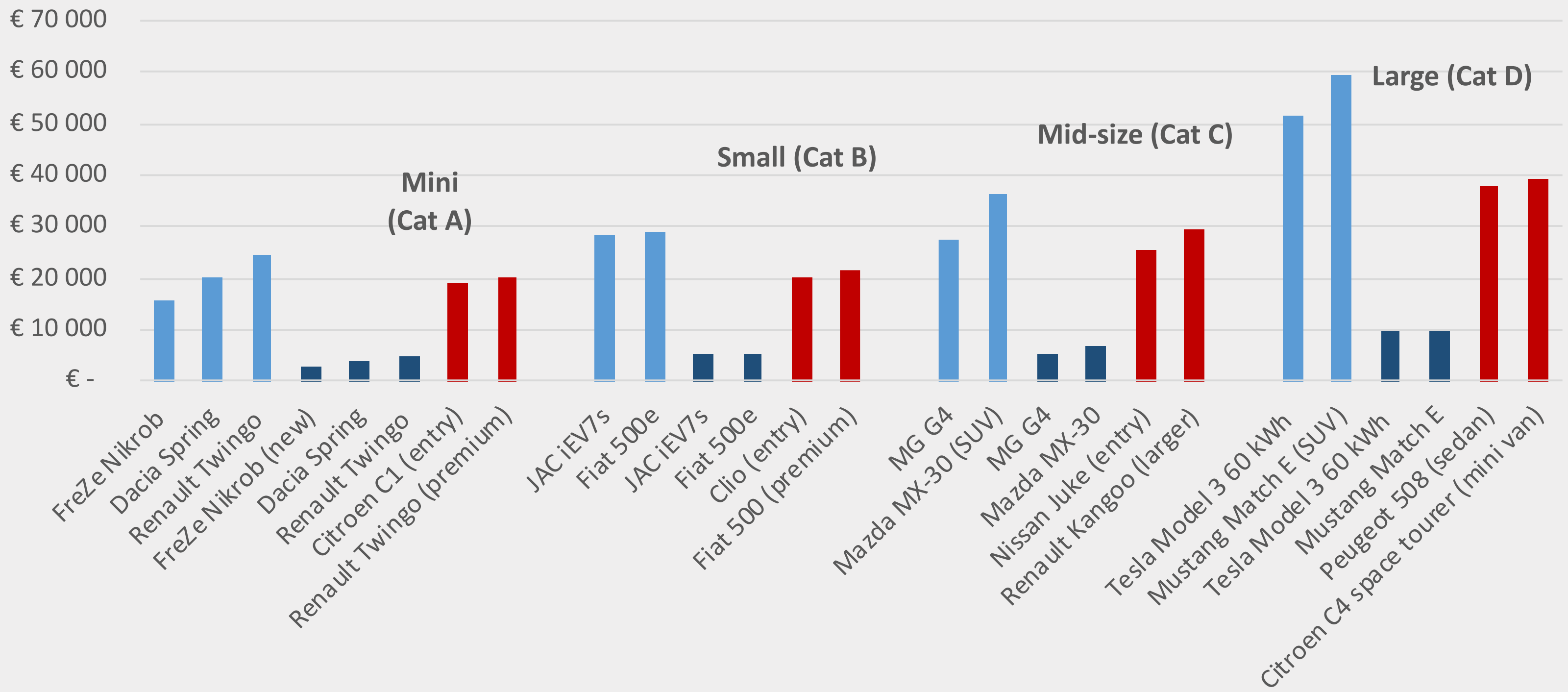
Low Adoption Scenario

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

E-retrofitted cars vs competitors in 2030



Scenario
Parameters

Year of the decision	2030	ICE donor age	15
Battery density scenario	C -Li-Ion 2030 scenario Moderate	ICE Residual value scenario	Scenario
Battery market price	€83	Premium on battery price	€97
E-retrofit specific subsidy	€0	Average retrofit price	€31 512
		Type of retrofit	Premium
Used EV age	15	Gain in efficiency Kit Prod.	12%
EV residual value scenario	Selected scenario	Labor cost	€58

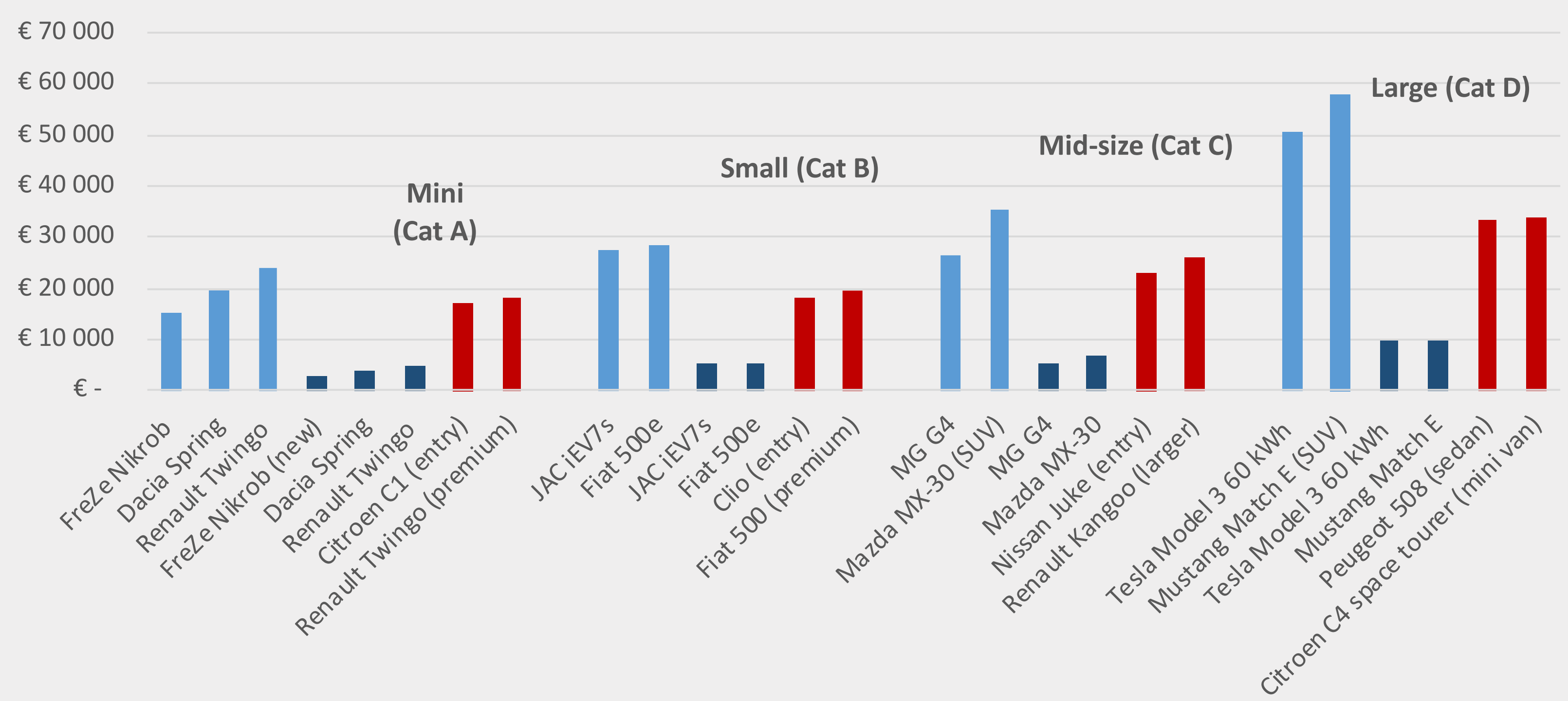
Low Adoption Scenario

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

E-retrofitted cars vs competitors in 2035



Scenario
Parameters

Year of the decision	2035	ICE donor age	15
Battery density scenario	C -Li-Ion 2030 scenario Moderate	ICE Residual value scenario	Scenario
Battery market price	€68	Premium on battery price	€65
E-retrofit specific subsidy	€0	Average retrofit price	€27 727
		Type of retrofit	Premium
Used EV age	15	Gain in efficiency Kit Prod.	21%
EV residual value scenario	Selected scenario	Labor cost	€57

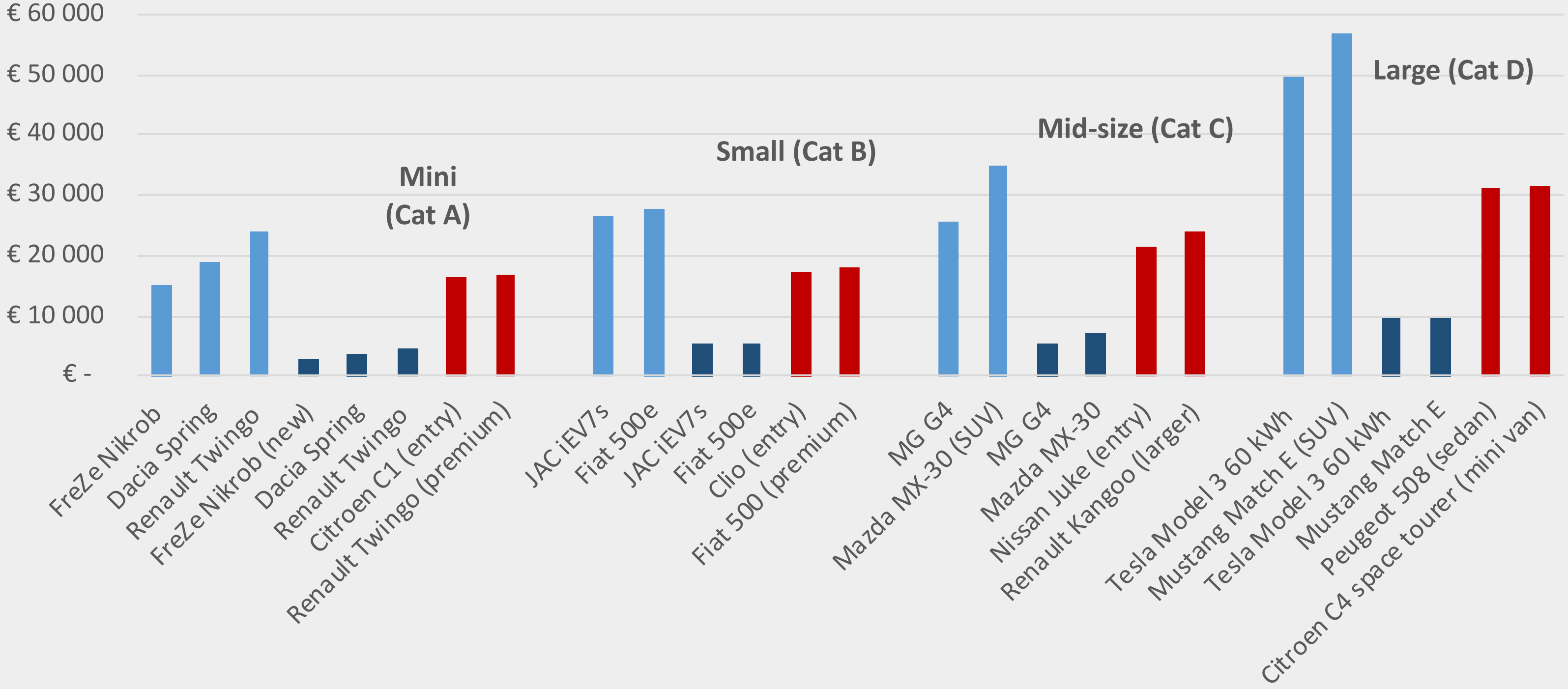
Low Adoption Scenario

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

E-retrofitted cars vs competitors in 2045



Scenario Parameters

Year of the decision	2045	ICE donor age	15
Battery density scenario	F -Solid State 2035 scenario Moderate	ICE Residual value scenario	Scenario
Battery market price	€55	Premium on battery price	€53
E-retrofit specific subsidy	€0	Average retrofit price	€25 845
		Type of retrofit	Premium
Used EV age	15	Gain in efficiency Kit Prod.	25%
EV residual value scenario	Selected scenario	Labor cost	€53

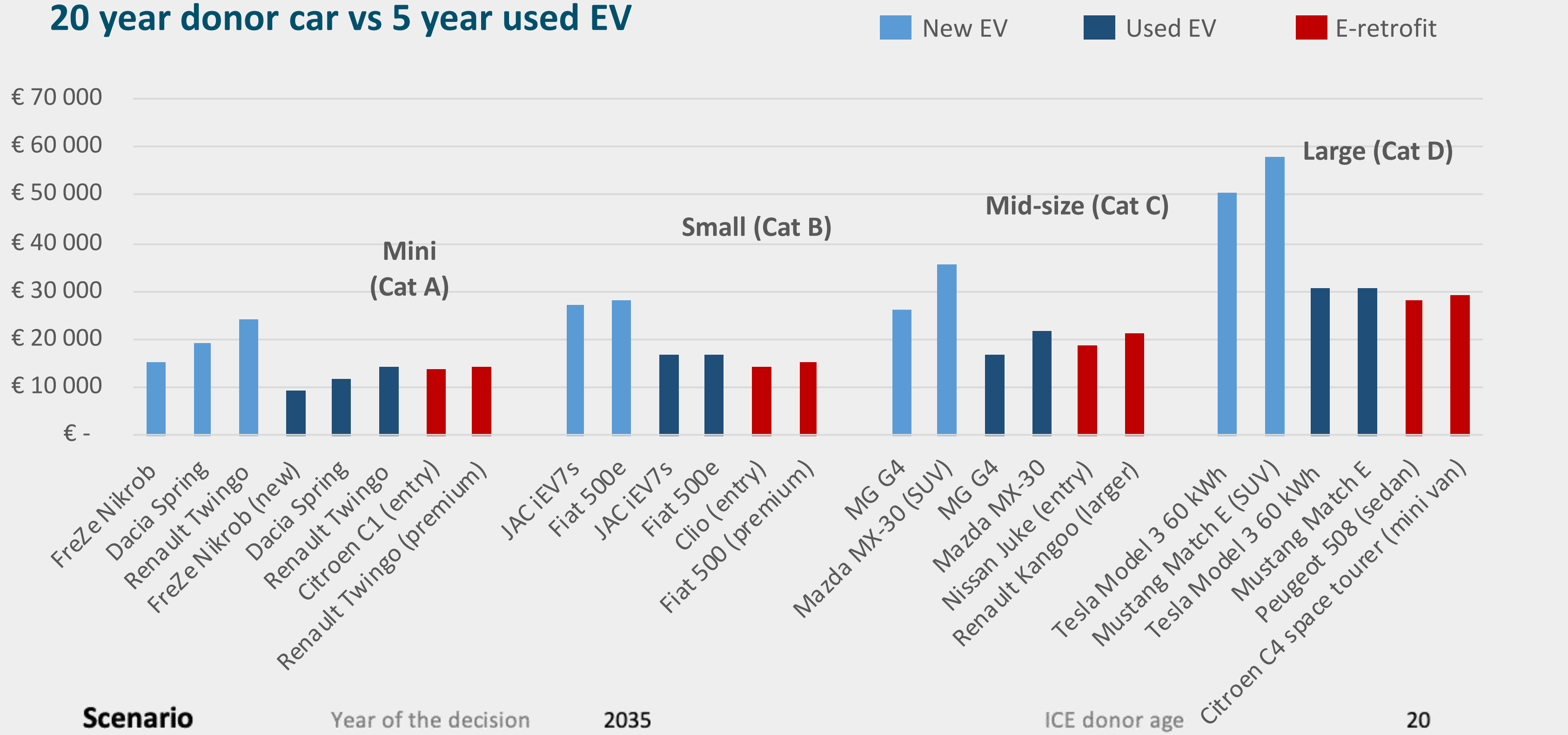
Low Adoption Scenario

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

Conditions for price parity with used EVs in 2035: 20 year donor car vs 5 year used EV



Scenario
Parameters

Year of the decision	2035
Battery density scenario	C -Li-Ion 2030 scenario Moderate
Battery market price	€68
E-retrofit specific subsidy	€0
Used EV age	5
EV residual value scenario	Selected scenario

ICE donor age	20
ICE Residual value scenario	Scenario
Premium on battery price	€65
Average retrofit price	€23 213
Type of retrofit	Ultra-Low cost
Gain in efficiency Kit Prod.	21%
Labor cost	€57

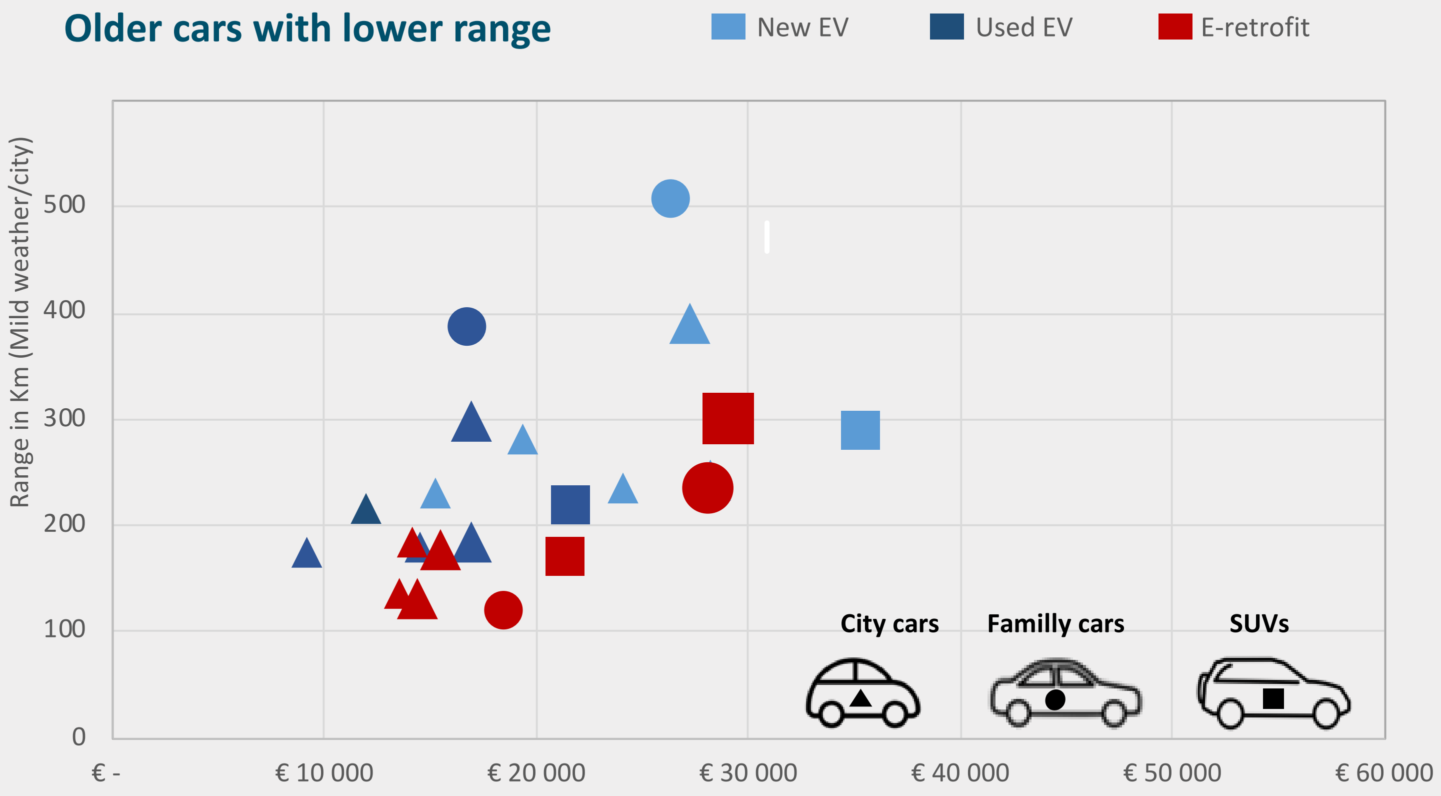
Low Adoption Scenario

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

E-retrofitted cars vs used EVs: Older cars with lower range



Scenario Parameters

Year of the decision	2035	ICE donor age	20
Battery density scenario	C -Li-Ion 2030 scenario Moderate	ICE Residual value scenario	Scenario
Battery market price	€68	Premium on battery price	€65
E-retrofit specific subsidy	€0	Average retrofit price	€23 213
		Type of retrofit	Ultra-Low cost
Used EV age	5	Gain in efficiency Kit Prod.	21%
EV residual value scenario	Selected scenario	Labor cost	€57

Conclusion: the economics limits e-retrofit to vintage cars and equipped minivans (e.g. campers).

Parameters settings

Settings of the key parameters in the scenario. The settings migh change from one year to the next.

Certain advanced settings might not appear on this slide. Access the model itself for details.

Parameter	Settings in the scenario
Batteries market price	BNEF 2022 forecast/17% learning rate
Batteries energy density	Adoption of best available Li-on tech
Premium paid above market price	The premium paid drops to +66% in 2045.
Kit manufacturing cost	-25% over 2022-2035 then stagnates
Labor cost	Drops from €60/h in 2023 to €24/h after 2048
Average type of retrofit	Ultra-low cost
Subsidies	None until 2028 2,700€ from 2028 to 2030 5,000€ from 2030 to 2050
Fossil cars resale value	High depreciation curve (-20%)
EV resale value	Slow depreciation curve (+20%)

High Adoption Scenario

Assumptions: Public policies

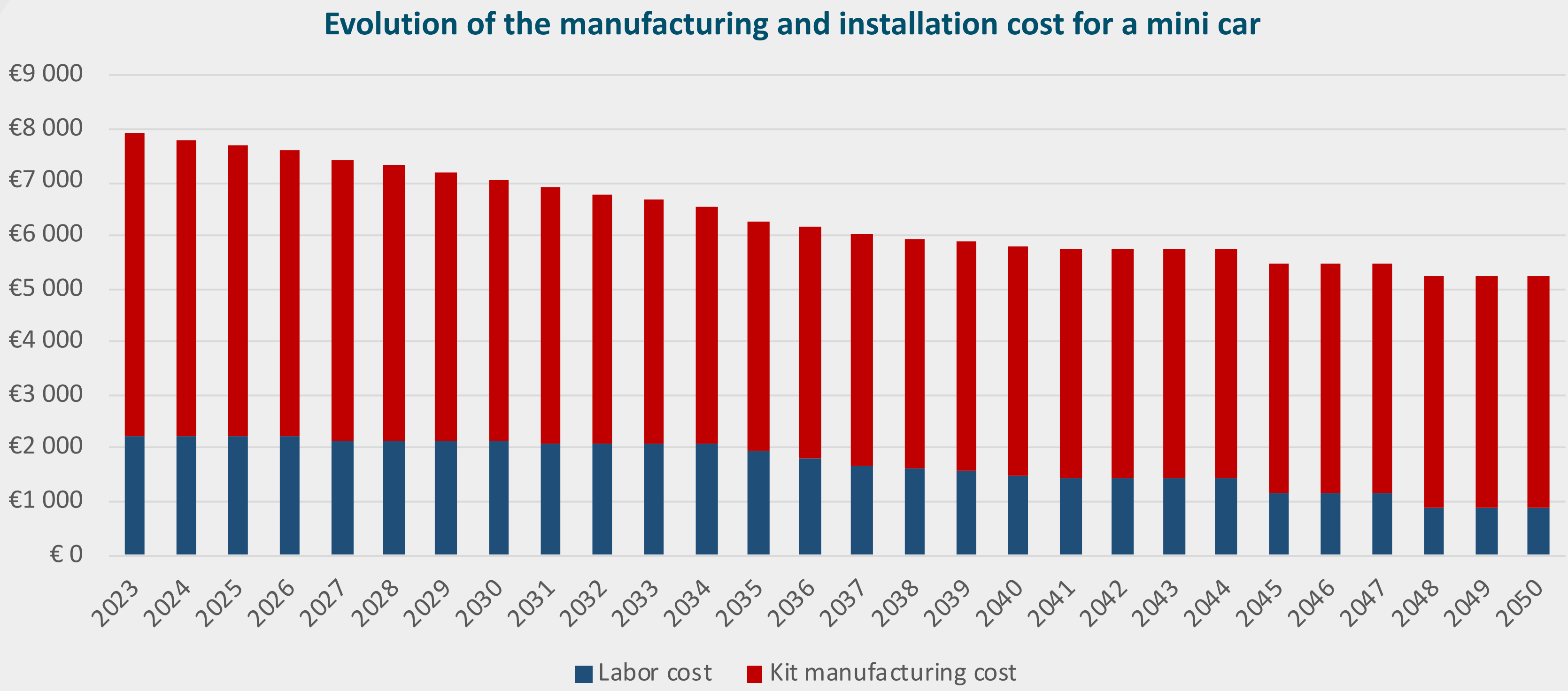
Policy instruments (fictional)	Implementation	Implications
Additional subsidies specific to e-retrofit	None until 2028 2,700€ from 2028 to 2030 5,000€ from 2030 to 2050	€495 Bn of public expenditures (assuming no subsidies for new EVs and limited to no subsidies for the purchase of an old EV).
Early retirement regulation and scrapping subsidies	No cars older than 35 years is allowed on the roads after 2035: they must be scrapped or retrofitted. The age limit is reduced to 30 years in 2050. Scrapping subsidy of €1,000 from 2030 to 2035 and €300 from 2036 to 2050.	The program cost a maximum of €27Bn of public expenditure (which overlaps with existing scrapping schemes) and lead to the early scrapping of 55 million cars.
Contraints on fossil car use	Low and Zero Emission Zones are implemented in most cities across Europe from 2035 onwards. Taxes on fuels and ownership increase.	The total residual value of old fossil cars drops by 20% relative to the default depreciation curve from 2028 onwards.

High Adoption Scenario

Minimum cost

The cost excludes the cost of battery and VAT.

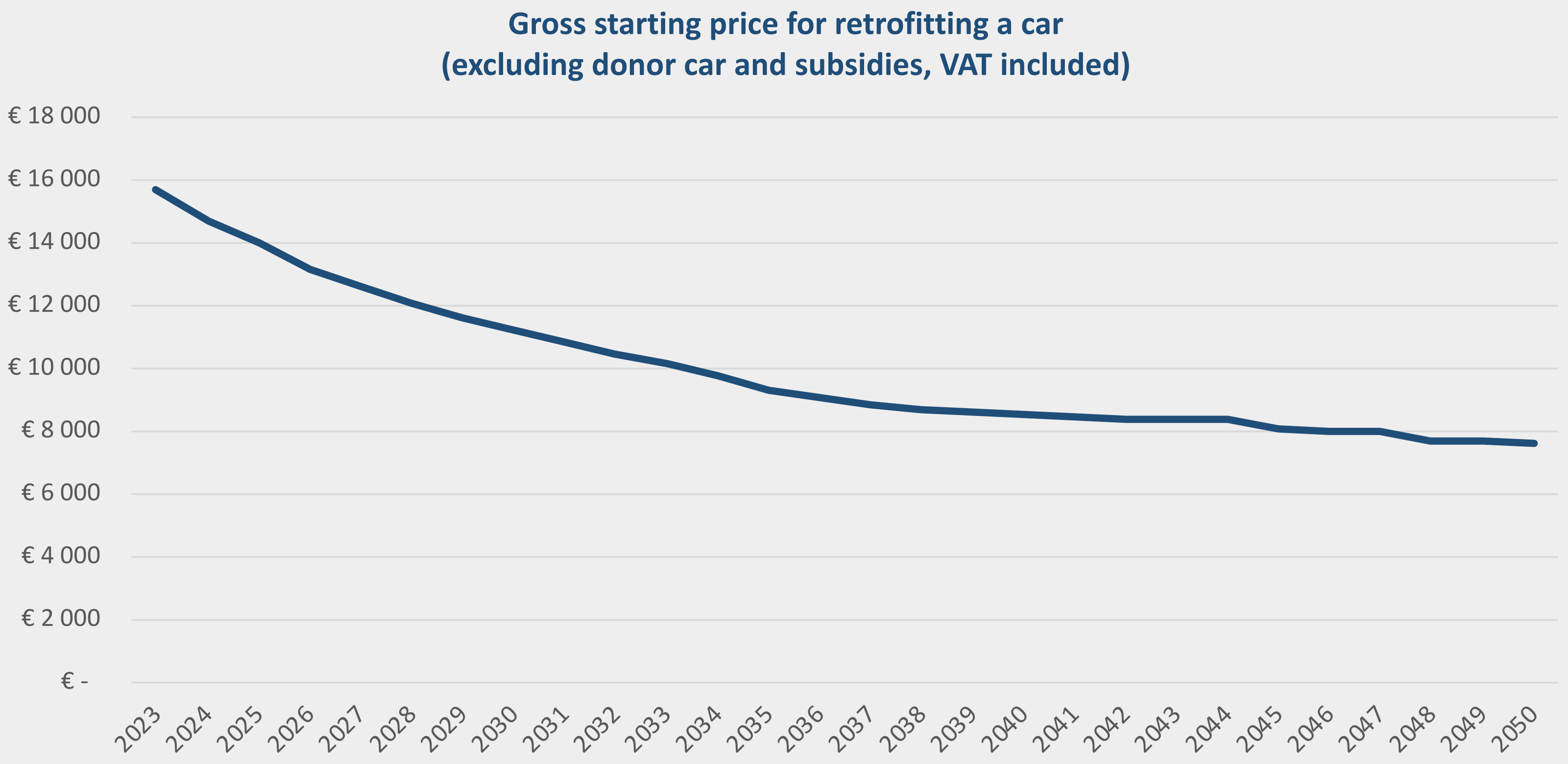
High Adoption Scenario



The entry price for retrofit (small car, ultra-low-cost retrofit, low range) drops significantly driven by economies of scale and lower labor cost in Eastern Europe.

Starting gross price

The gross price excludes the cost of the donor car (resale value) and the subsidies. VAT is included.



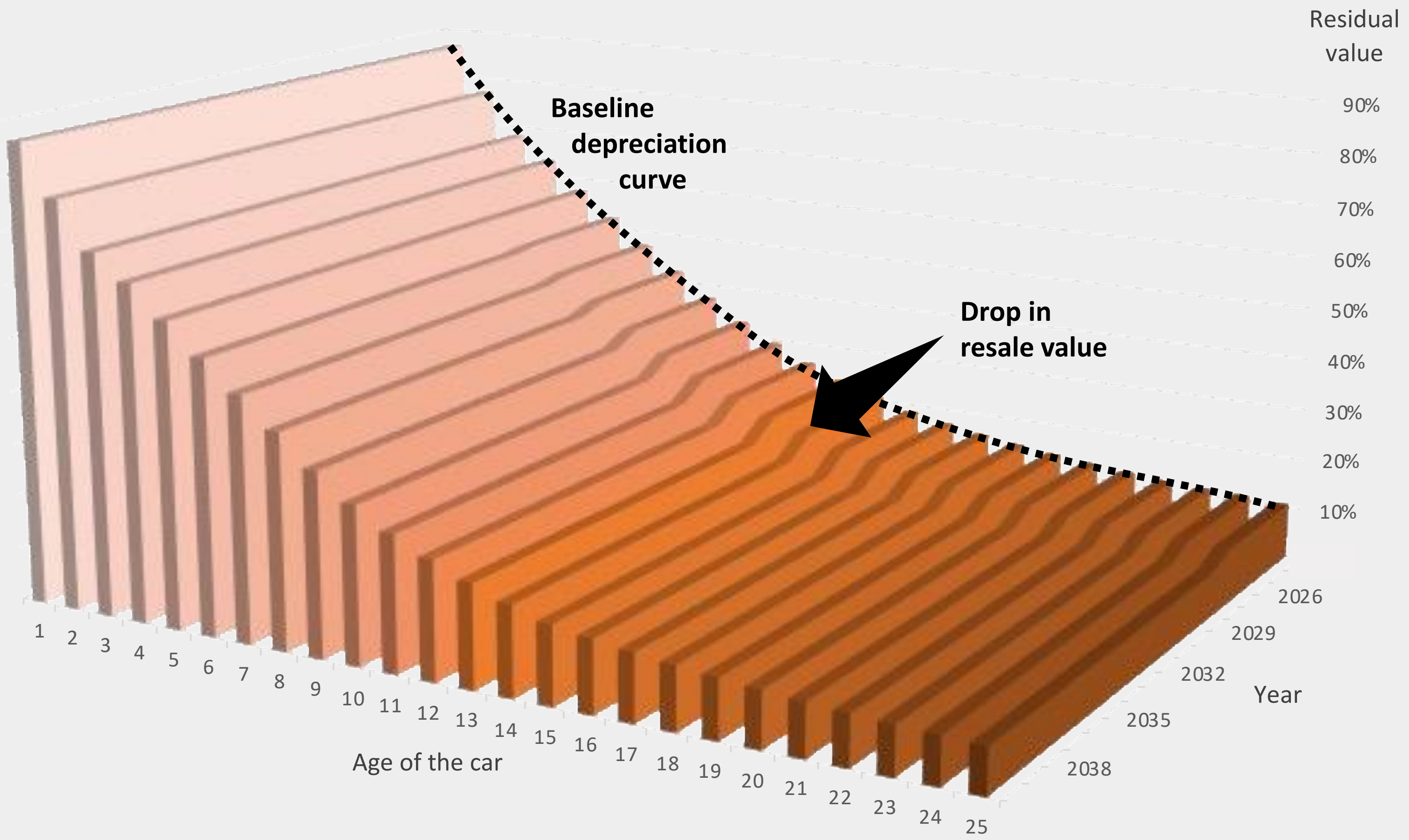
The starting price for retrofit (small car, ultra-low-cost retrofit, low range) drops by a factor of two driven by economies of scale and lower battery prices.

High Adoption Scenario

Resale value of the donor car

Key factor of competitiveness for e-retrofit in the scenario

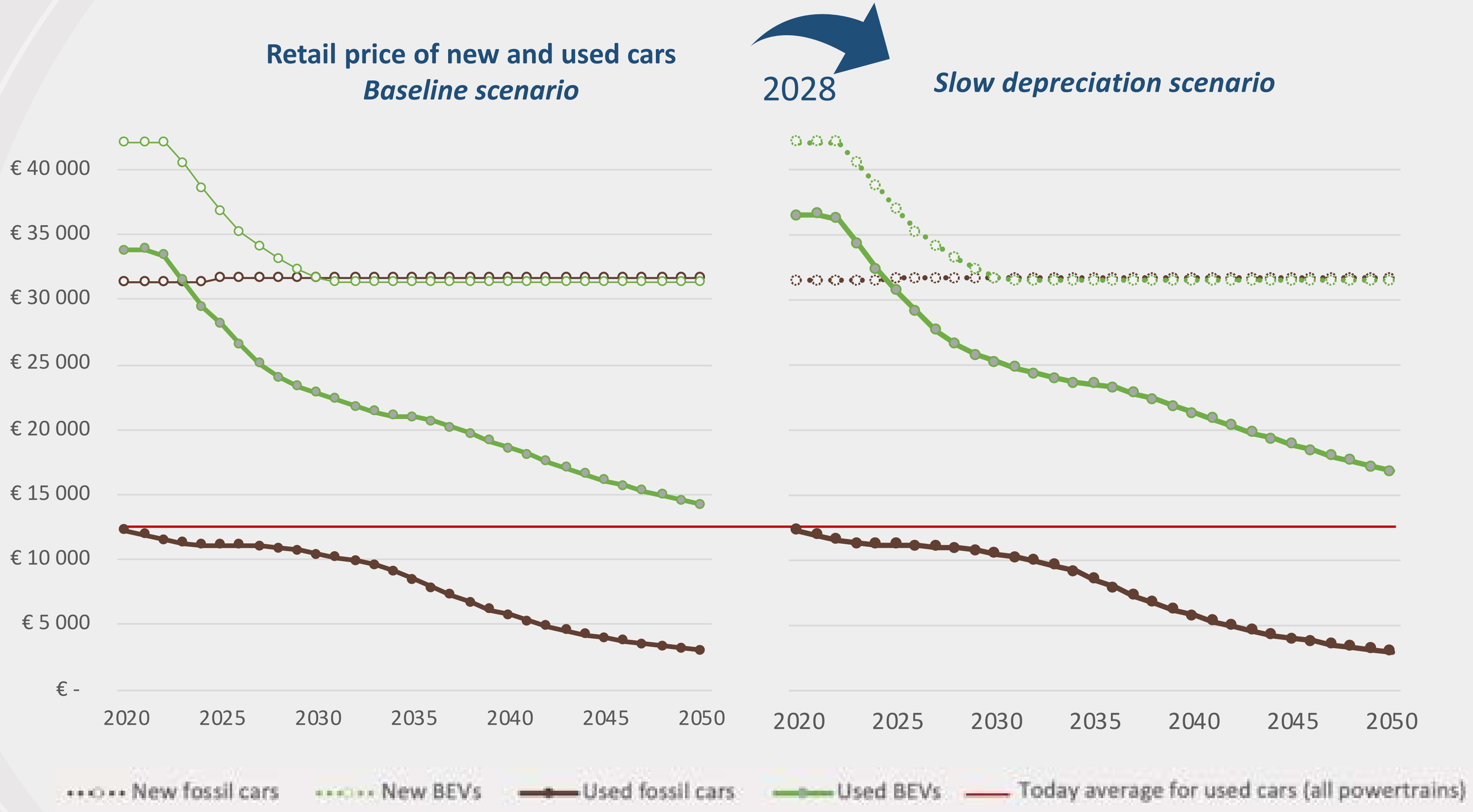
Fossil cars depreciation curve in the scenario
(Resale value as a percentage of original price)



The depreciation of old fossil cars accelerates in 2028 by 20% due to regulatory pressure (taxes, LEZs)

High Adoption Scenario

Assumptions: Residual value of used EVs



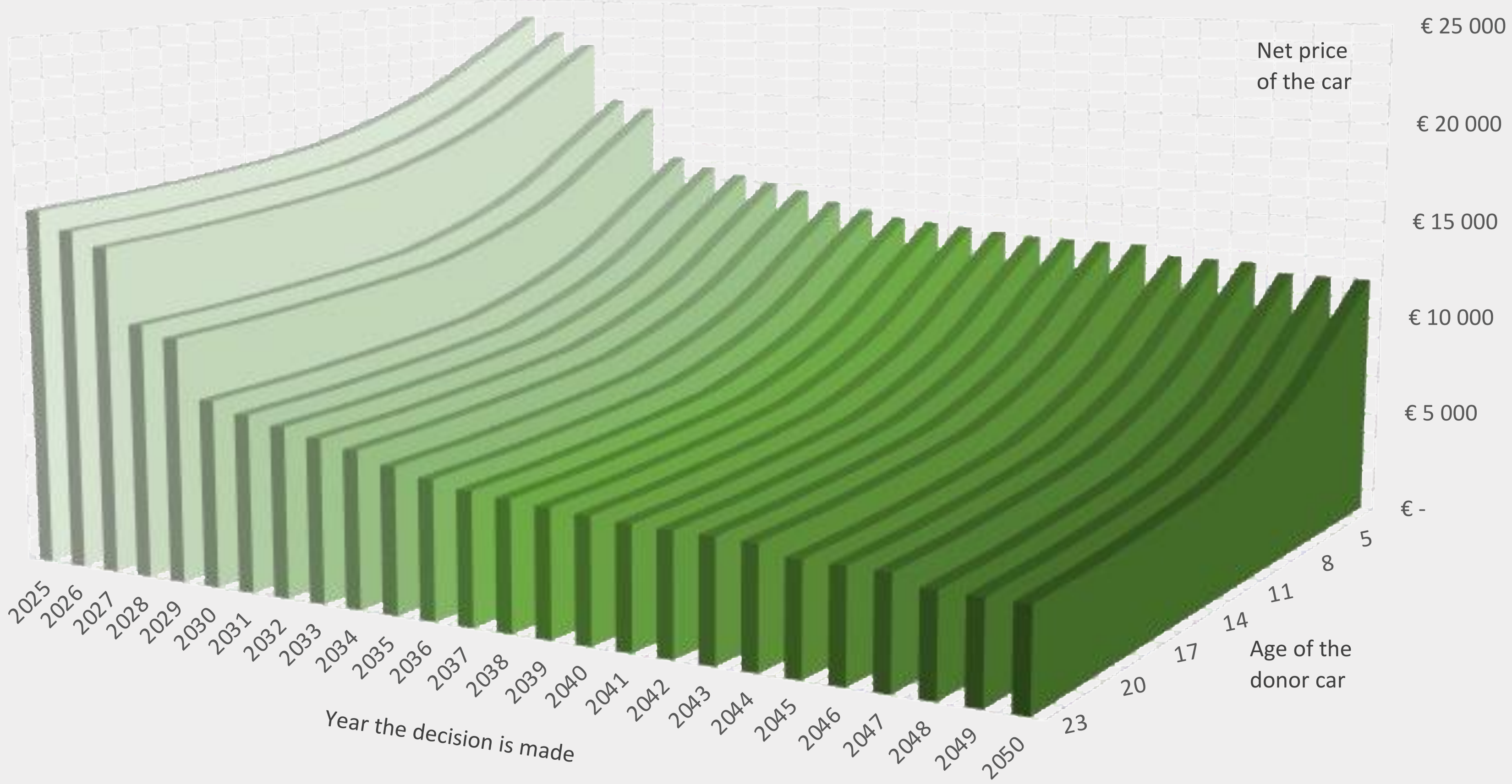
High Adoption Scenario

The demand for affordable used EV rises dramatically **from 2028**, while less than 1 million EVs are 10 years or older: this situation triggers inflation for old used EVs (+20%). The depreciation curve switches from the baseline (left) to the **slow depreciation scenario** (right).

Starting net price

The net price includes the cost of the donor car (resale value), subsidies, and VAT.

Starting price of e-retrofitted cars in the scenario

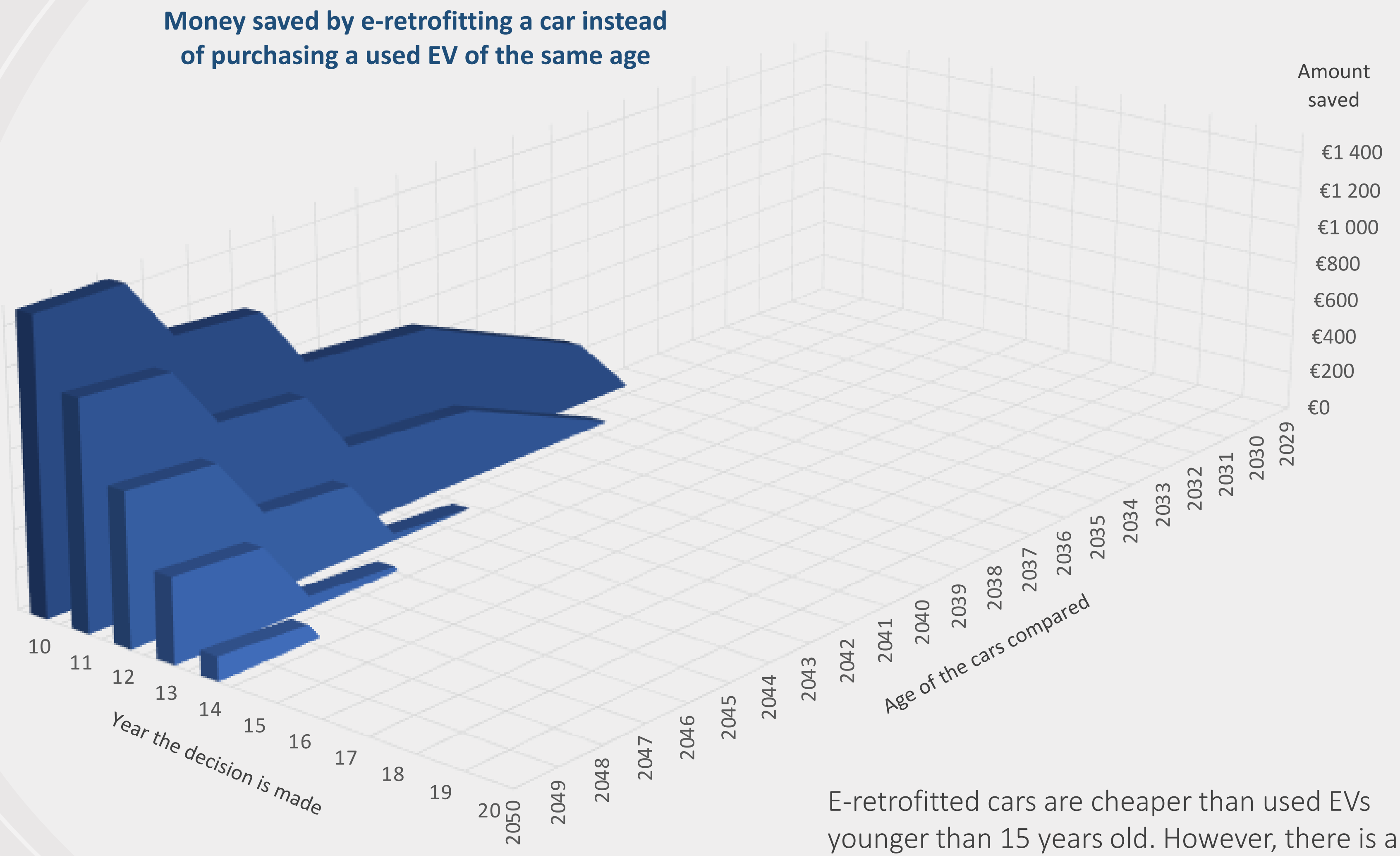


High Adoption Scenario

The starting **net** price drops even more than the gross price thanks to the introduction of subsidies, introduced in 2028 (€2,700) and increased from 2030 onwards (€5,000).

Money saved

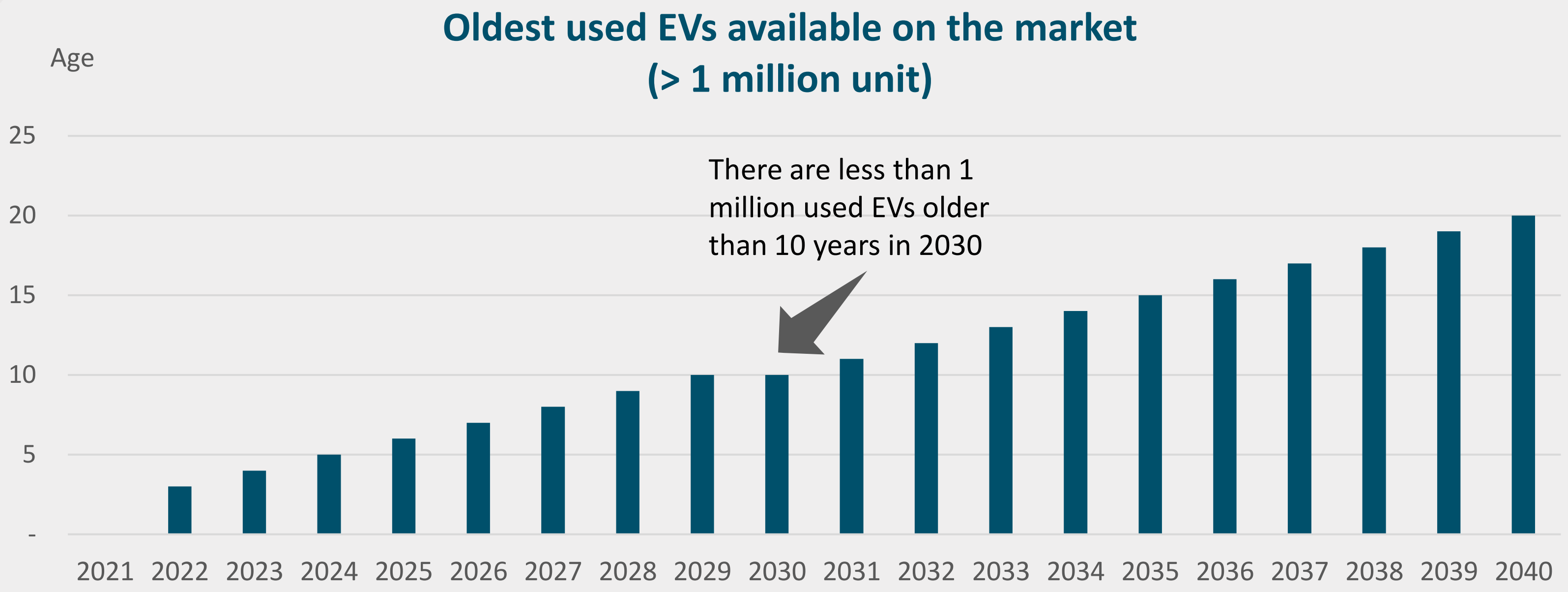
Comparison for a sample of small cars, including the cost of the donor car, subsidies, and VAT.



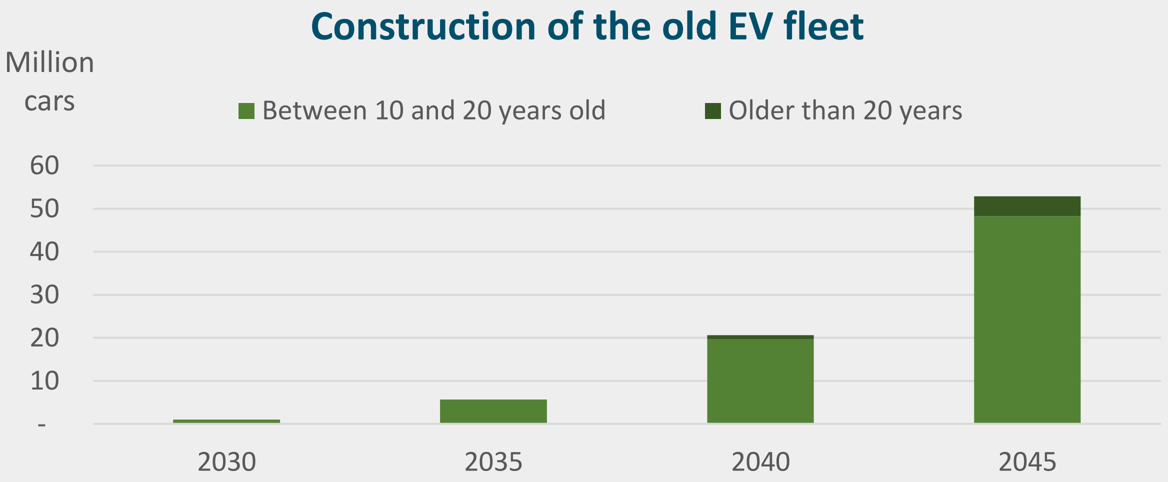
E-retrofitted cars are cheaper than used EVs younger than 15 years old. However, there is a shortage of old EVs on the market, so the competition from older EVs is limited.

High Adoption Scenario

Context: competition from used EVs



In this scenario, we assume that the increasing TCO of fossil cars triggers high demand for old EVs.



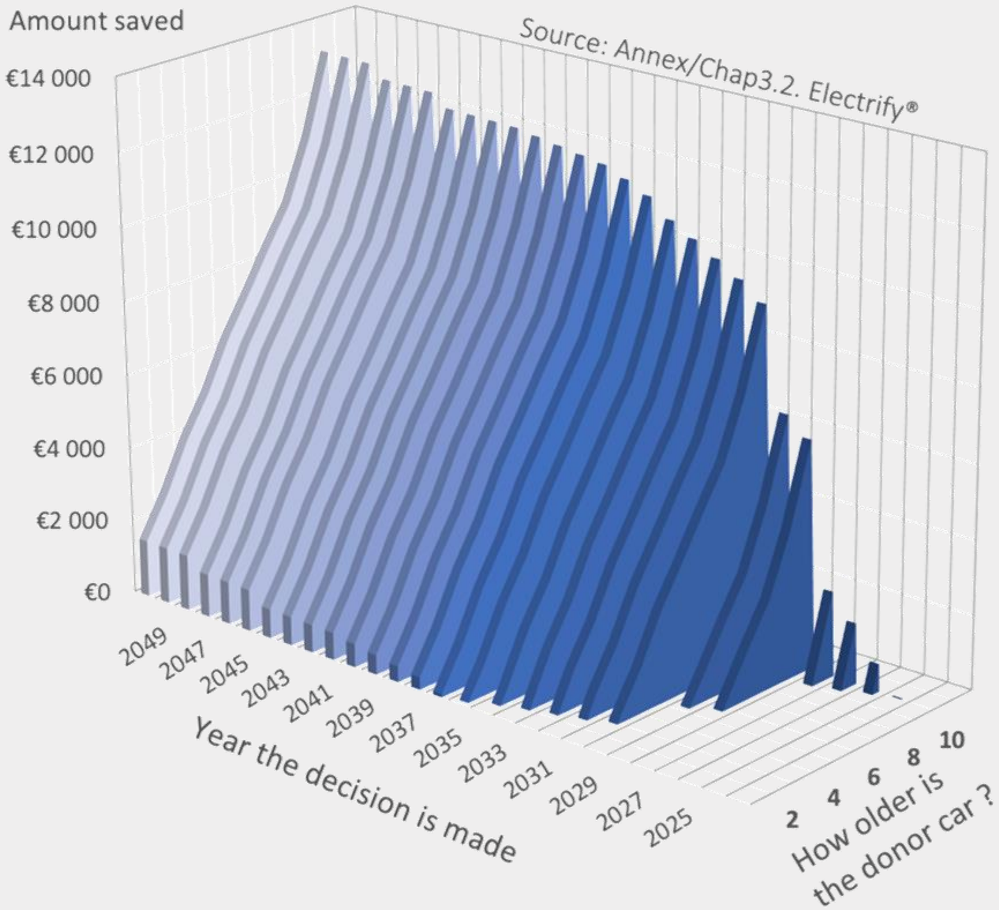
High Adoption Scenario

Money saved

Comparison for a sample of small cars, including the cost of the donor car, subsidies, and VAT.

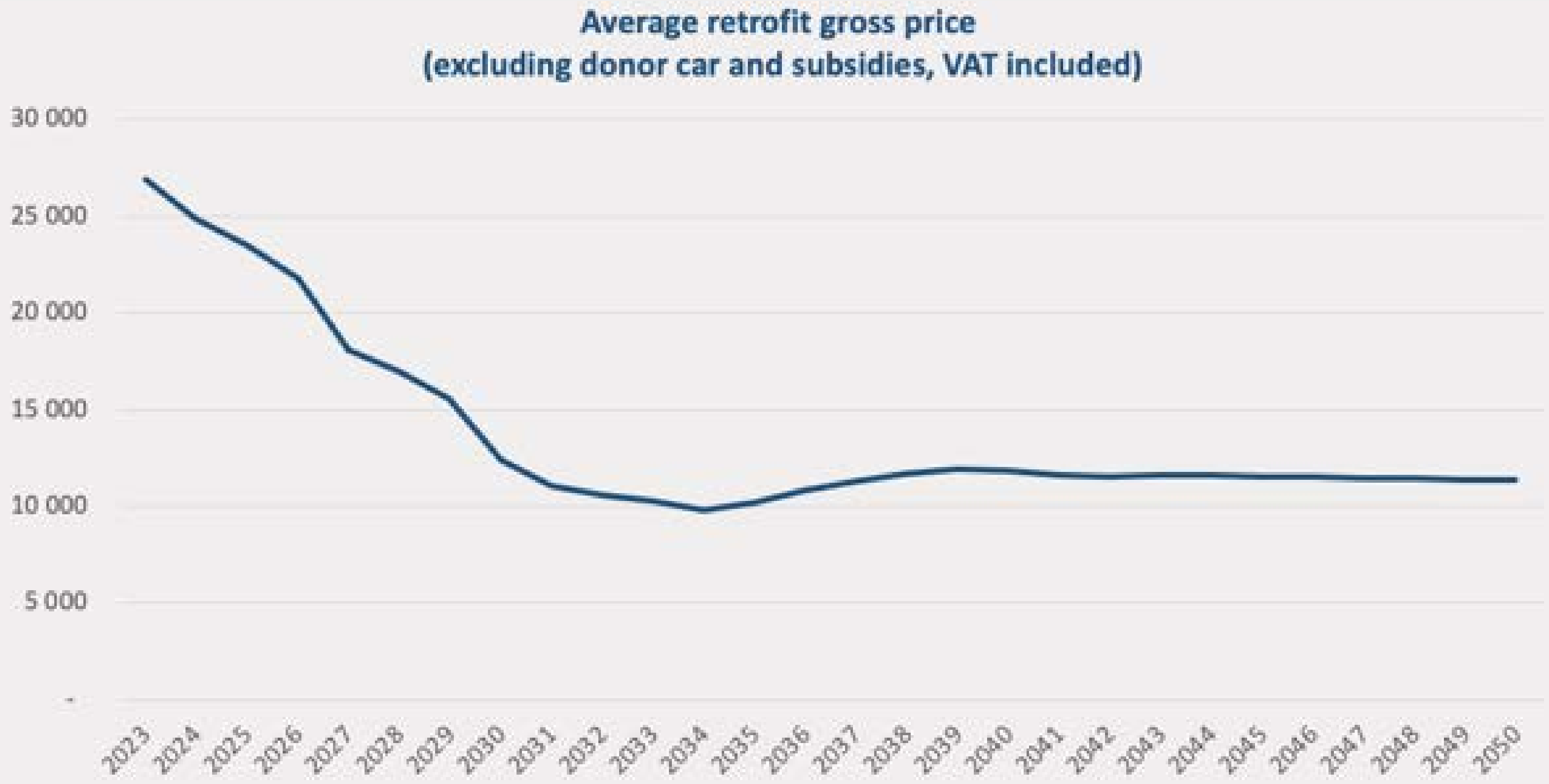
Starting price of a retrofit
(excluding donor car & subsidies)

Amount saved by e-retrofitting an old fossil car instead of purchasing a more recent used EV (including donor car & subsidies)



High Adoption Scenario

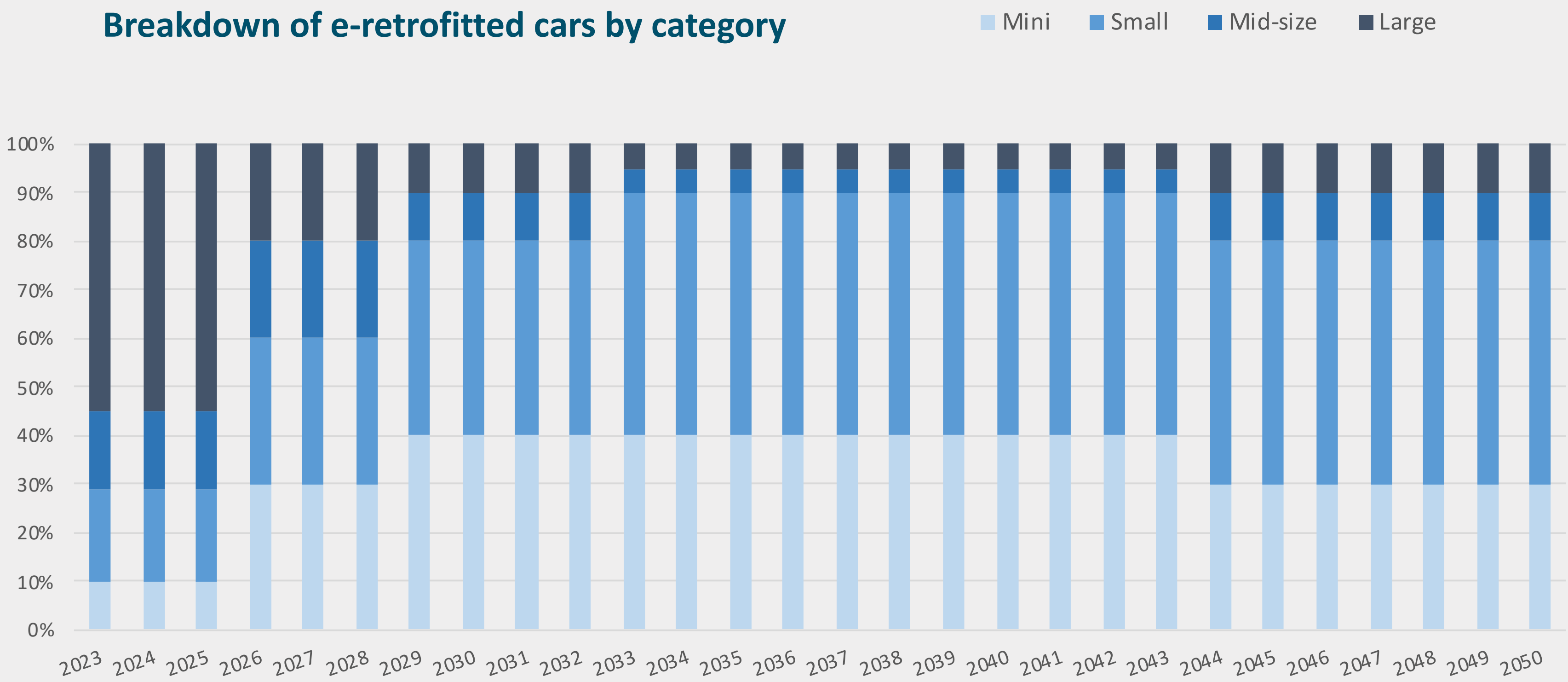
Average price



The average retrofit price of an ultra-low-cost conversion drops fast from 2023 to 2034 driven by economies of scale and a focus of conversions on small vehicles. After 2035 larger cars start to be retrofitted, which increases the average price.

High Adoption Scenario

Assumptions: Category Mix

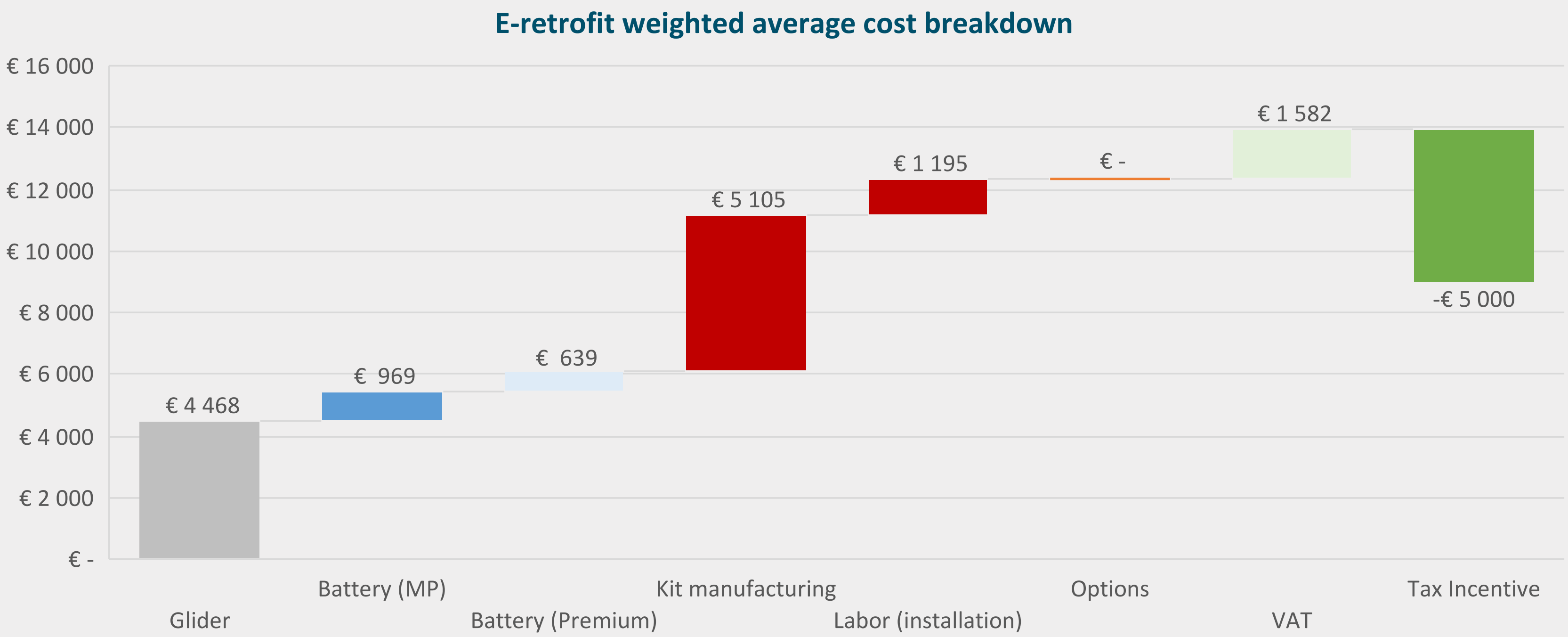


The category mix has a significant influence on the average e-retrofitted car price, and the total amount of VAT collected by Member States. In this scenario, the mix is aligned with the market at the beginning (when only vintage cars are retrofitted), then it becomes heavily tweaked towards mini and small cars when the market focuses on the affordable segment.

High Adoption Scenario

Breakdown of the average price

Once the price of batteries has dropped significantly, the largest cost items are kit manufacturing and the cost of the donor car. Subsidies play a significant role in keeping the price affordable.



Scenario
Parameters

Year of the decision	2045	ICE donor age	12
Battery density scenario	A -Li-Ion 2020 baseline	ICE Residual value scenario	Scenario
Battery market price	€45	Premium on battery price	€30
E-retrofit specific subsidy	-€5 000	Average retrofit price	€8 958
		Type of retrofit	Ultra-Low cost
Used EV age	12	Gain in efficiency Kit Prod.	25%
EV residual value scenario	Selected scenario	Labor cost	€32

High Adoption Scenario

Retail prices

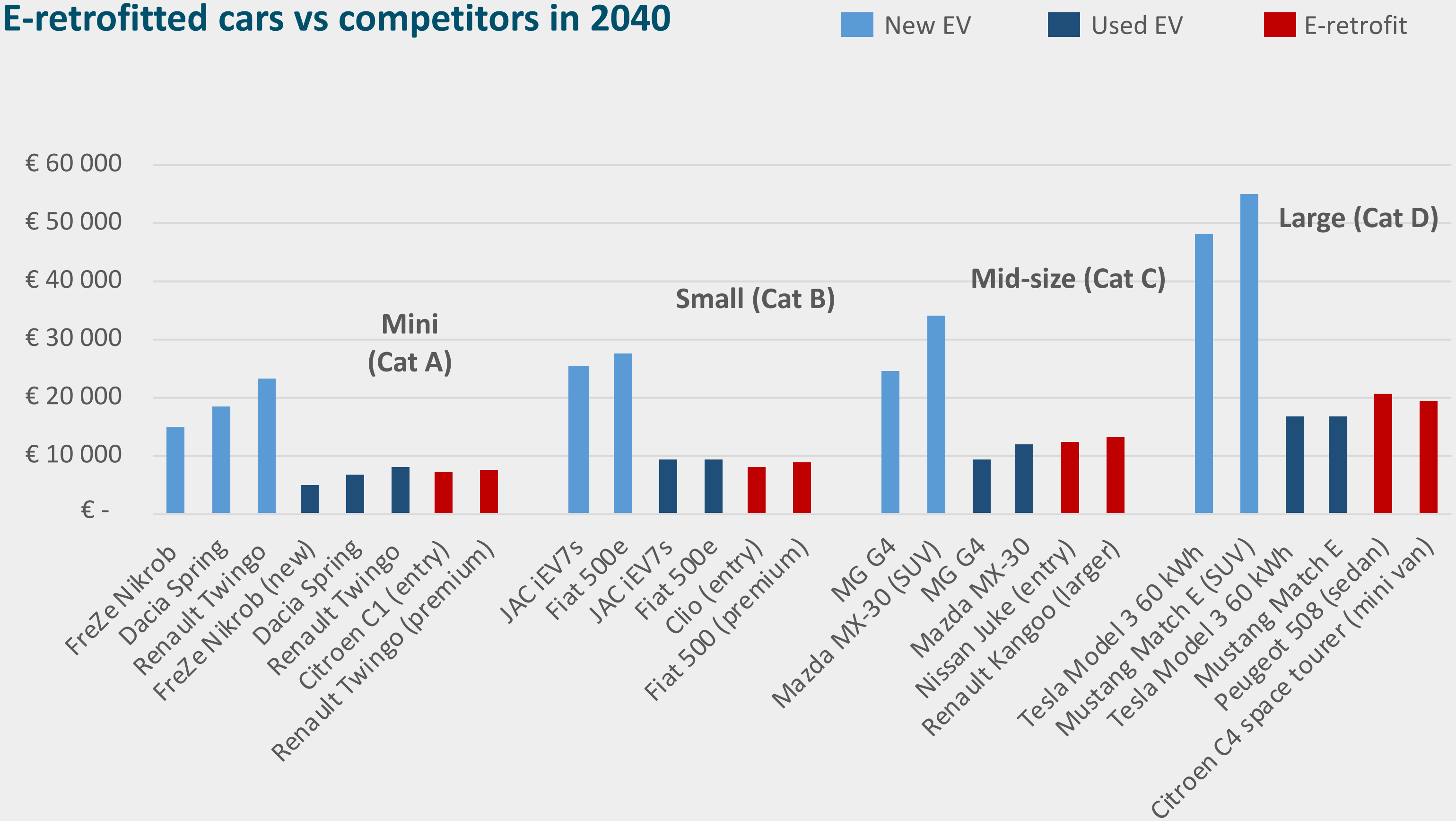
Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

High Adoption Scenario

Price parity with used EVs of the same age is achieved for small cars in 2040

E-retrofitted cars vs competitors in 2040



Scenario
Parameters

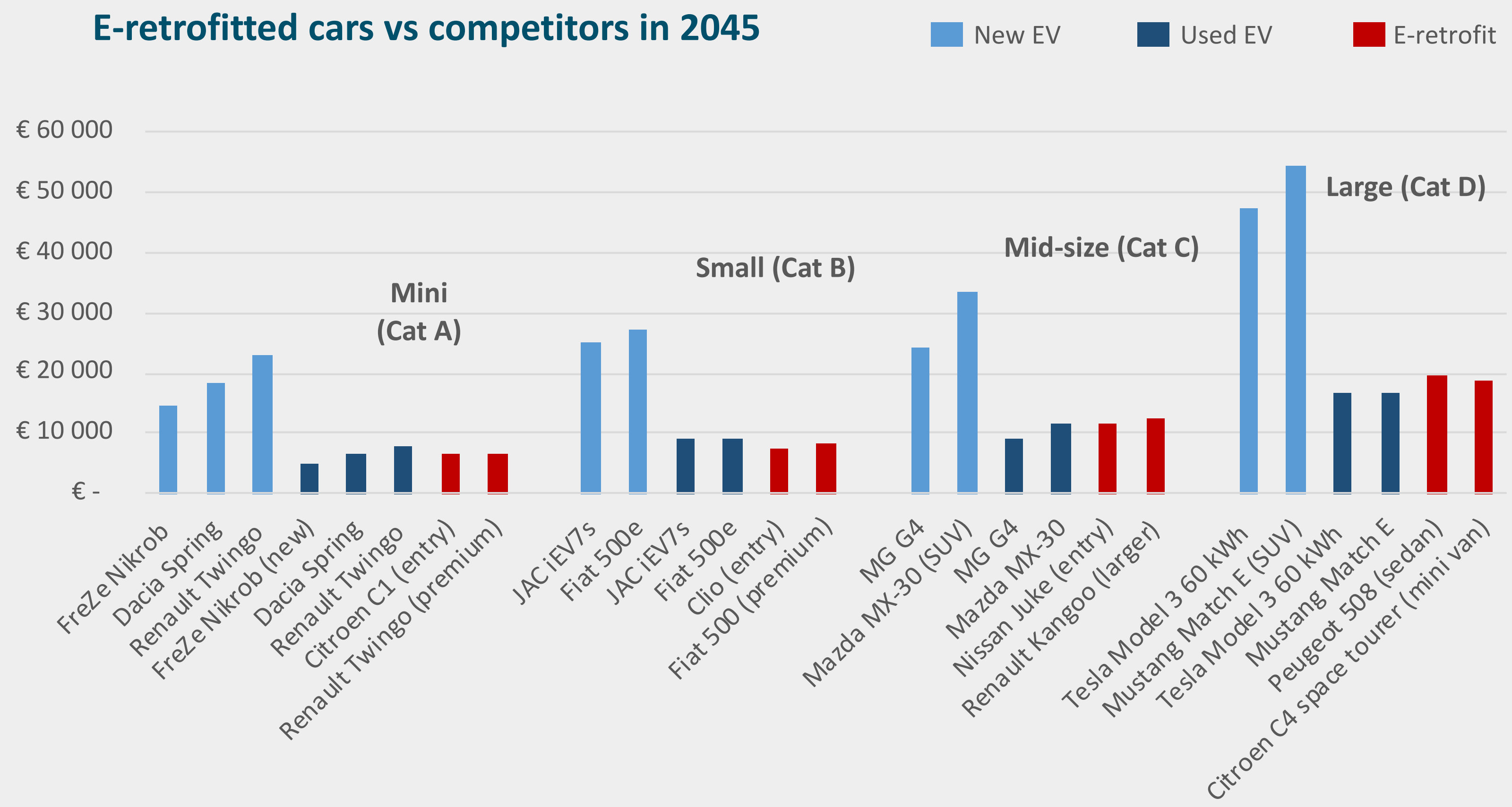
Year of the decision	2040	ICE donor age	12
Battery density scenario	A -Li-Ion 2020 baseline	ICE Residual value scenario	Scenario
Battery market price	€50	Premium on battery price	€30
E-retrofit specific subsidy	-€5 000	Average retrofit price	€8 563
		Type of retrofit	Ultra-Low cost
Used EV age	12	Gain in efficiency Kit Prod.	25%
EV residual value scenario	Selected scenario	Labor cost	€40

Retail prices

Including cost of the donor car, subsidies specific to e-retrofit and VAT.

Excluding subsidies applicable to all electric cars

High Adoption Scenario



Price parity with used EVs of the same age is achieved for mid-size cars cars in 2040

In the second phase (2028-2030), dedicated subsidies and changes in residual values enable e-retrofit to compete with used EVs in the affordable used car segment, for relatively older e-retrofitted cars

Parameters settings

Settings of the key parameters in the scenario. The settings migh change from one year to the next.

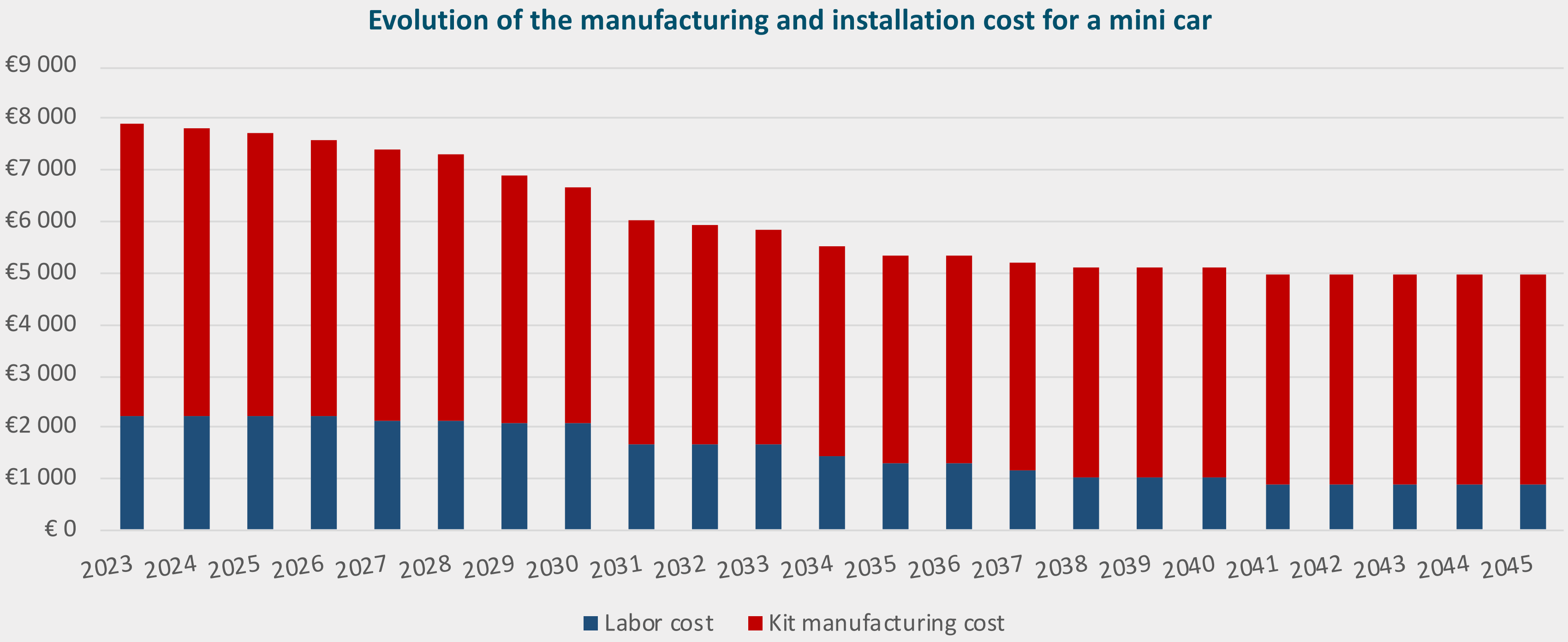
Certain advanced settings might not appear on this slide. Access the model itself for details.

Parameter	Settings in the scenario
Batteries market price	BNEF 2022 forecast/17% learning rate
Batteries energy density	Adoption of best available Li-on tech
Premium paid above market price	The premium paid drops to +66% in 2045.
Kit manufacturing cost	-25% over 2022-2035 then stagnates
Labor cost	Drops from €60/h in 2023 to €24/h after 2040
Average type of retrofit	Ultra-low cost
Subsidies	None until 2028 2,700€ from 2028 to 2030 5,000€ from 2030 to 2033 2,700€ from 3024 to 2035 1,500€ from 2036 to 2040
Fossil cars resale value	High depreciation curve (-20%) then price collapse curve (-80%)
EV resale value	High depreciation curve (+20%) then EV shortage curve (+70%)

1.5°C Scenario

Minimum cost

The cost excludes the cost of battery and VAT.

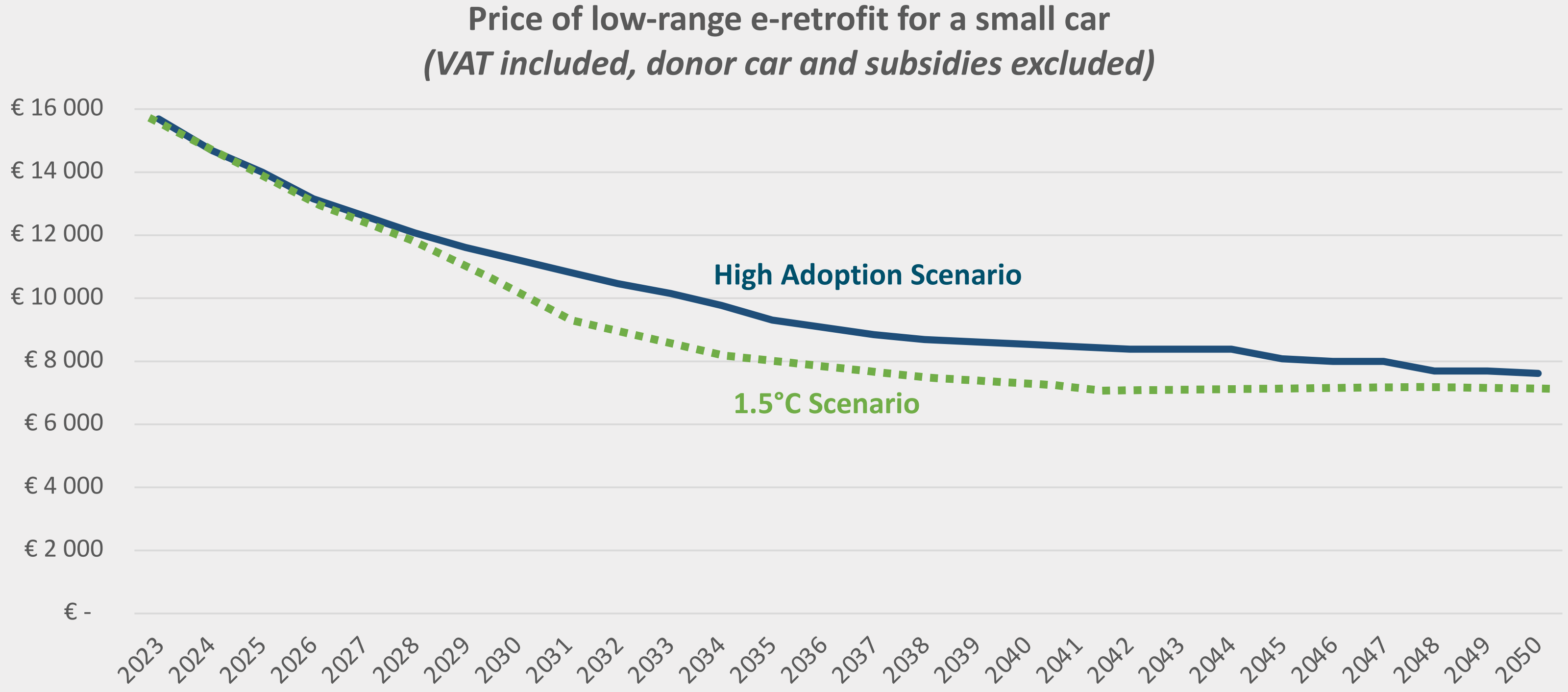


The entry price for retrofit (small car, ultra-low-cost retrofit, low range) drops by a factor of two driven by economies of scale and lower battery prices.

1.5°C Scenario

Starting gross price

The gross price excludes the cost of the donor car (resale value) and the subsidies. VAT is included.

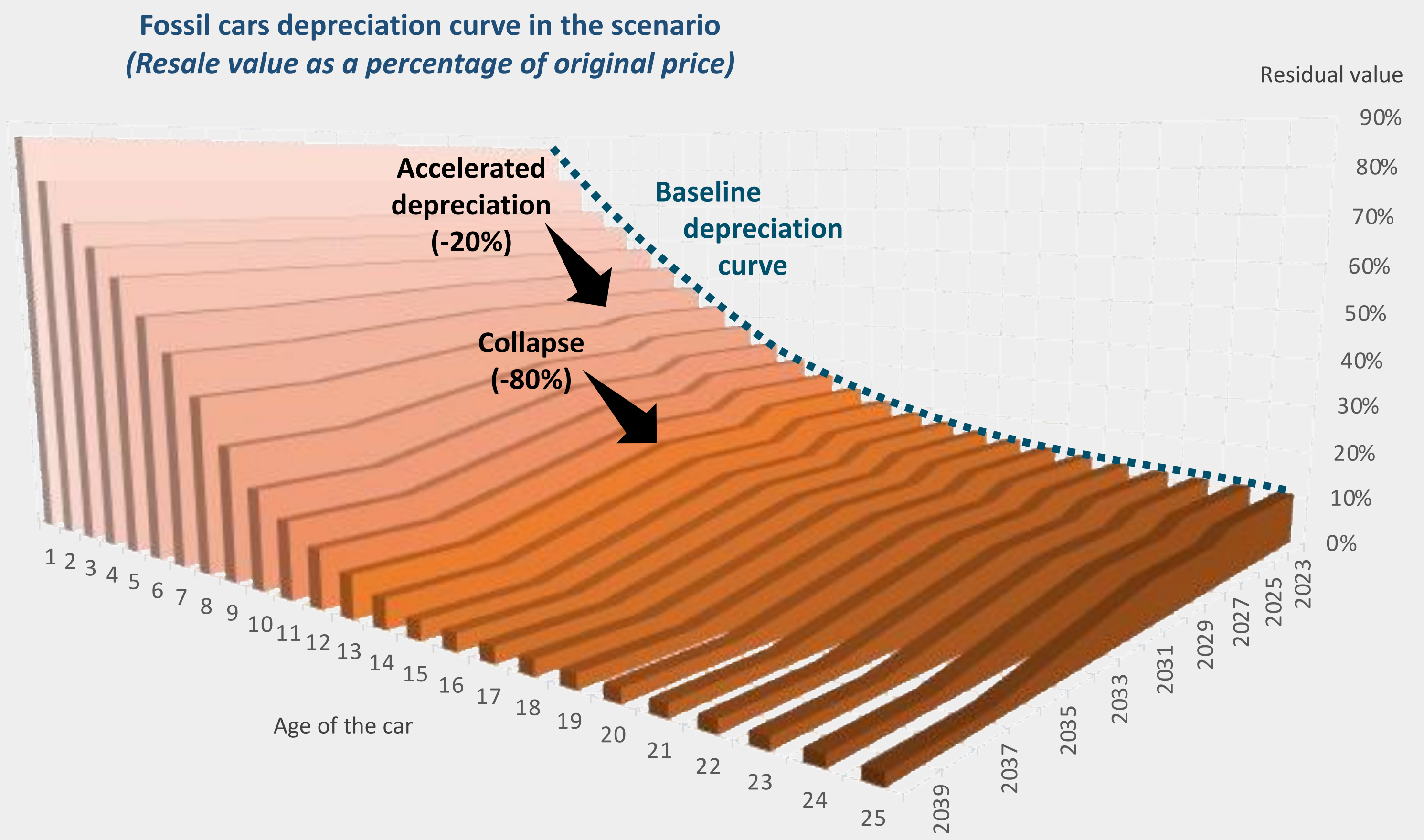


The entry price for retrofit (small car, ultra-low-cost retrofit, low range) drops by a factor of two driven by economies of scale and lower battery prices.

1.5°C Scenario

Resale value of the donor car

Key factor of competitiveness for e-retrofit in the scenario

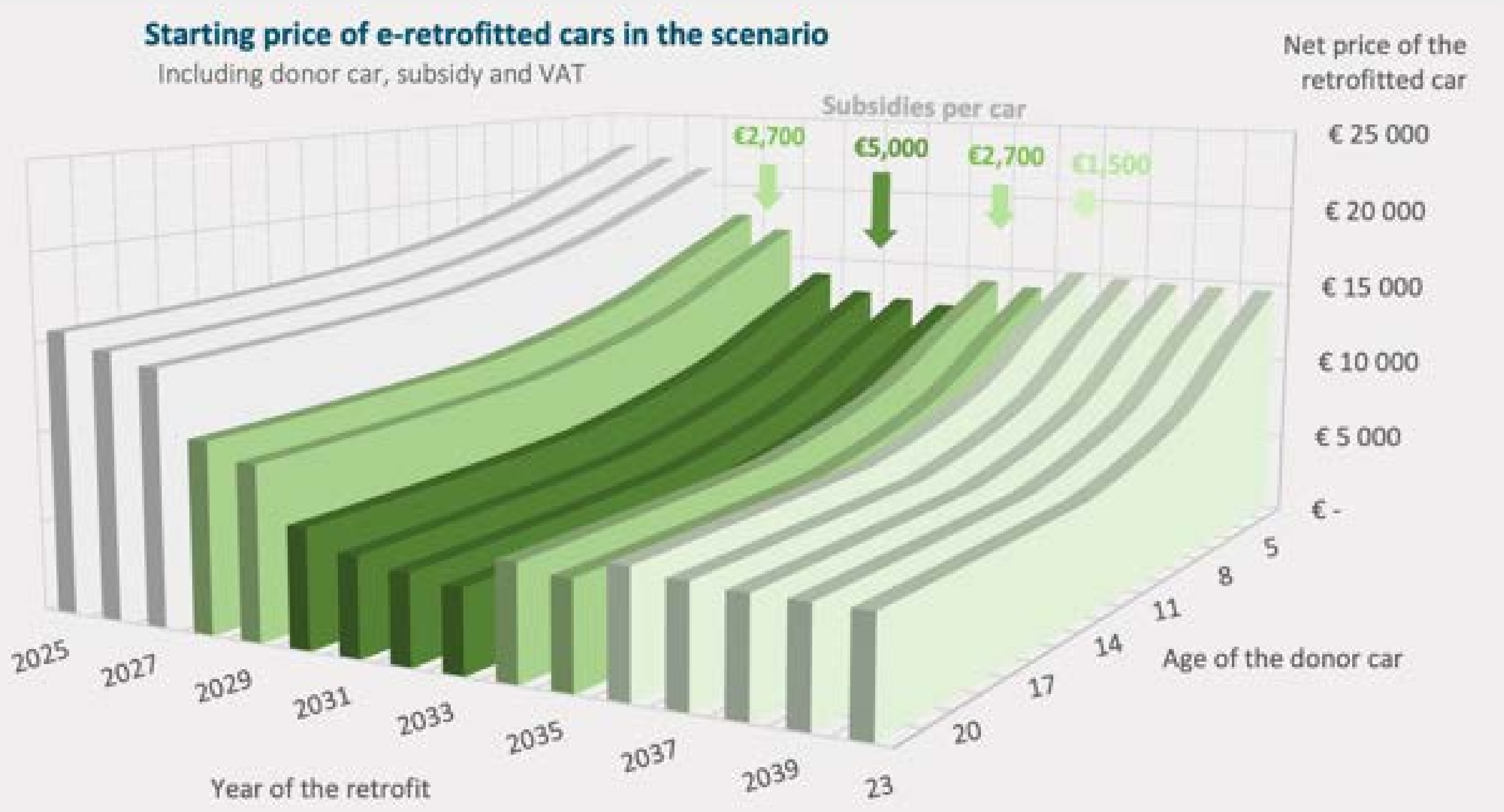


The depreciation of **old** fossil cars accelerates in 2028 by 20% due to regulatory pressure (taxes, LEZs) and collapses (-80% for third-hand cars and older relative to the baseline scenario) when expiration dates are introduced.

1.5°C Scenario

Starting net price

The net price includes the cost of the donor car (resale value), subsidies, and VAT.

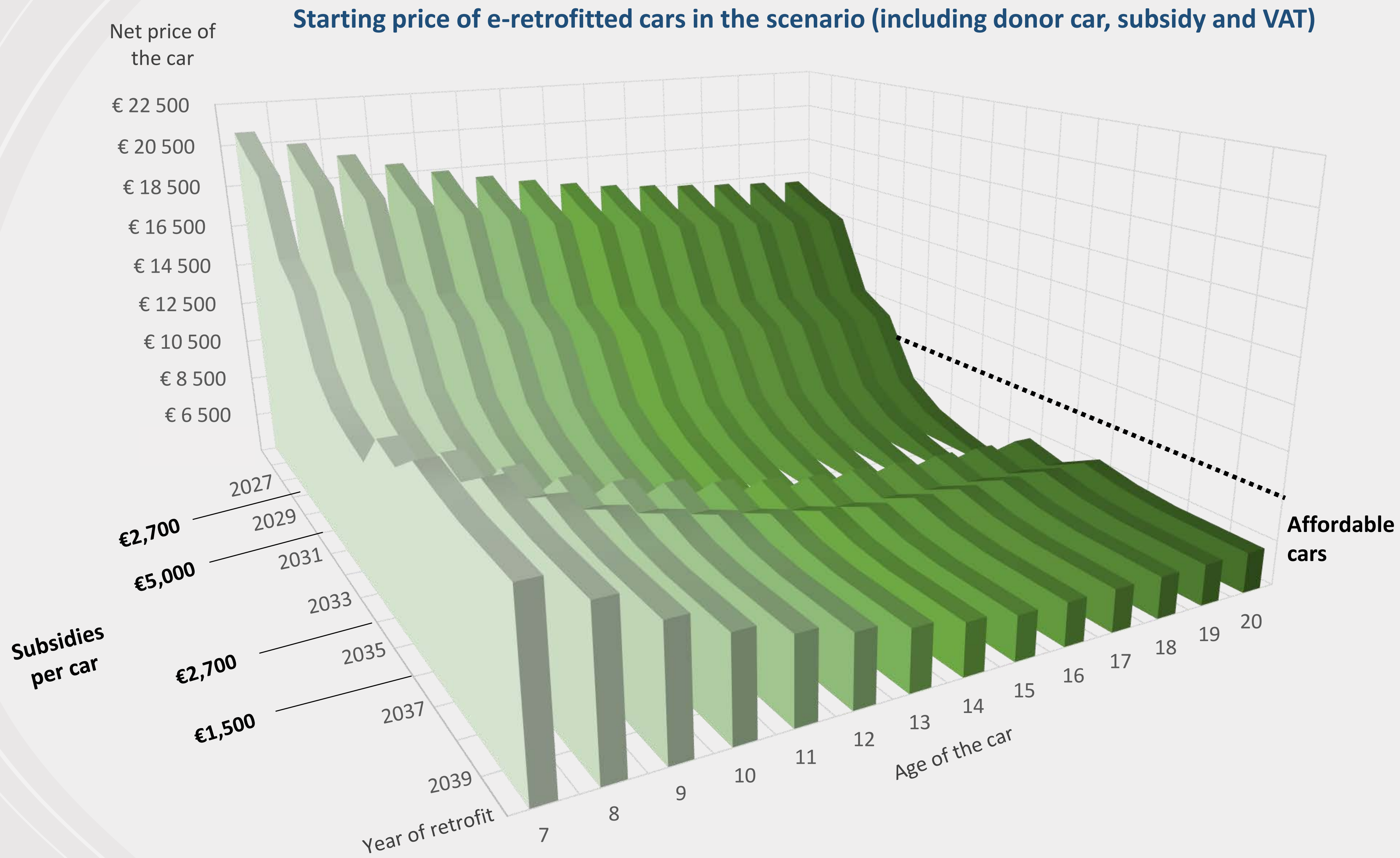


1.5°C Scenario

In practice, most consumers retrofit cars slightly older than the EV they would purchase (due to the shortage of old EVs), leading to even bigger savings.

Starting net price

The net price includes the cost of the donor car (resale value), subsidies, and VAT.

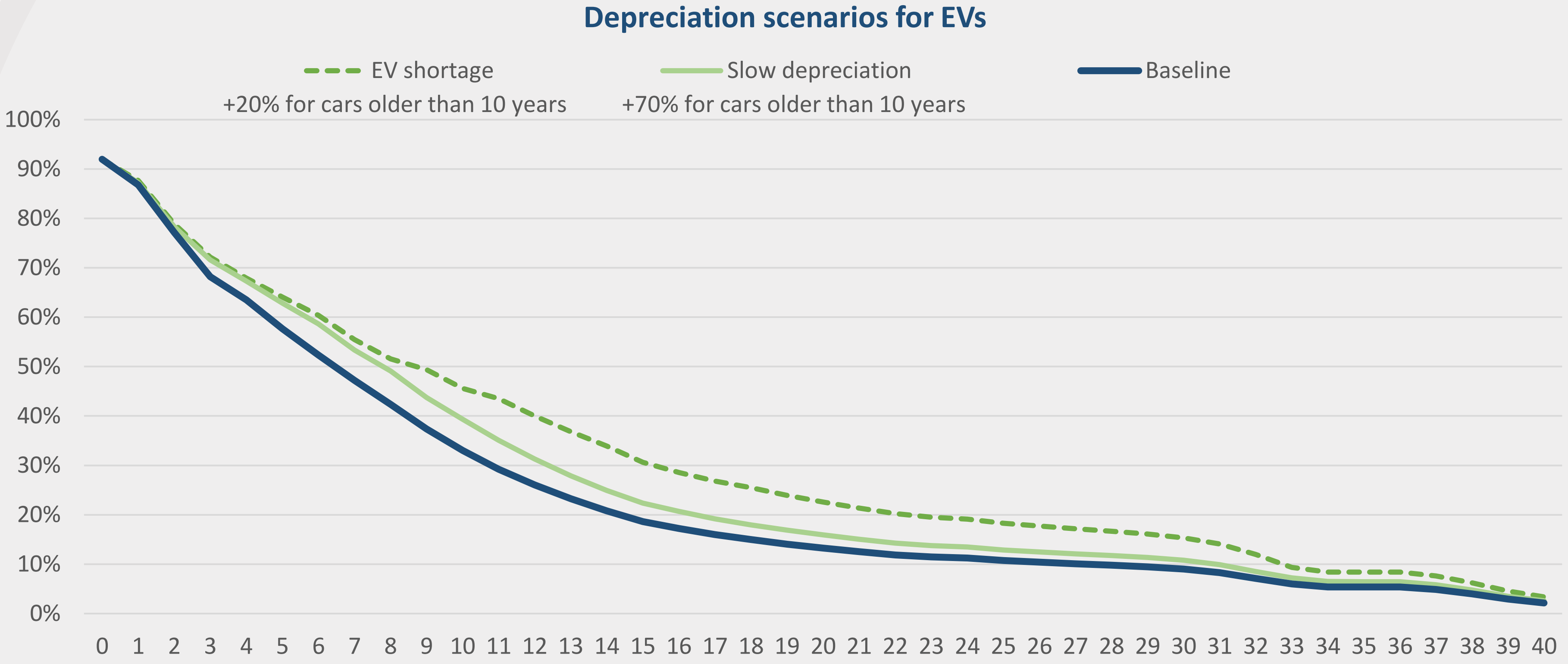


The starting **net** price drops even more thanks to two factors:

- The collapse of the resale value of donor cars from 2030 due to expiration dates.
- Subsidies, introduced in 2028 and increased from 2030 to 2033.

1.5°C Scenario

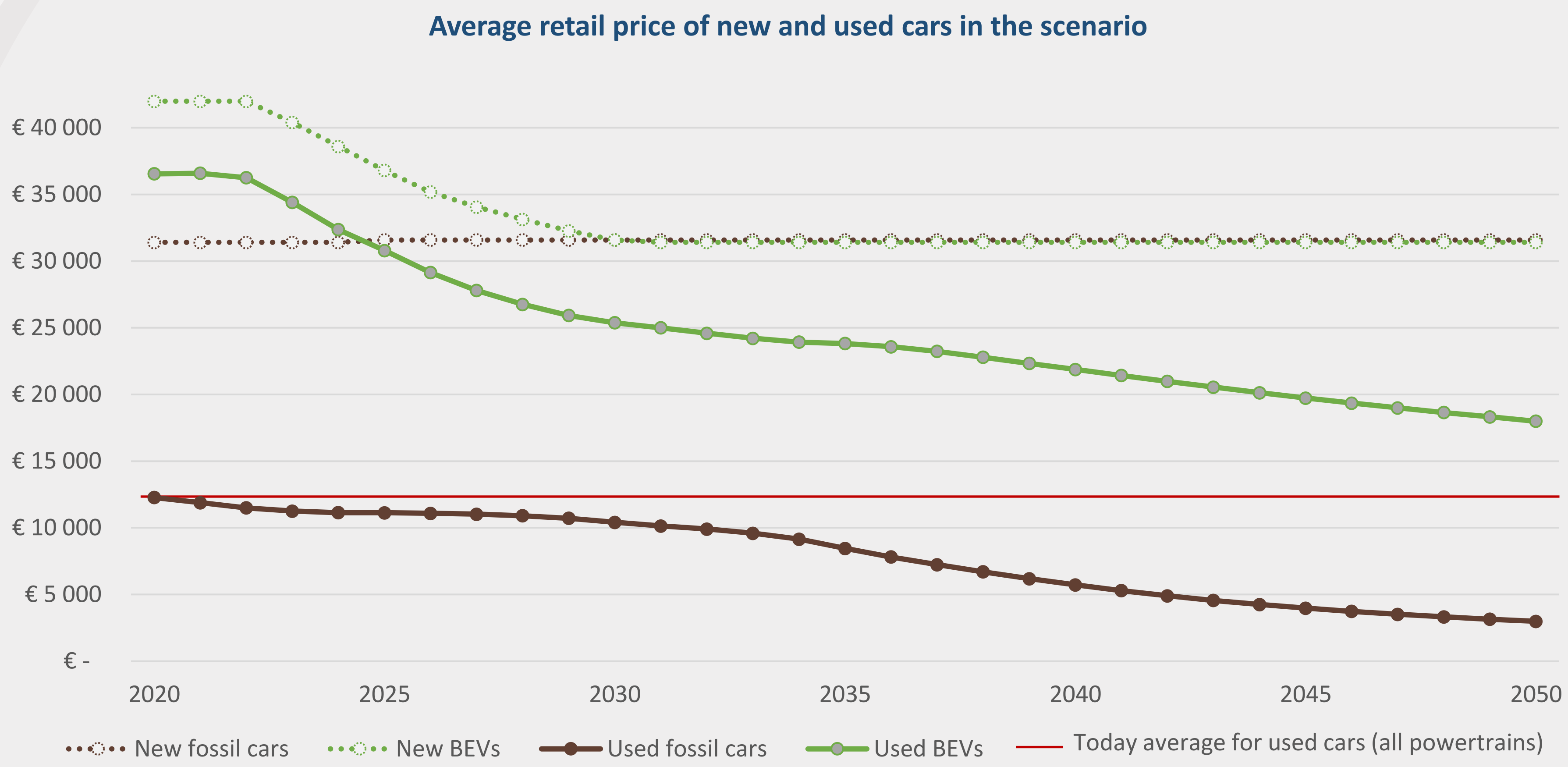
Assumption: Residual value of used EVs



The demand for affordable used EV rises from 2028 onwards, while less than 1 million EVs are 10 years or older: this situation triggers inflation for old used EVs (slow depreciation curve), which further increases in 2030 (EV shortage curve) when expiration dates on fossil cars are announced.

1.5°C Scenario

Assumption : Price of used EVs (subsidies excluded)



The demand for affordable used EV rises dramatically from 2028, while less than 1 million EVs are 10 years or older: this situation triggers inflation for old used EVs (+20%), which reaches +70% in 2030 when expiration dates on fossil cars are announced.

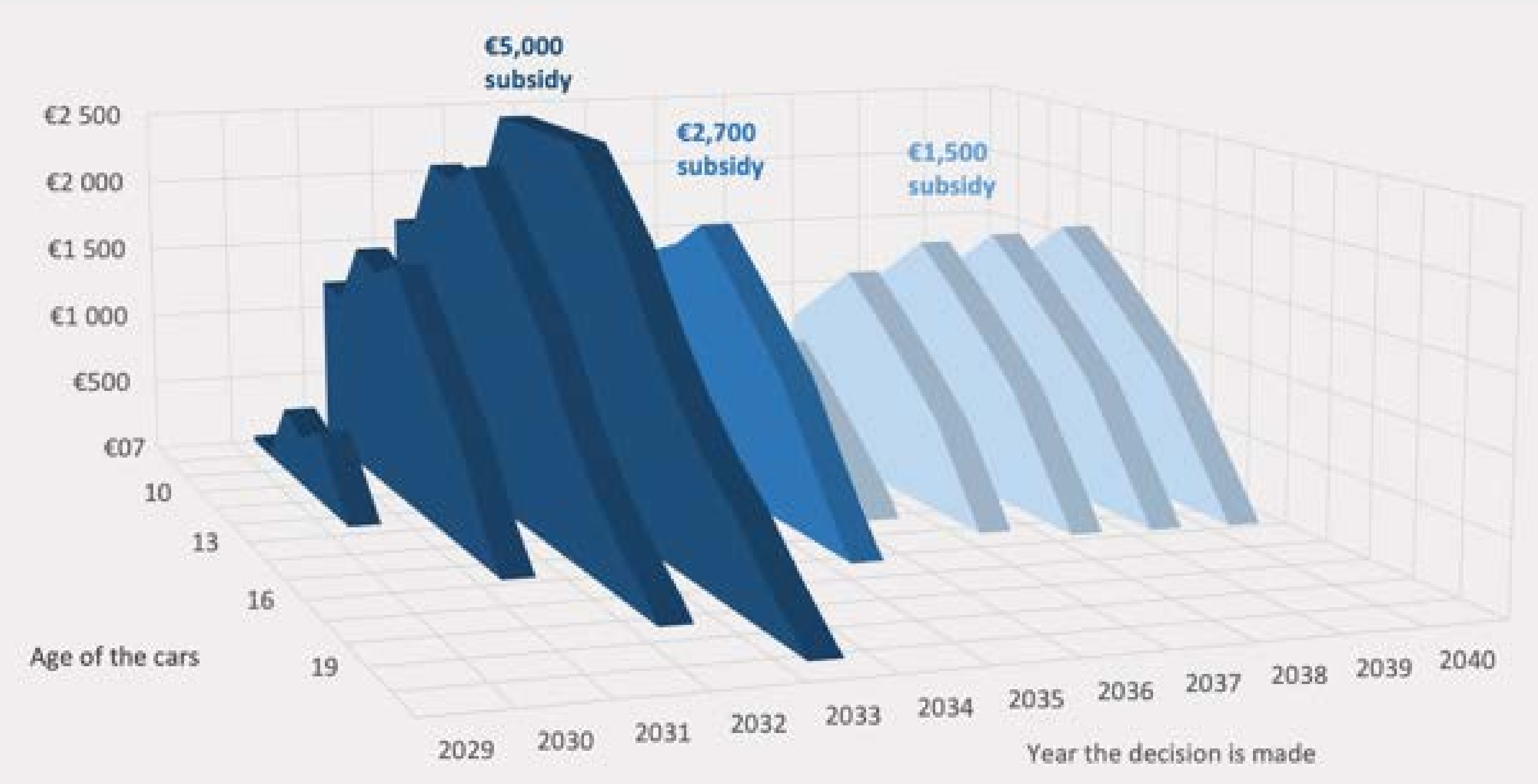
1.5°C Scenario

Money saved

Comparison for a sample of small cars, including the cost of the donor car, subsidies, and VAT.

Amount saved by e-retrofitting a car instead of purchasing a used EV of the same age

Including donor car, subsidy and VAT



When subsidies are at their peak, e-retrofit is economically preferable to purchasing an EV of the same age for all age groups: it helps generate a pool of affordable electric cars quickly.

1.5°C Scenario

Price comparison

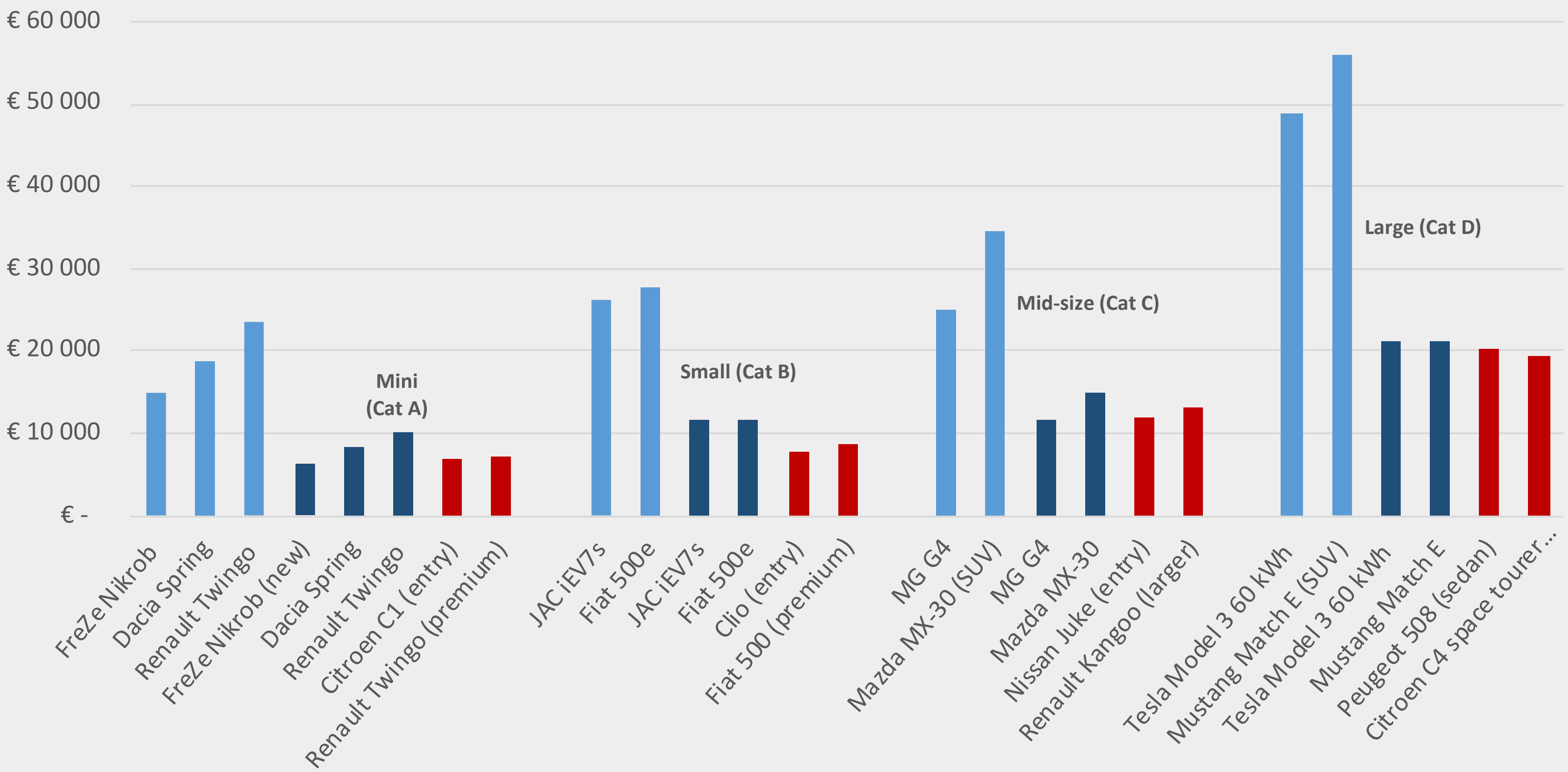
Across categories

1.5°C Scenario

During its peak, e-retrofit is more affordable than a used EV for all categories of cars

E-retrofitted cars vs competitors in 2032

Including donor car, subsidy and VAT.



Scenario

Parameters

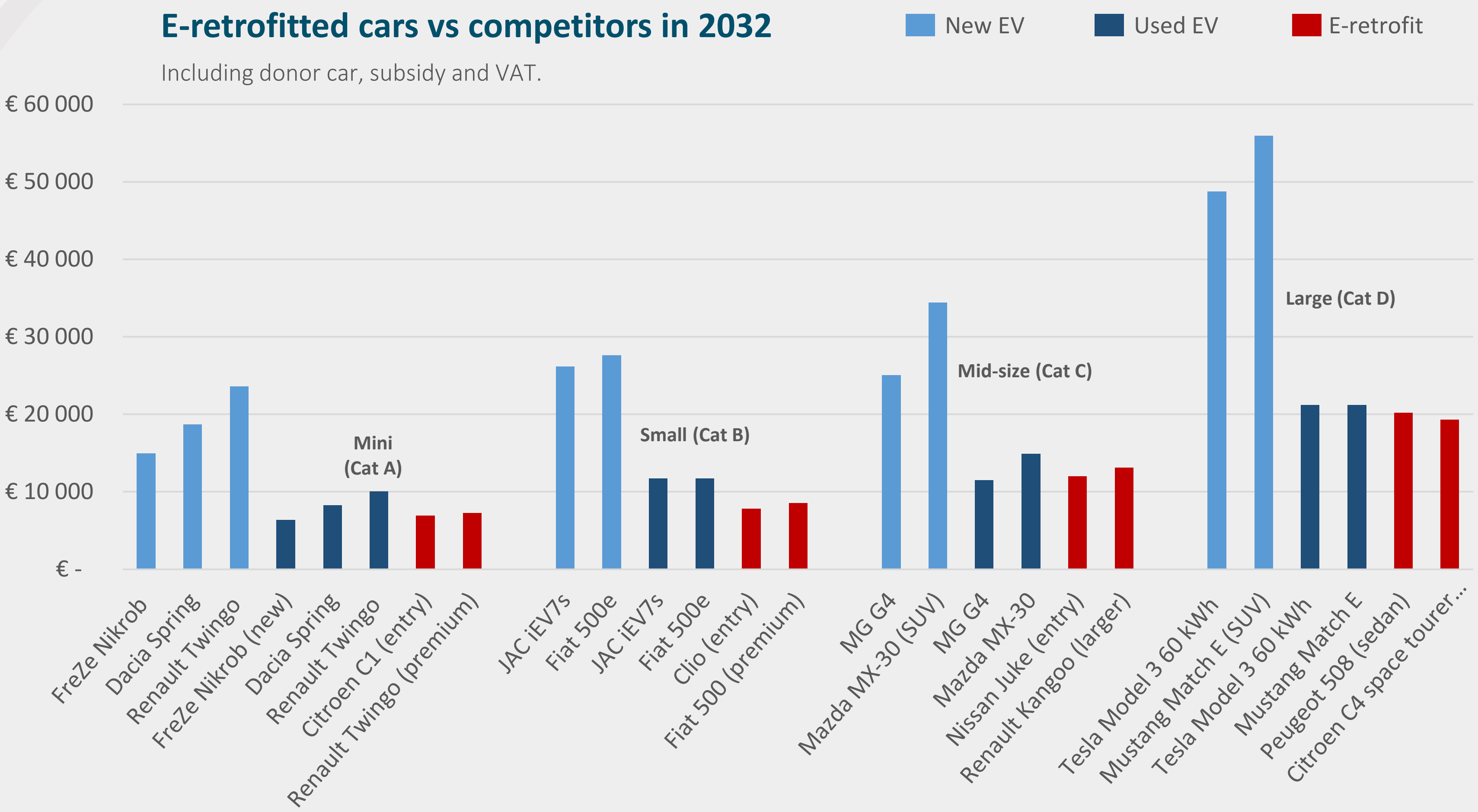
Year of the decision	2032	ICE donor age	12
Battery density scenario	A -Li-Ion 2020 baseline	ICE Residual value scenario	Scenario
Battery market price	€63	Premium on battery price	€26
E-retrofit specific subsidy	-€5 000	Average retrofit price	€9 881
		Type of retrofit	Ultra-Low cost
Used EV age	12	Gain in efficiency Kit Prod.	26%
EV residual value scenario	Selected scenario	Labor cost	€45

Price comparison

Across categories

1.5°C Scenario

During its peak, e-retrofit is more affordable than a used EV for all categories of cars



Scenario
Parameters

Year of the decision	2032
Battery density scenario	A -Li-Ion 2020 baseline
Battery market price	€63
E-retrofit specific subsidy	-€5 000
Used EV age	12
EV residual value scenario	Selected scenario

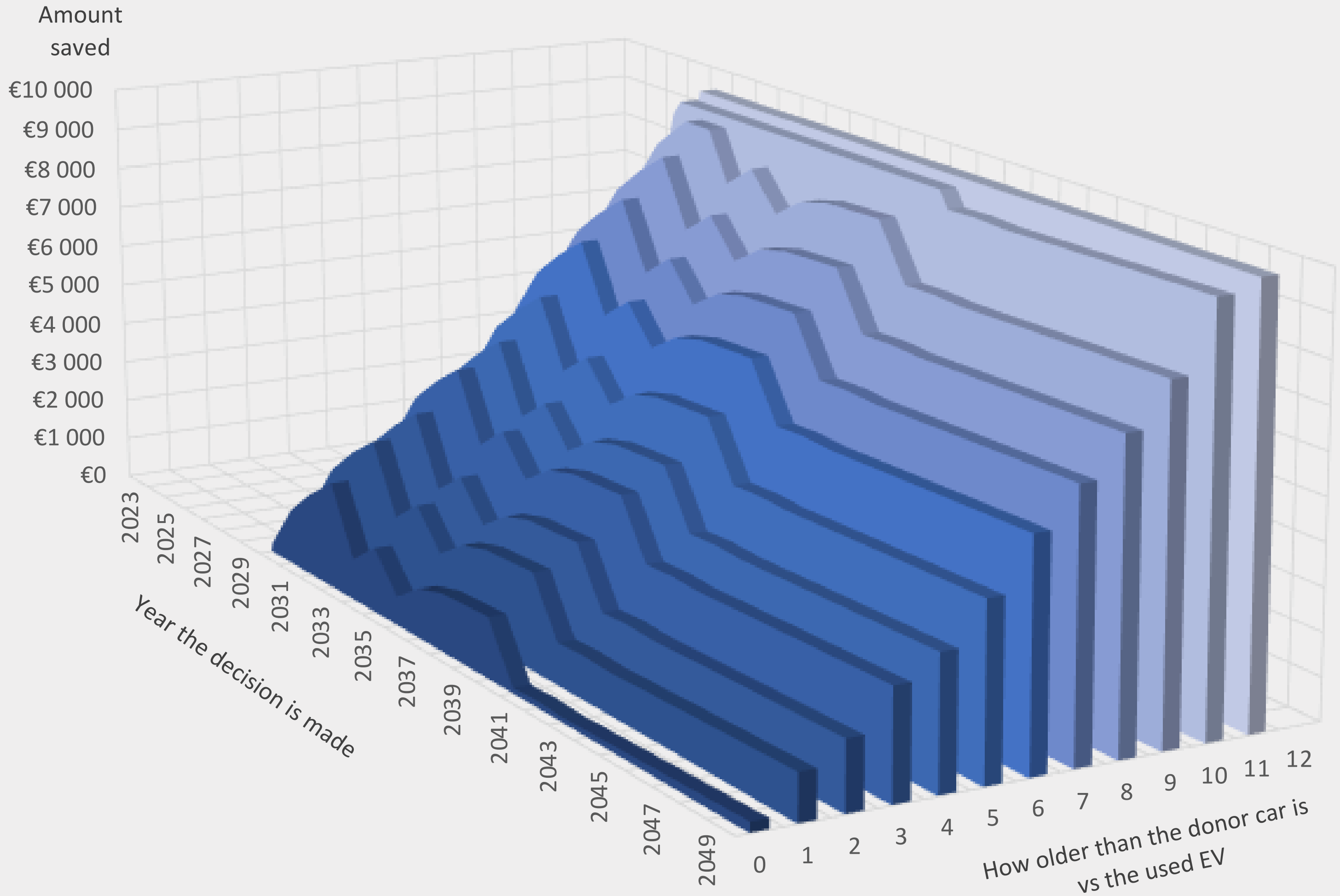
ICE donor age	12
ICE Residual value scenario	Scenario
Premium on battery price	€26
Average retrofit price	€9 881
Type of retrofit	Ultra-Low cost
Gain in efficiency Kit Prod.	26%
Labor cost	€45

Starting net price

The net price includes the cost of the donor car (resale value), subsidies, and VAT.

1.5°C Scenario

Amount saved by e-retrofitting a car instead of purchasing an younger used EV



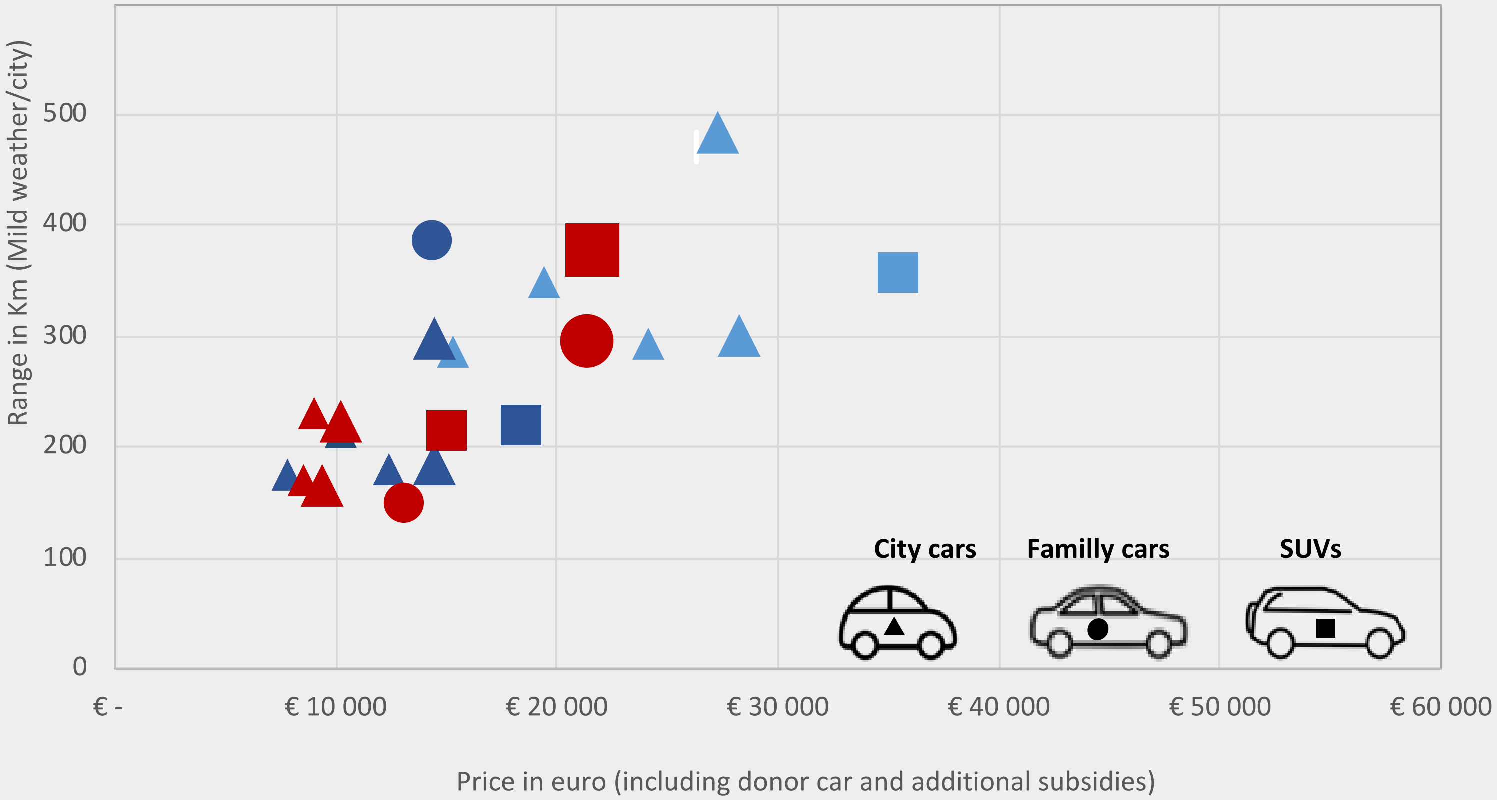
In practice, most consumers retrofit cars slightly older than the EV they would purchase (due to the shortage of old EVs), leading to even bigger savings.

Long-range retrofits

The net price includes the cost of the donor car (resale value), subsidies, and VAT.

1.5°C Scenario

Thanks to higher battery energy density and lower prices e-retrofitted cars with long-range options also reach range parity with the 2022 generation of used EVs



Price parity scenario analysis: E-retrofit vs new & used EVs

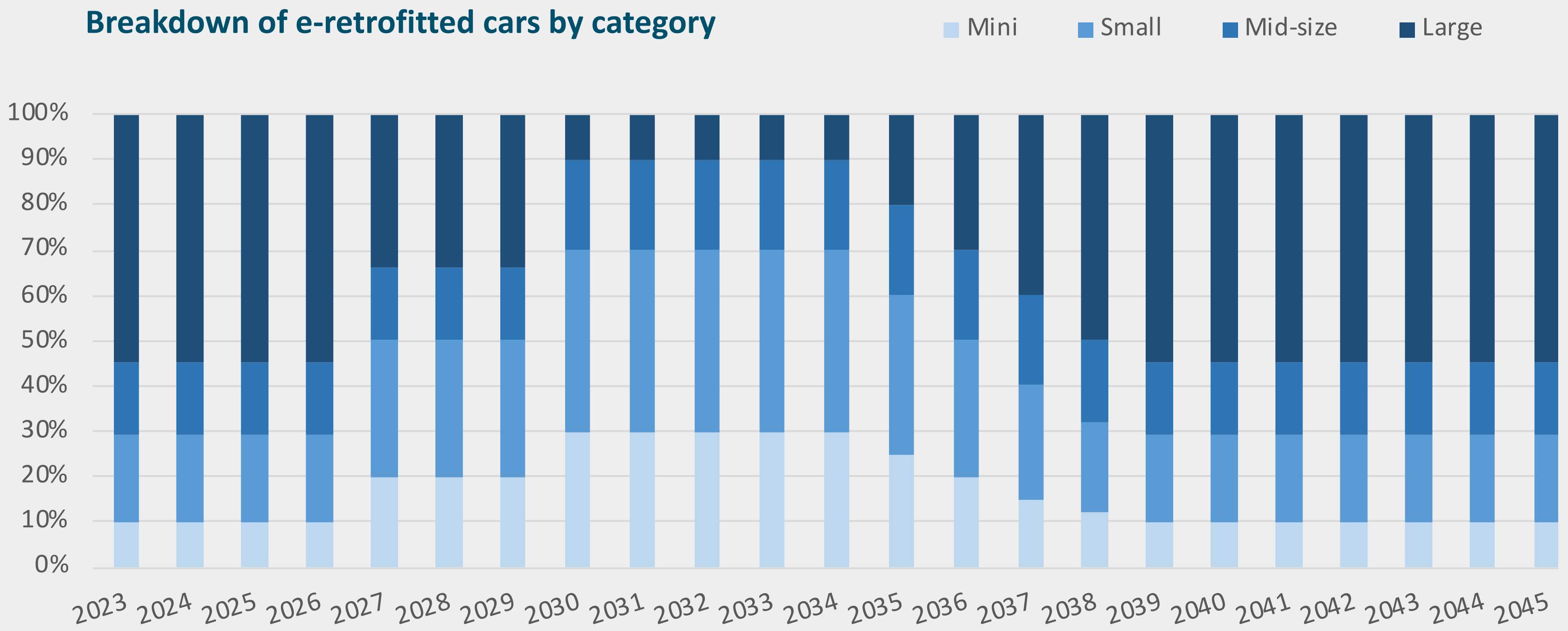
New EV Used EV E-retrofit

Scenario
Parameters

Year of the decision	2035	ICE donor age	12
Battery density scenario	G - Solid State 2035 scenario High	ICE Residual value scenario	Scenario
Battery market price	€56	Premium on battery price	€21
E-retrofit specific subsidy	-€2 700	Average retrofit price	€12 793
		Type of retrofit	Ultra-Low cost
Used EV age	9	Gain in efficiency Kit Prod.	30%
EV residual value scenario	Selected scenario	Labor cost	€35

Category Mix

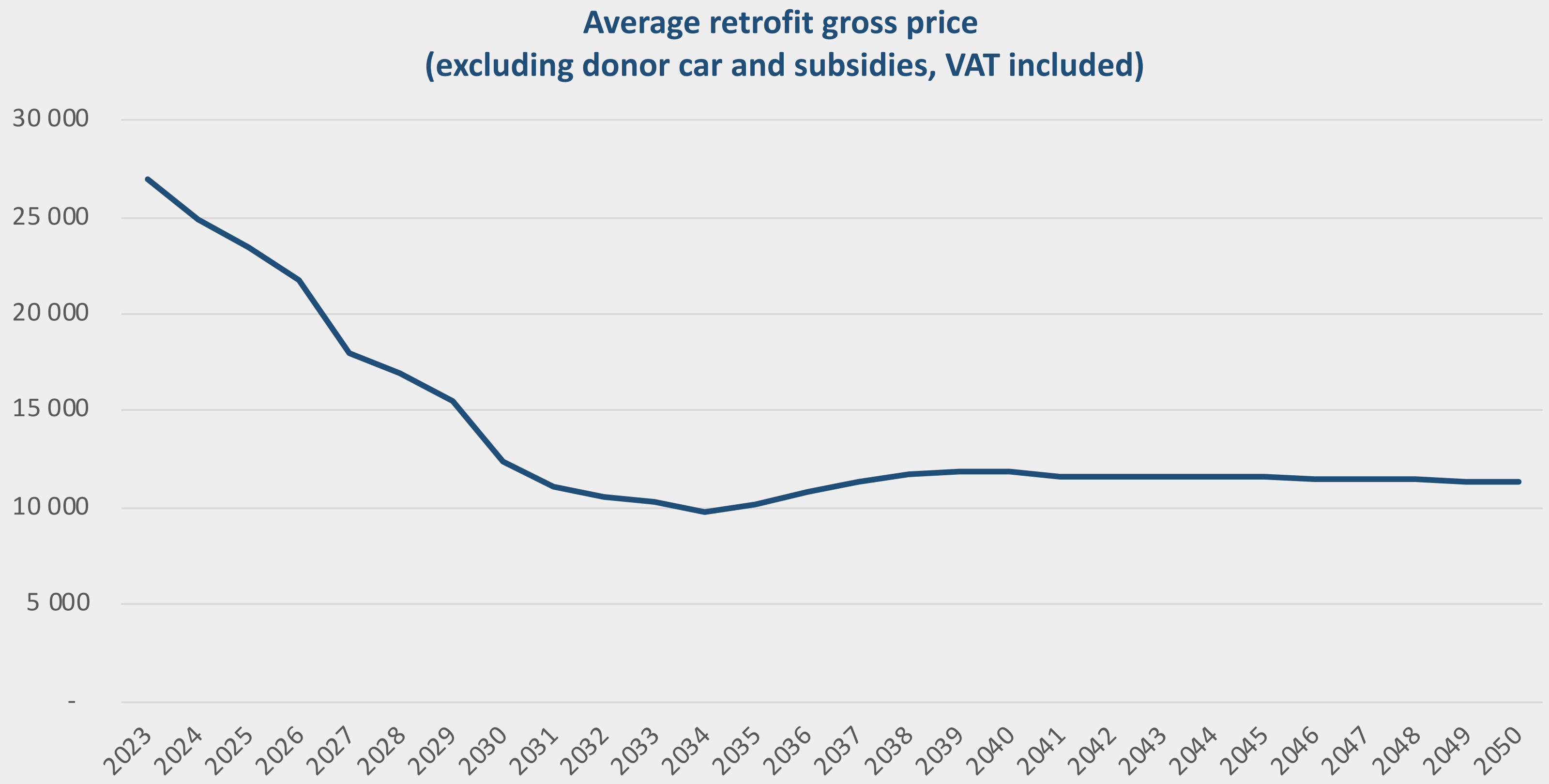
1.5°C Scenario



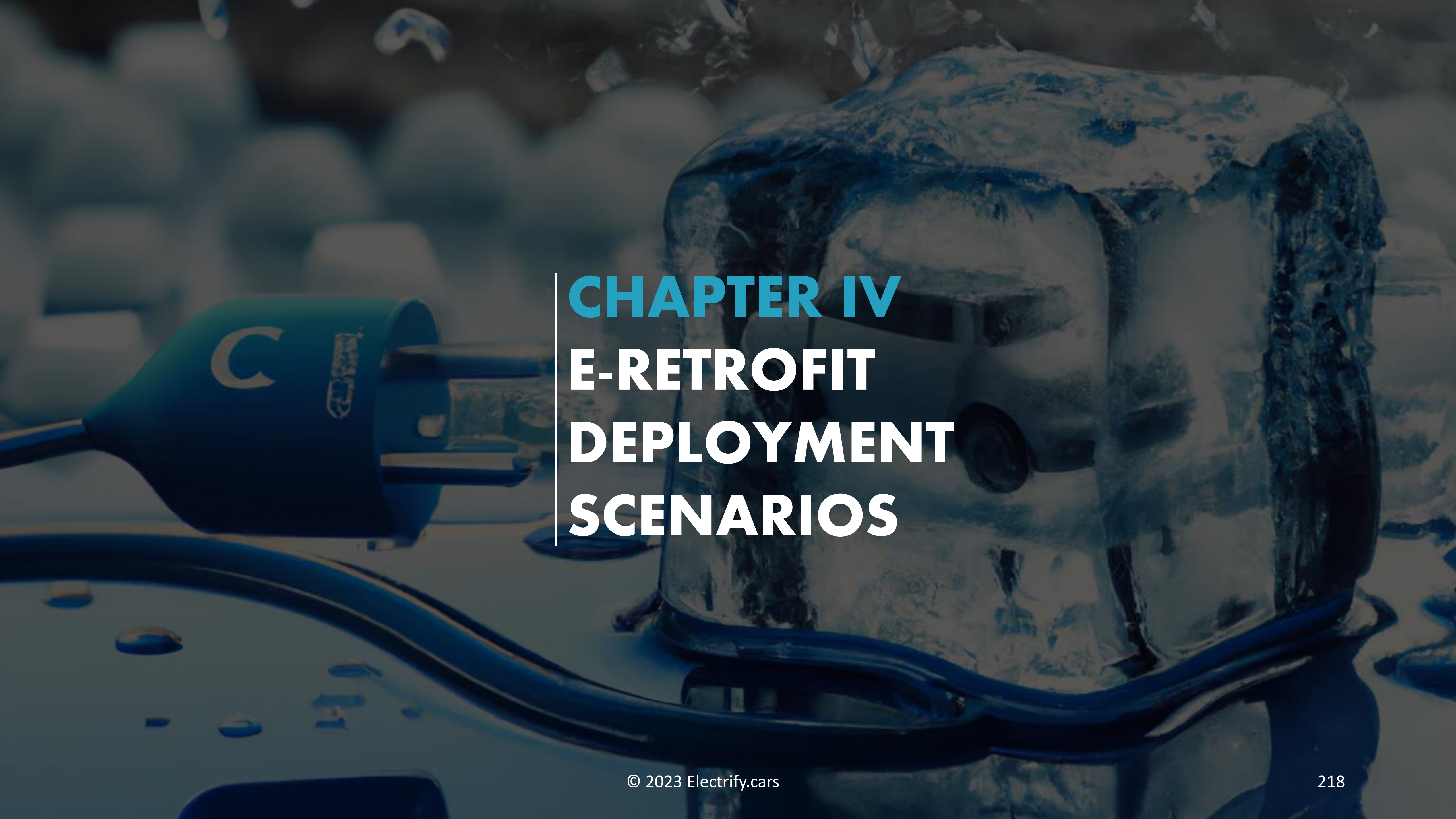
The category mix significantly influences the average e-retrofitted car price (previous slide), and the total amount of VAT collected by Member States. In this scenario, the mix is aligned with the market at the beginning (when only vintage cars are retrofitted), then it becomes heavily tweaked towards mini and small cars when the market focuses on the affordable segment. Finally, it realigns with the average market mix at the end of the period, when e-retrofit (or scrapping) becomes mandatory for all cars.

Average gross price

1.5°C Scenario



The average retrofit price of an ultra-low-cost conversion drops fast from 2023 to 2034 driven by economies of scale and a focus of conversions on small vehicles. After 2035 larger cars start to be retrofitted, which increases the average price.



CHAPTER IV
E-RETROFIT DEPLOYMENT SCENARIOS

1. Review of third-party forecast

2. Technology adoption curves

3.1 Low Adoption Scenario

3.2 High Adoption Scenario

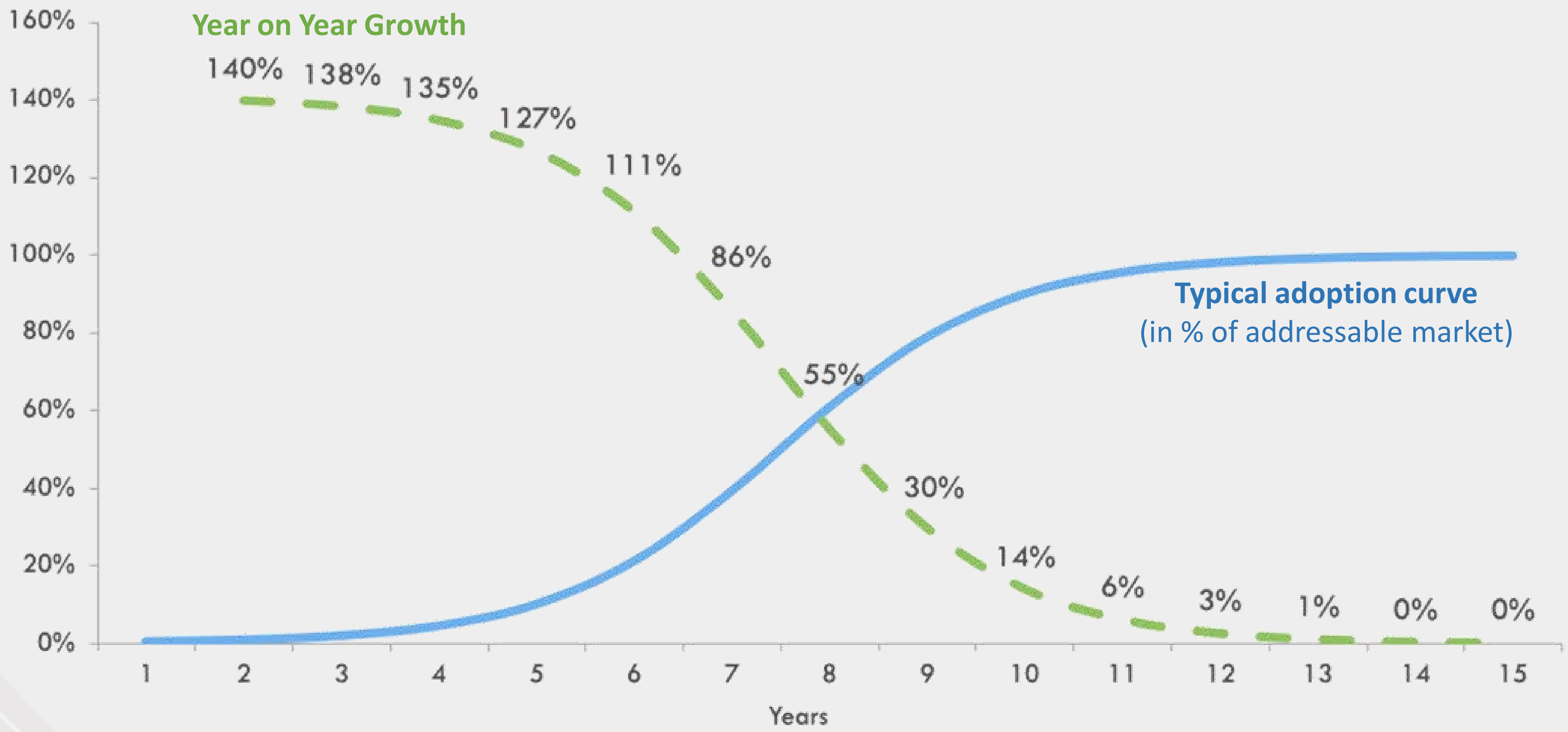
3.3 1.5°C Scenario

3.4 Comparing scenarios

- 1. Review of third-party forecast
- 2. Technology adoption curves
- 3.1 Low Adoption Scenario
- 3.2 High Adoption Scenario
- 3.3 High Adoption Scenario
- 3.4 Comparing scenarios

Starting point: Adoption curves

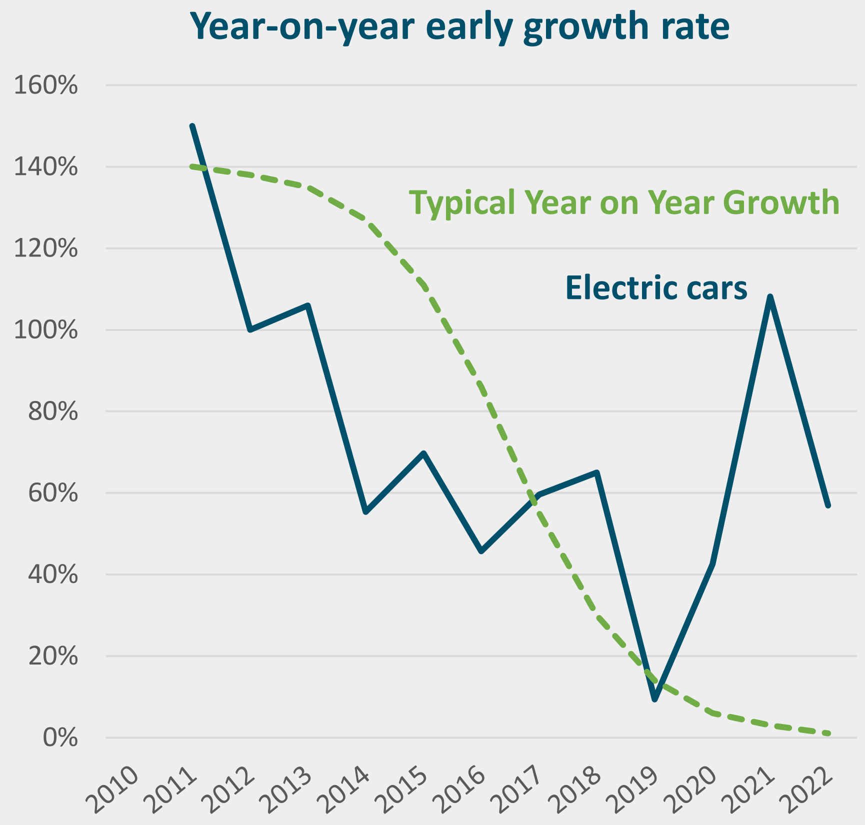
Typical adoption curve and growth rate for new technologies

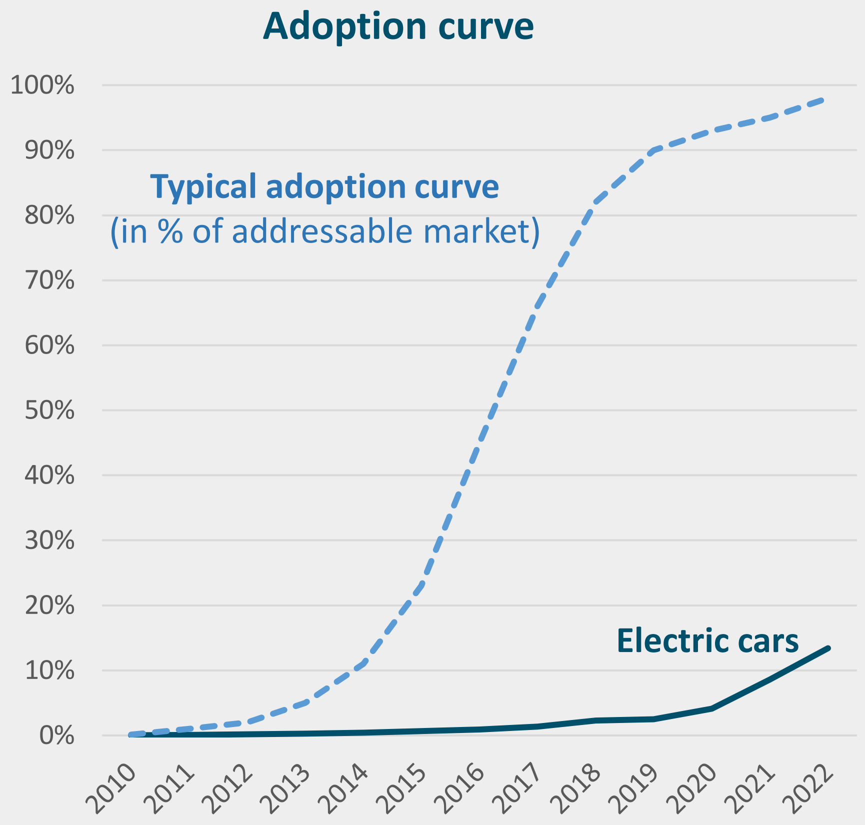


Source: ARK IM (2019)

This chart shows the typical annual growth rate and adoption rate for new technologies in general.

Starting point: Adoption curves



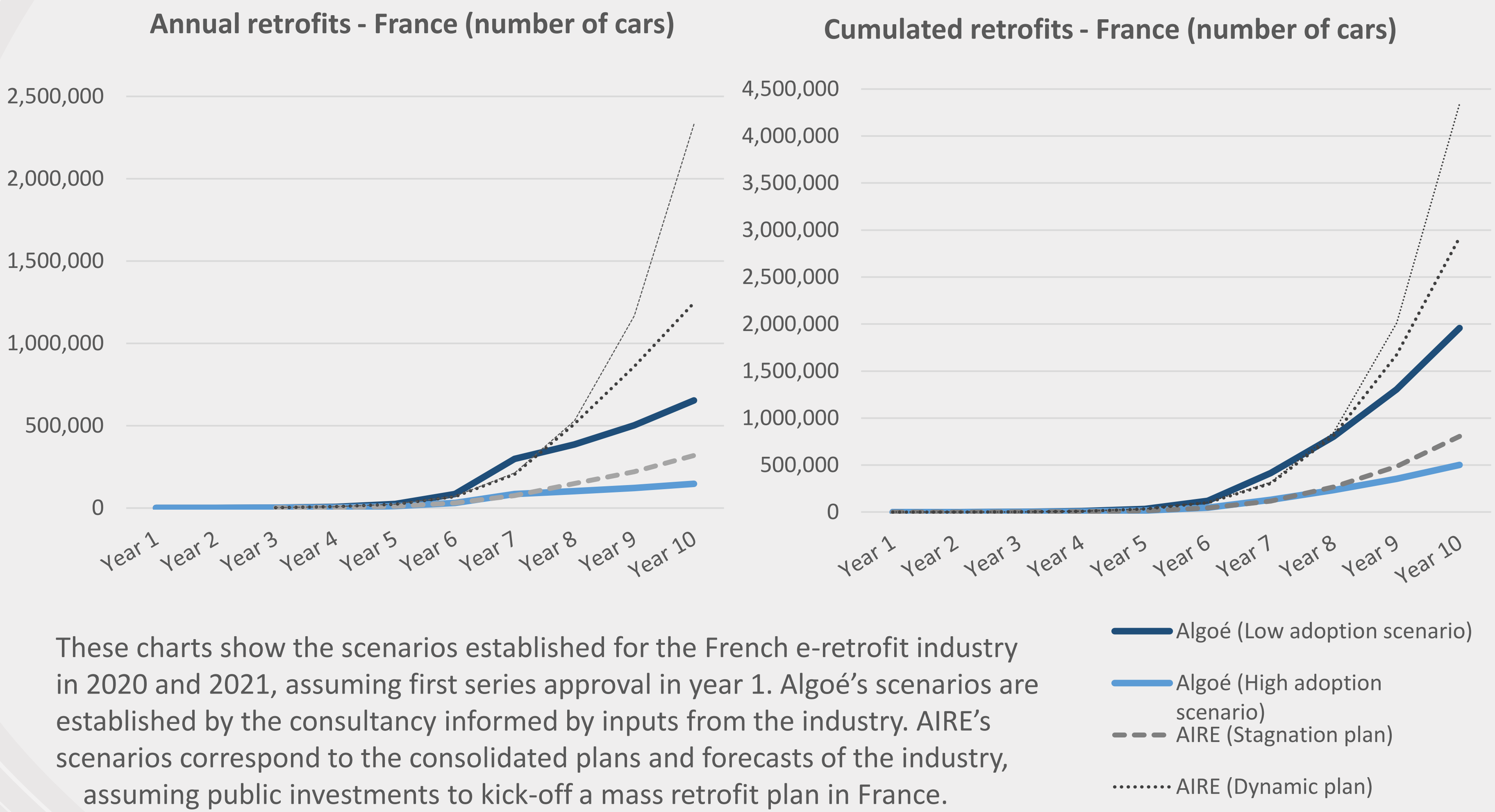


Source: EV-Volumes.com (2023)

These charts compare the typical annual growth rate and adoption rate for new technologies with the figures for mass production EVs and PHEVs early adoption

Step 1: Review of bottom-up scenarios

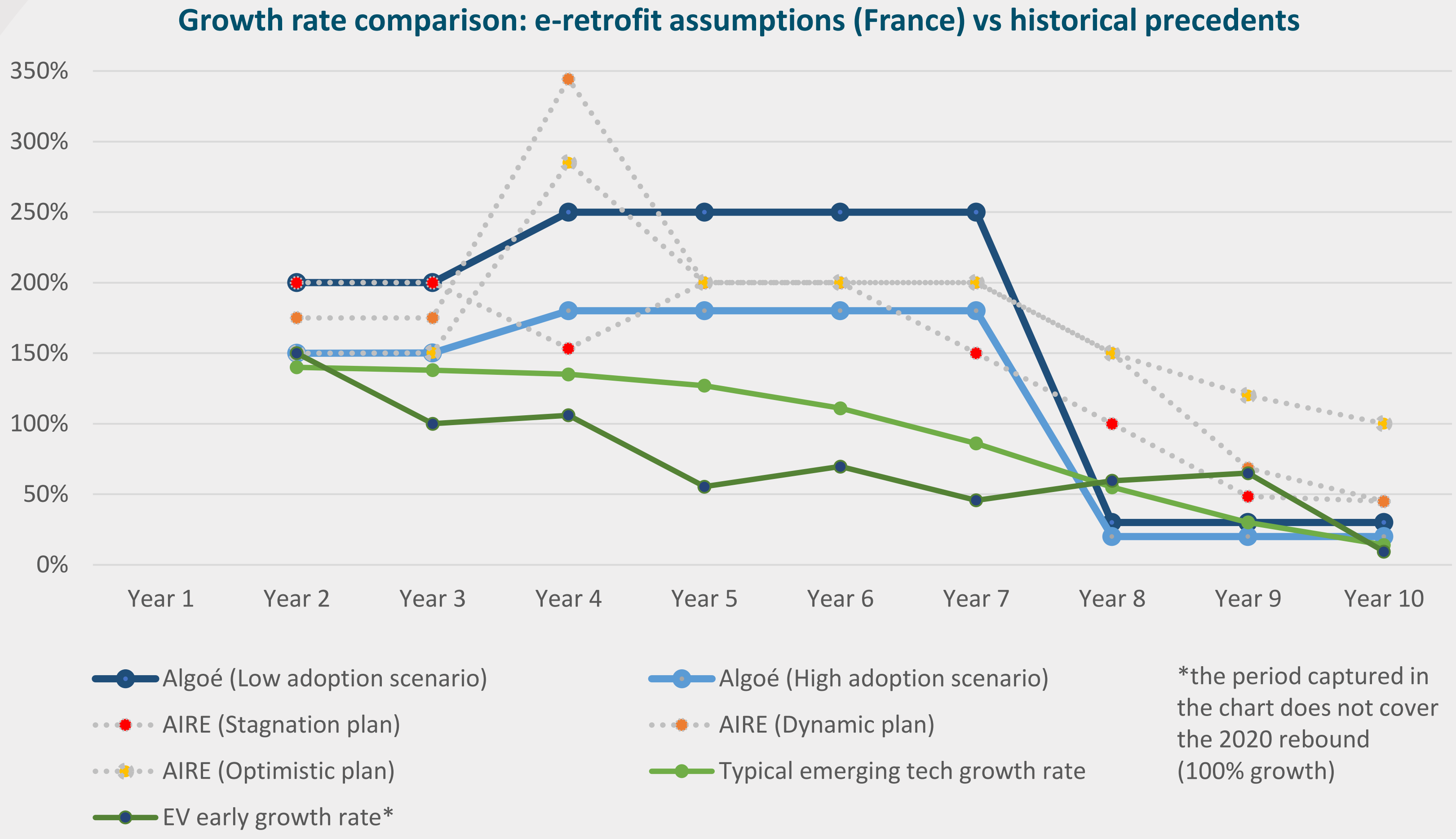
Mid-term scenarios for the French e-retrofit industry



These charts show the scenarios established for the French e-retrofit industry in 2020 and 2021, assuming first series approval in year 1. Algoé's scenarios are established by the consultancy informed by inputs from the industry. AIRE's scenarios correspond to the consolidated plans and forecasts of the industry, assuming public investments to kick-off a mass retrofit plan in France.

Sources: Algoé (2020), AIRE/Beyond Financials (2021)

Step 1: Review of bottom-up scenarios



This chart shows that the early growth rate assumed for the French e-retrofit industry across different scenarios are more optimistic than historical data for early tech in general and EVs. The e-retrofit CAGR assumptions for the period range from 92% to 153%.

1. Review of third-party forecast
2. Technology adoption curves
3.1 Low Adoption Scenario
3.2 High Adoption Scenario
3.3 High Adoption Scenario
3.4 Comparing scenarios

Low Adoption Scenario

Drivers

Most conversions take place after 2045 when the economic and regulatory pressure on fossil car use intensifies.

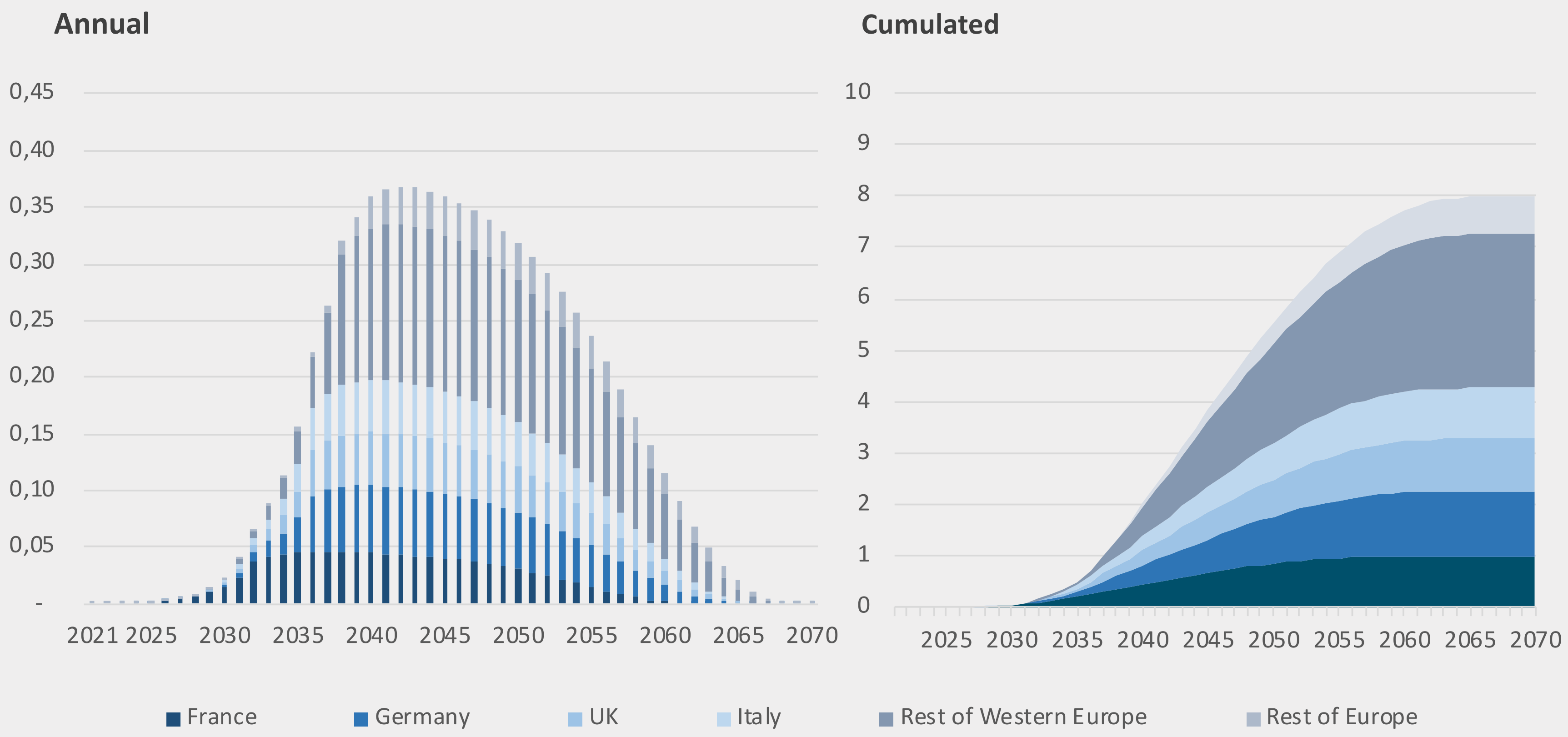
In this scenario, e-retrofit focuses on vintage cars and vehicles for niche low-range use cases, the technical barriers remain and e-retrofit does not play any significant role in addressing the demand for affordable cars.

Policy instruments	Implementation	Implications
Additional subsidies specific to e-retrofit	None. E-retrofit benefits from the same subsidies as scrapping + purchase of an EV, when they are available.	The impact on public expenditures is aligned with the baseline scenario.
Early retirement regulation and scrapping subsidies	We assume a stable regulatory environment without mandatory early retirement for cars.	The impact on public expenditures is aligned with the baseline scenario.
Contraints on fossil car use	Low Emission Zones are implemented in certain cities of Western Europe. The regulatory & tax pressure use and ownership of fossil cars is eased to reduce the burden on low-income households who depend on their car.	The total residual value of fossil cars and used EVs is aligned with the baseline scenario (i.e. historical trends)

Low Adoption Scenario

Retrofits by country

Million passenger cars retrofitted

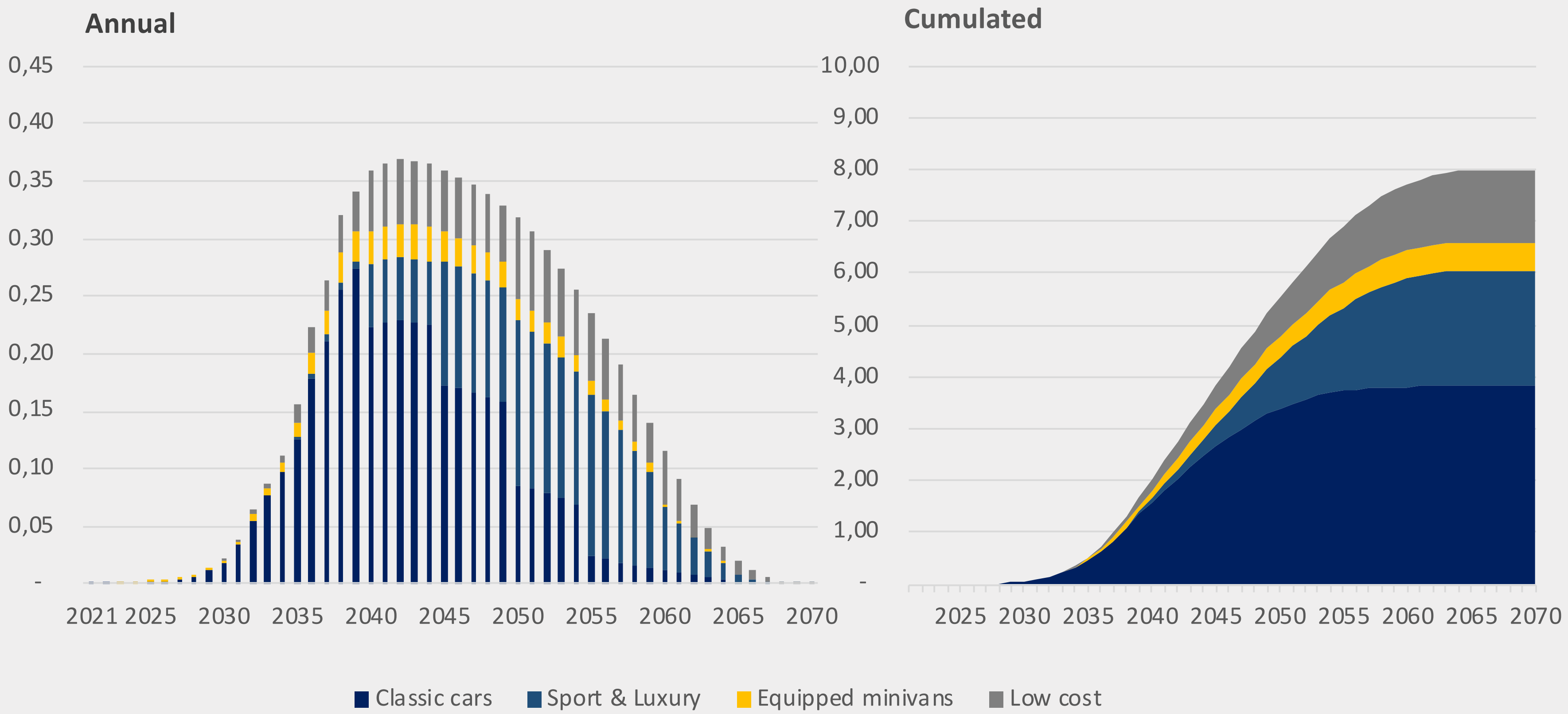


The market first takes off in France around 2024 thanks to series regulation, that is then introduced in other European countries with a delay. In each country, e-retrofit experiences the early adoption growth rate of EVs for the first ten years and then plateaus and declines. Most conversions take place after 2045 when the economic and regulatory pressure on fossil car use intensifies.

Low Adoption Scenario

Retrofits by segment

Million passenger cars retrofitted

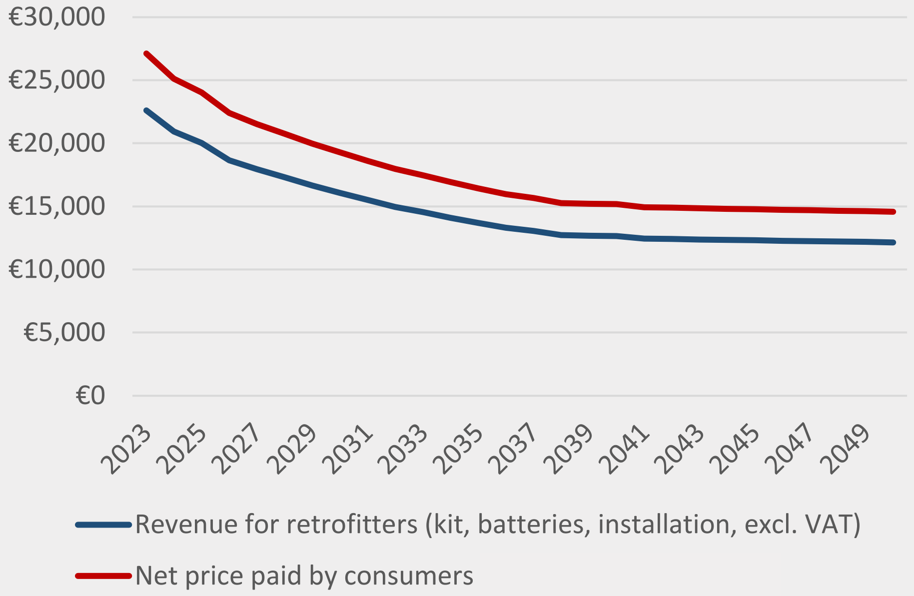


Most conversions focus on keeping classic and luxury cars on the roads despite regulatory pressure with a penetration respectively 75% and 55% of the technically eligible fleet. The other use cases include equipped minivans (for disable people or as campers) as well as low-cost retrofits at the end of the period when battery become more affordable, the penetration reaching 5% of eligible cars.

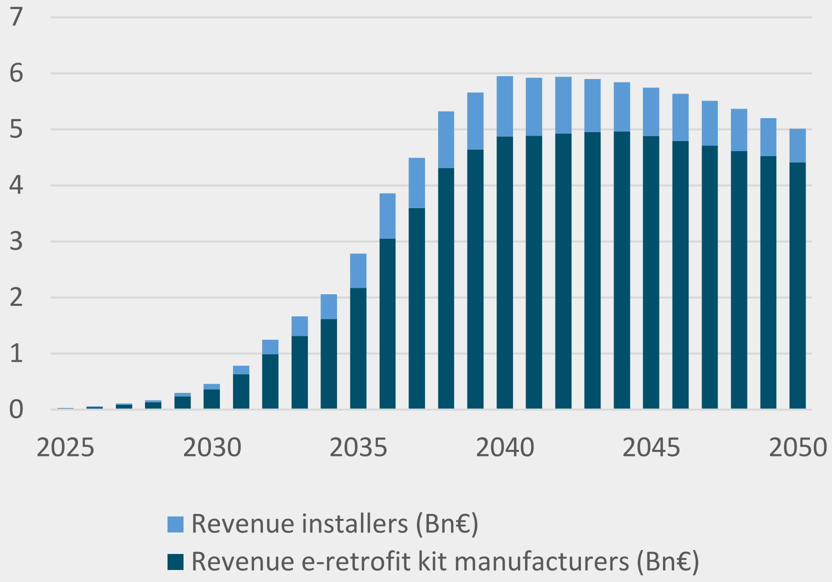
Low Adoption Scenario

Revenues

Average retail price and revenues per car



Market size (€Bn of sales)



In this scenario, the average price (as opposed to the starting price) is inflated by the fact that most customers opt for premium retrofits. The market size peaks at €6Bn of annual revenues which represents 17 times the size of the European collectible car market (auctions) in 2019 (source Axa XL).

Source: Axa Classic Car Market Review 2019 (Axa XL)

High Adoption Scenario

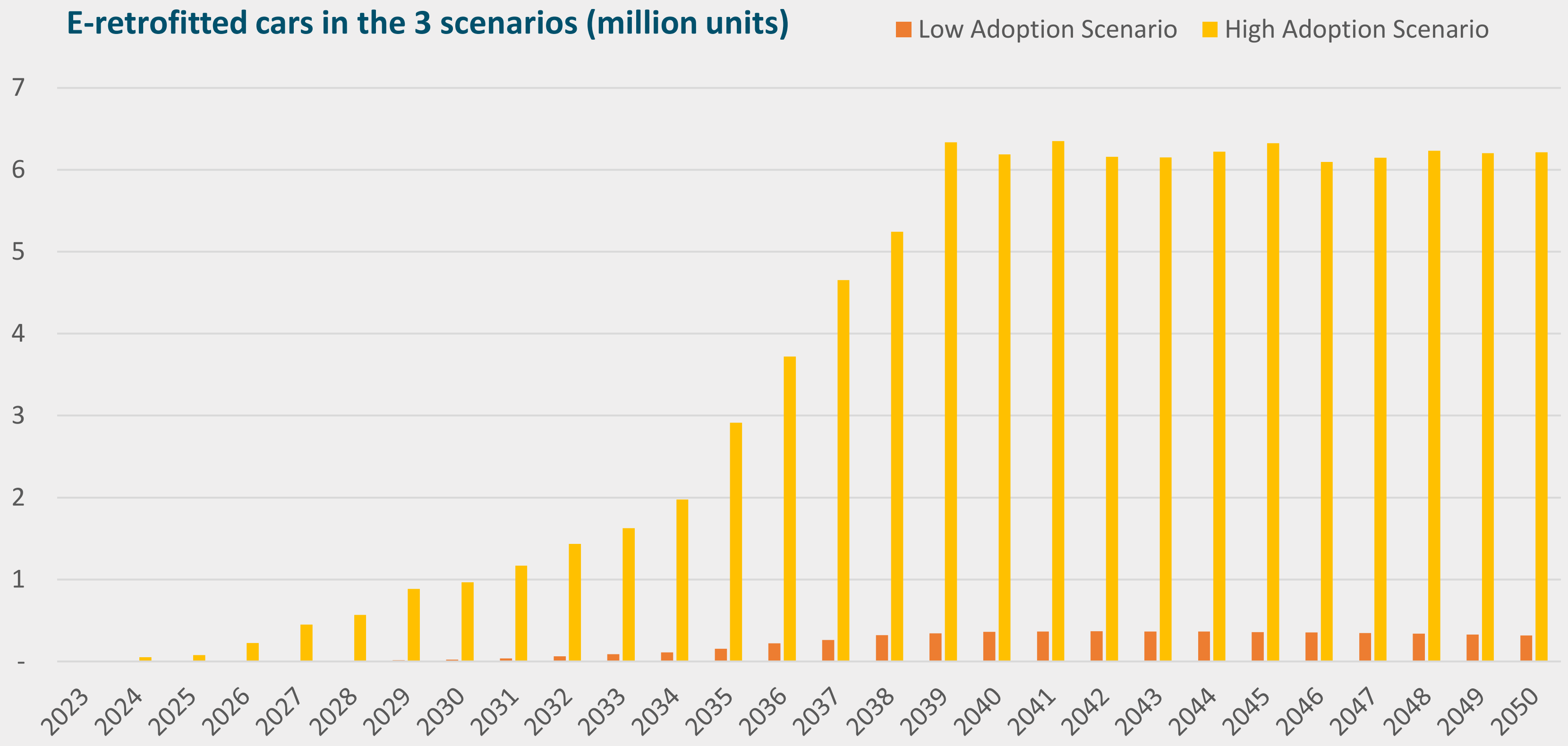
Drivers

This scenario involves strong public support for e-retrofit, which becomes the main solution for generating affordable used electric cars and smoothing the transition to zero emission roads.

Policy instruments (fictional)	Implementation	Implications
Additional subsidies specific to e-retrofit	None until 2028 2,700€ from 2028 to 2030 5,000€ from 2030 to 2050	€495 Bn of public expenditures (assuming no subsidies for new EVs and limited to no subsidies for the purchase of an old EV).
Early retirement regulation and scrapping subsidies	No cars older than 35 years is allowed on the roads after 2035: they must be scrapped or retrofitted. The age limit is reduced to 30 years in 2050. Scrapping subsidy of €1,000 from 2030 to 2035 and €300 from 2036 to 2050.	The program cost a maximum of €27Bn of public expenditure (which overlaps with existing scrapping schemes) and lead to the early scrapping of 55 million cars.
Contraints on fossil car use	Low and Zero Emission Zones are implemented in most cities across Europe from 2035 onwards. Taxes on fuels and ownership increase.	The total residual value of donor cars drops by 20% relative to the default depreciation curve.

High Adoption Scenario

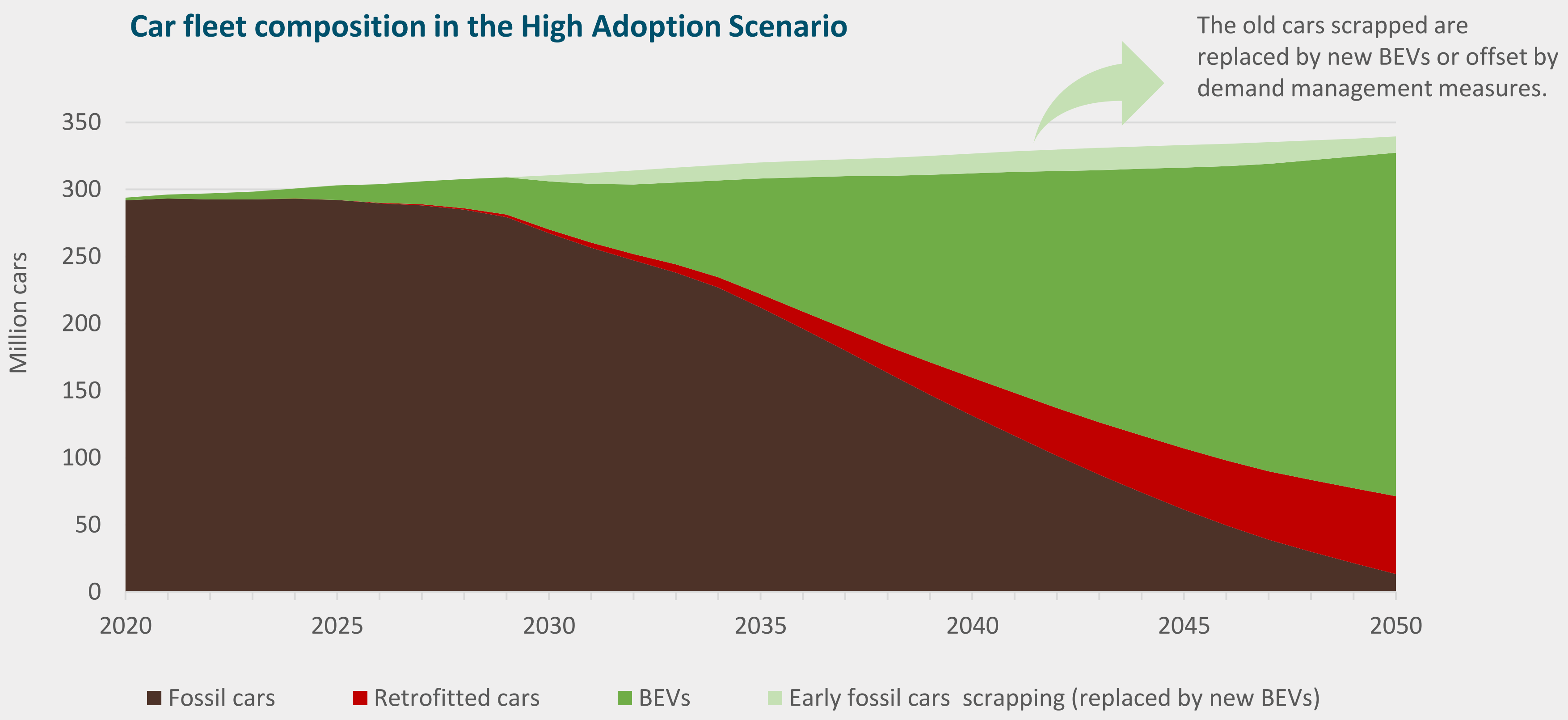
Number of cars retrofitted



100 million cars are retrofitted from 2023 to 2050, all of them older than 10 years, reducing CO_2 emissions by 0.5 Gt relative to the baseline. **Another 50 million cars, older than 35 years are scrapped** earlier than their 'natural' lifetime.

High Adoption Scenario

Impact on the fleet composition

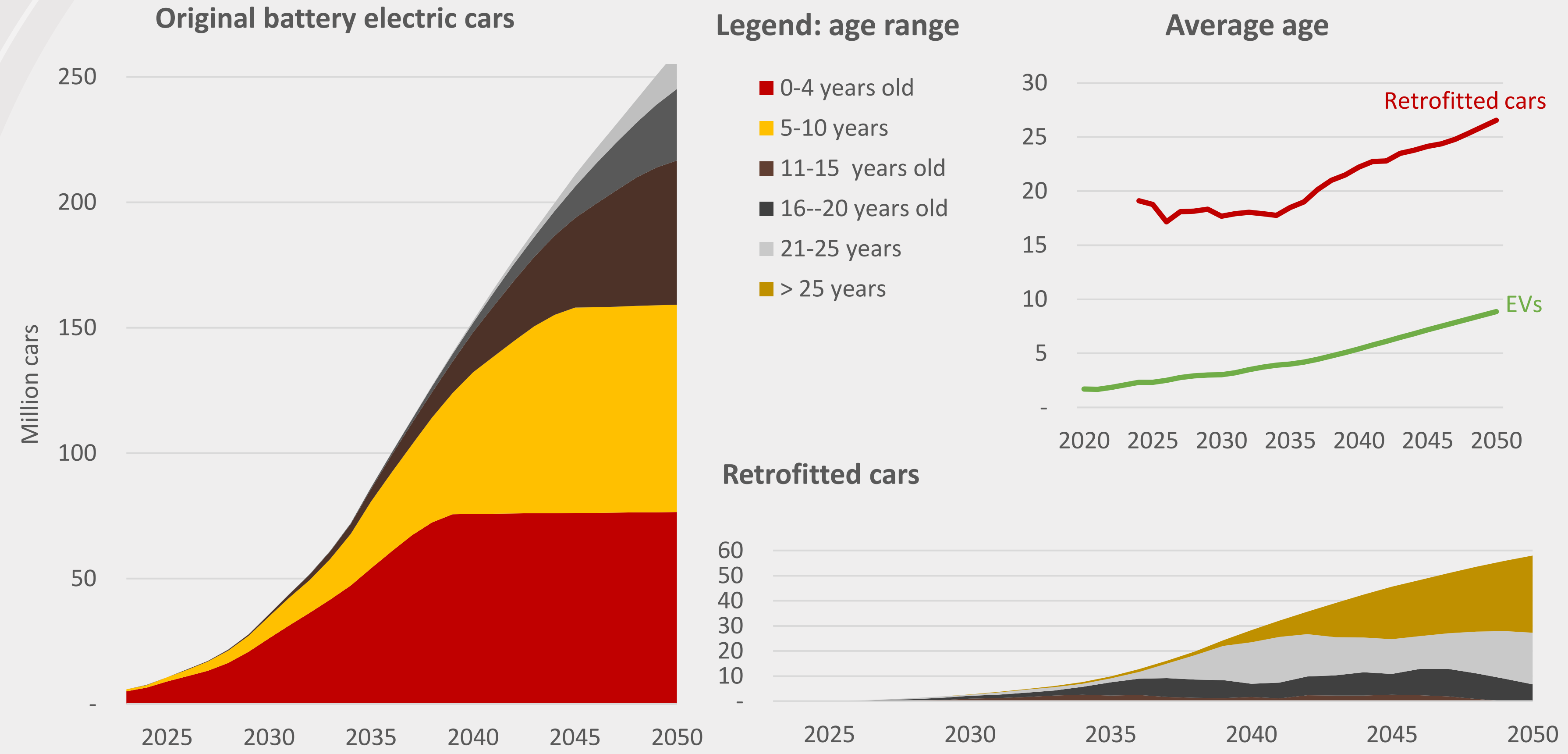


E-retrofited cars constitute a small share of the fleet relative to standard BEVs. However, they represent the majority of old cars on the road.

High Adoption Scenario

Impact on the availability of affordable used electric cars

Distribution of the electric car fleet by age



E-retrofitted cars and BEVs compete on completly different segments of the used car market: the average age of used BEVs rise from 3 year in 2030 to 9 years in 2050, while the average age of e-retrofitted car over the period is above 20 years old, with a significant number above 20 years old.

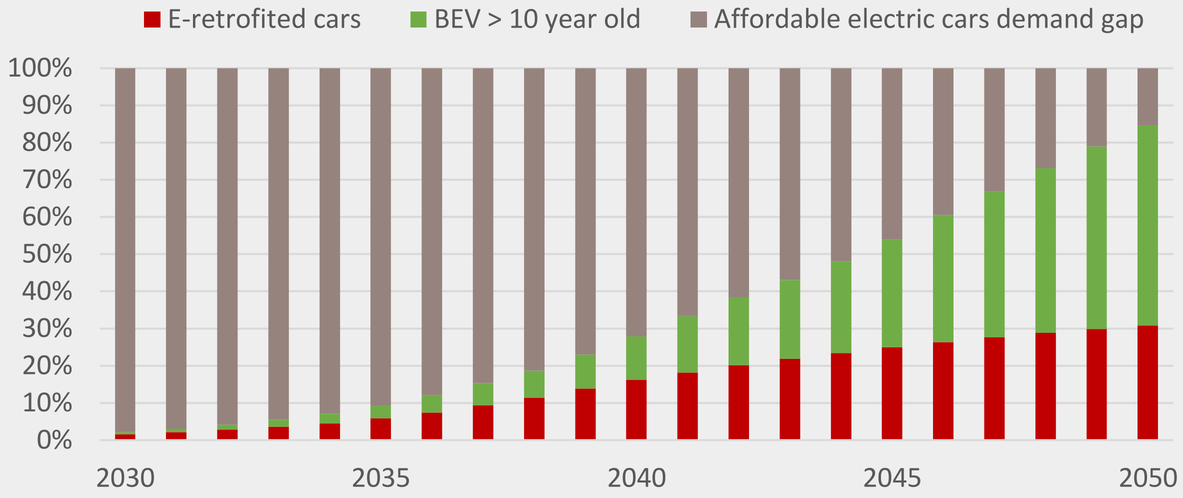
High Adoption Scenario

Impact on the availability of affordable used electric cars

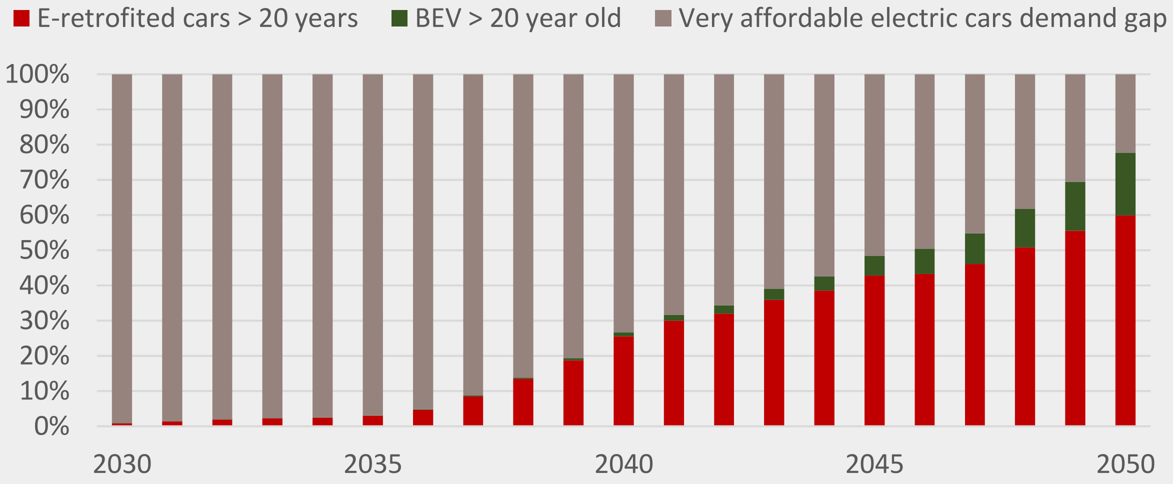
Composition of the car fleet

E-retrofitted cars represent a significant share of old/affordable cars, offsetting the effect of the transition to EVs on the age structure of the fleet.

Affordable used electric car gap



Very affordable used electric car gap

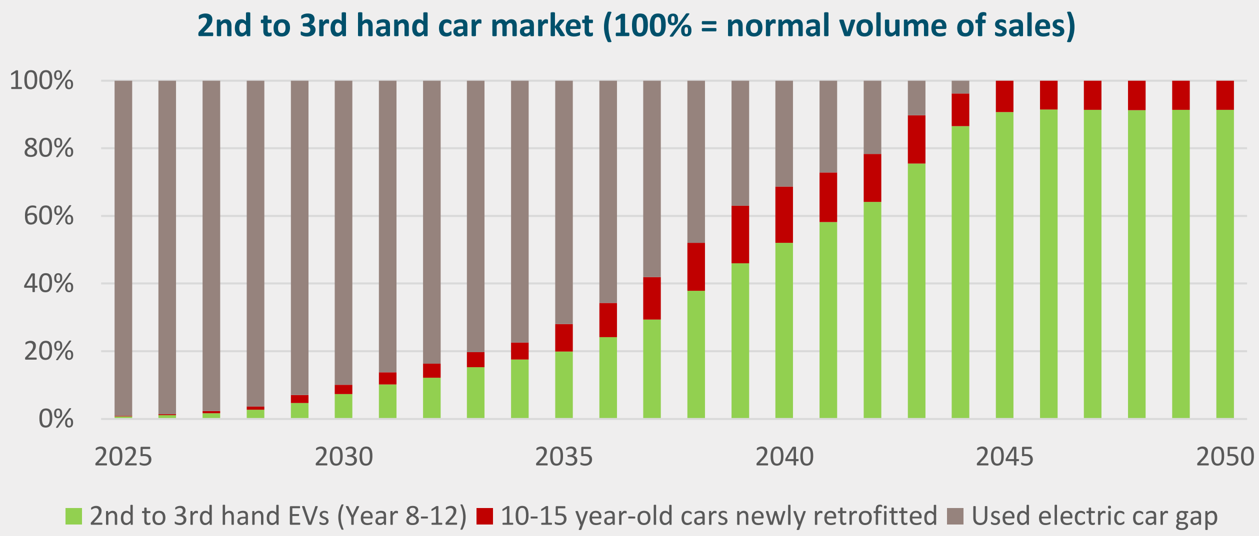


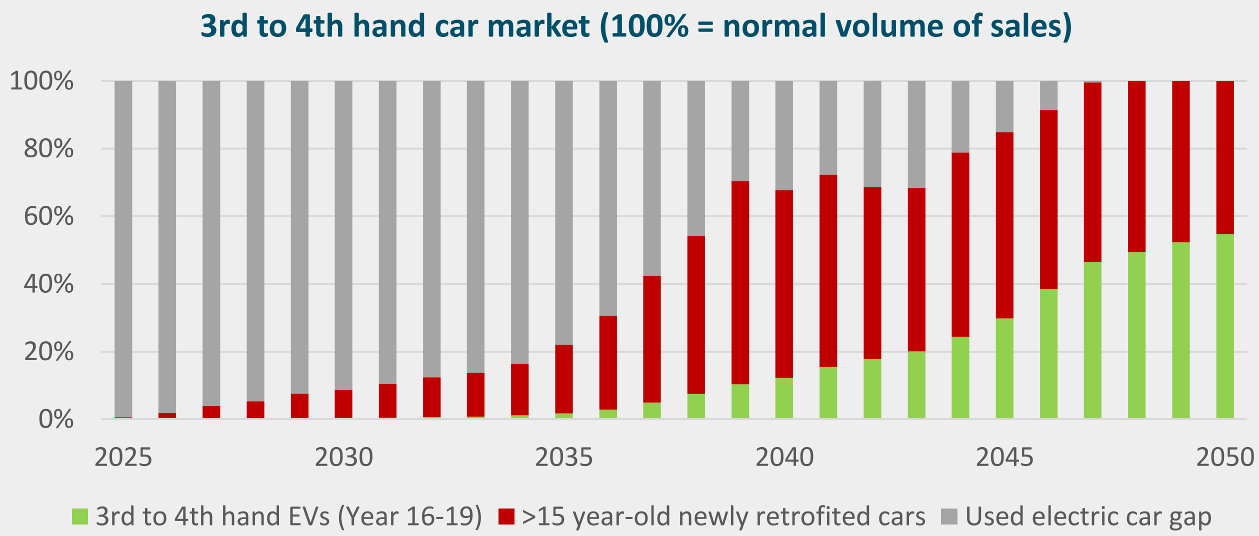
High Adoption Scenario

Impact on the availability of affordable used electric cars

Volume of transactions on the used car market

E-retrofitted cars represent a limited share of 2nd hand cars transactions, but the majority of the 3rd hand car market





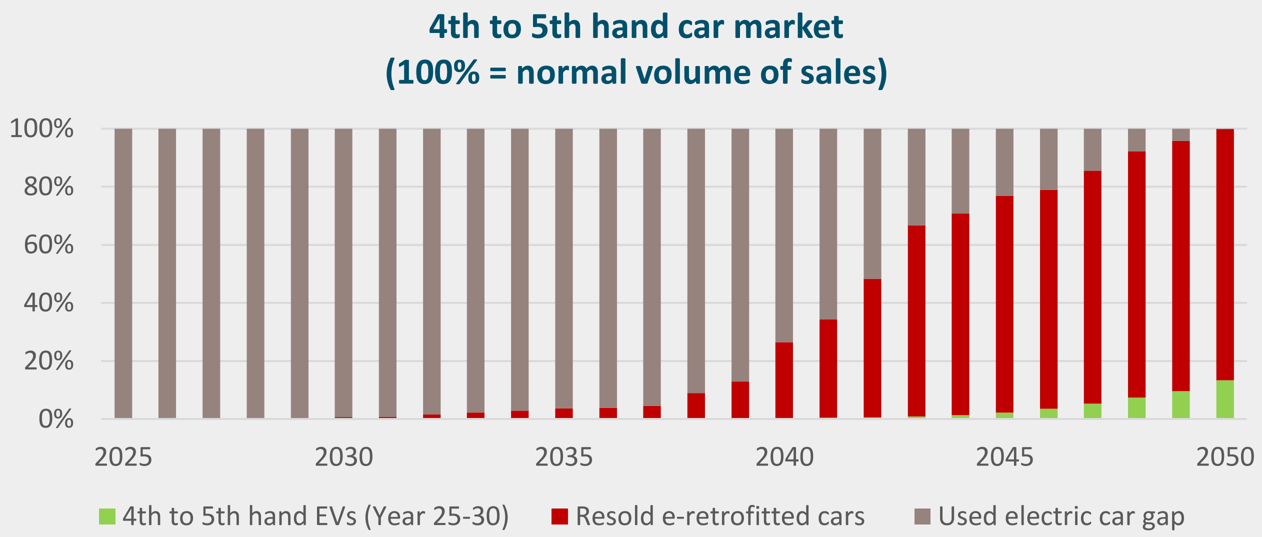
High Adoption Scenario

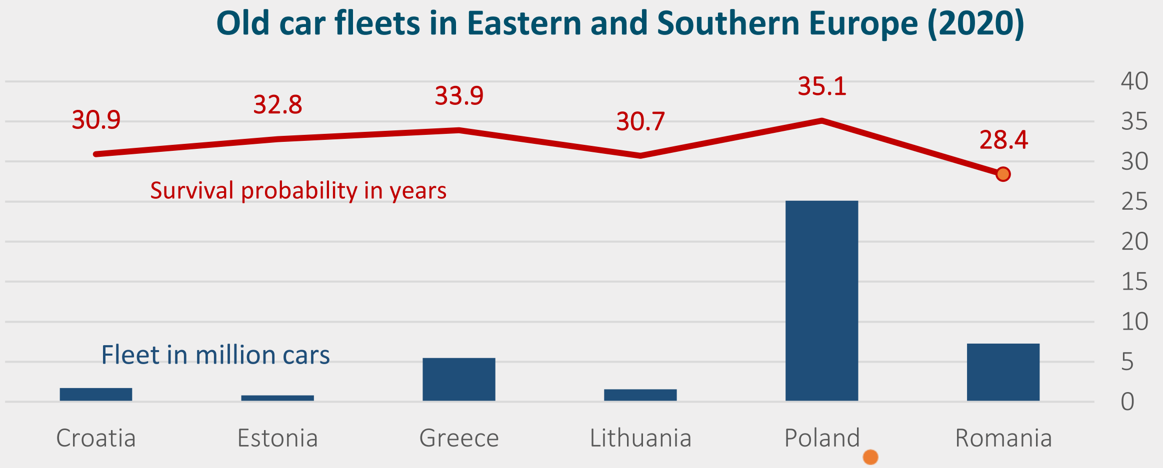
Impact on the availability of affordable used electric cars

Volume of transactions on the used car market

E-retrofitted cars replace fossil cars on the 4th hand car market, were EVs are absent.

E-retrofit plays a major role in the transition to electric mobility of Eastern Europe markets that are dominated by old cars.

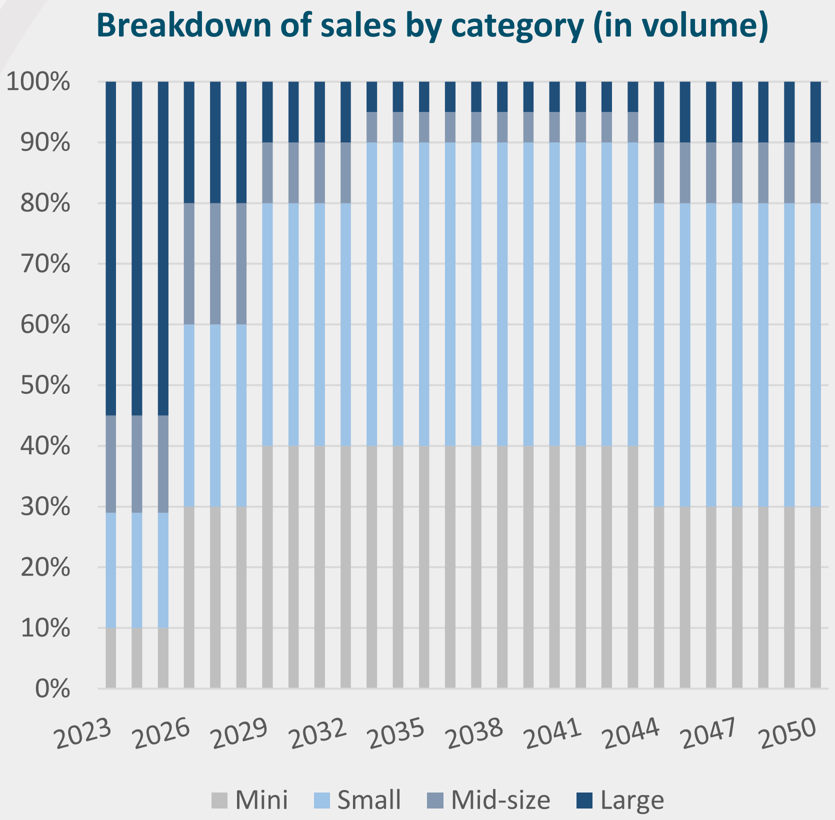


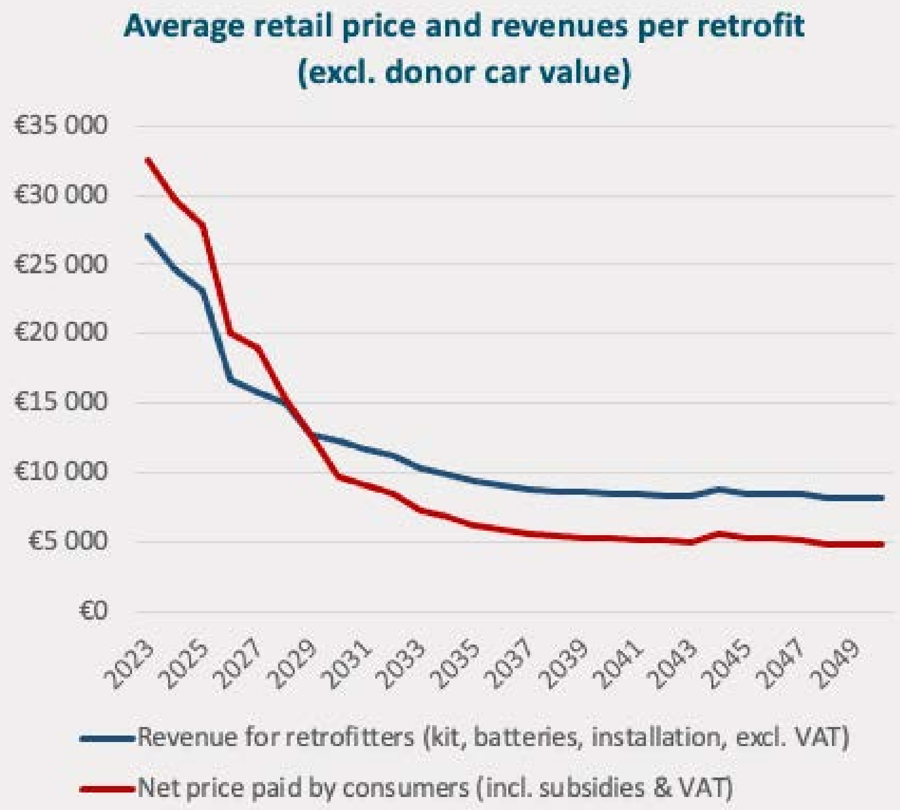


Source : Eurostat, Held et al (2021)

High Adoption Scenario

Revenues of the e-retrofit sector



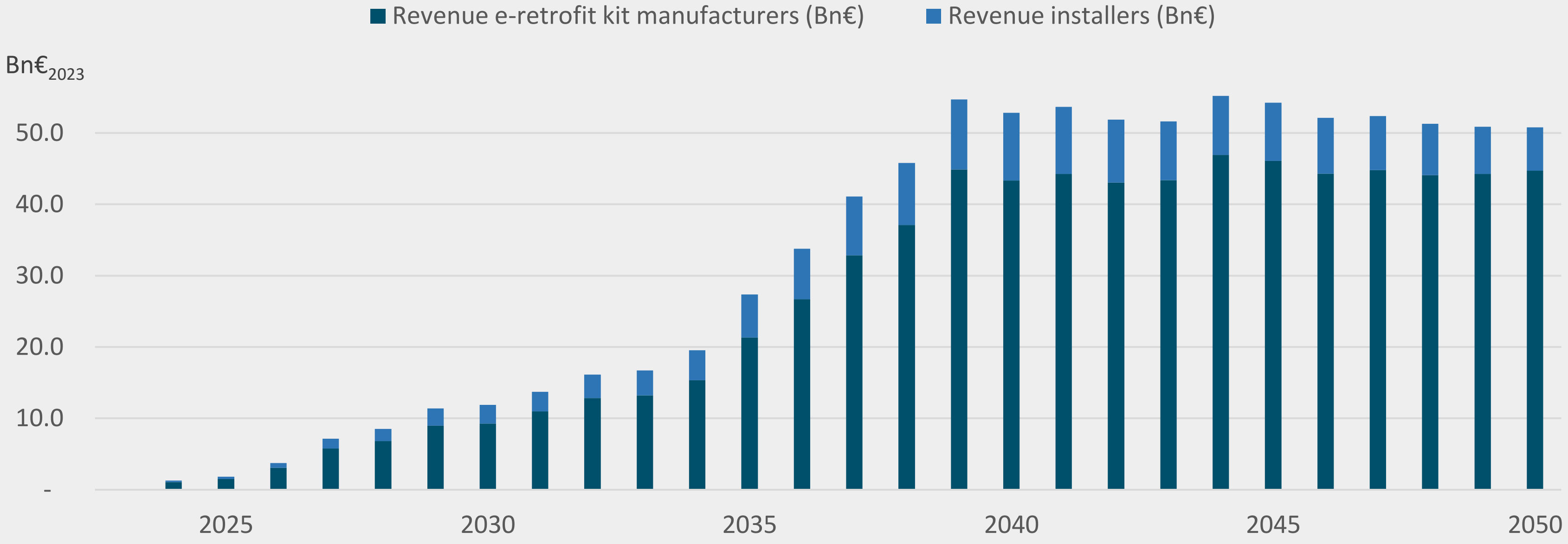


The category mix evolves over the period: it is aligned with the fleet mix at the beginning when vintage cars are converted, then mini and small cars (more affordable) are overrepresented in retrofits. The average retrofit price is calculated based on the mix of size category, battery capacity and standard of retrofit (ultra-low cost on average). It is is kep artificially low from 2030 thanks to subsidies.

High Adoption Scenario

Revenues of the e-retrofit sector

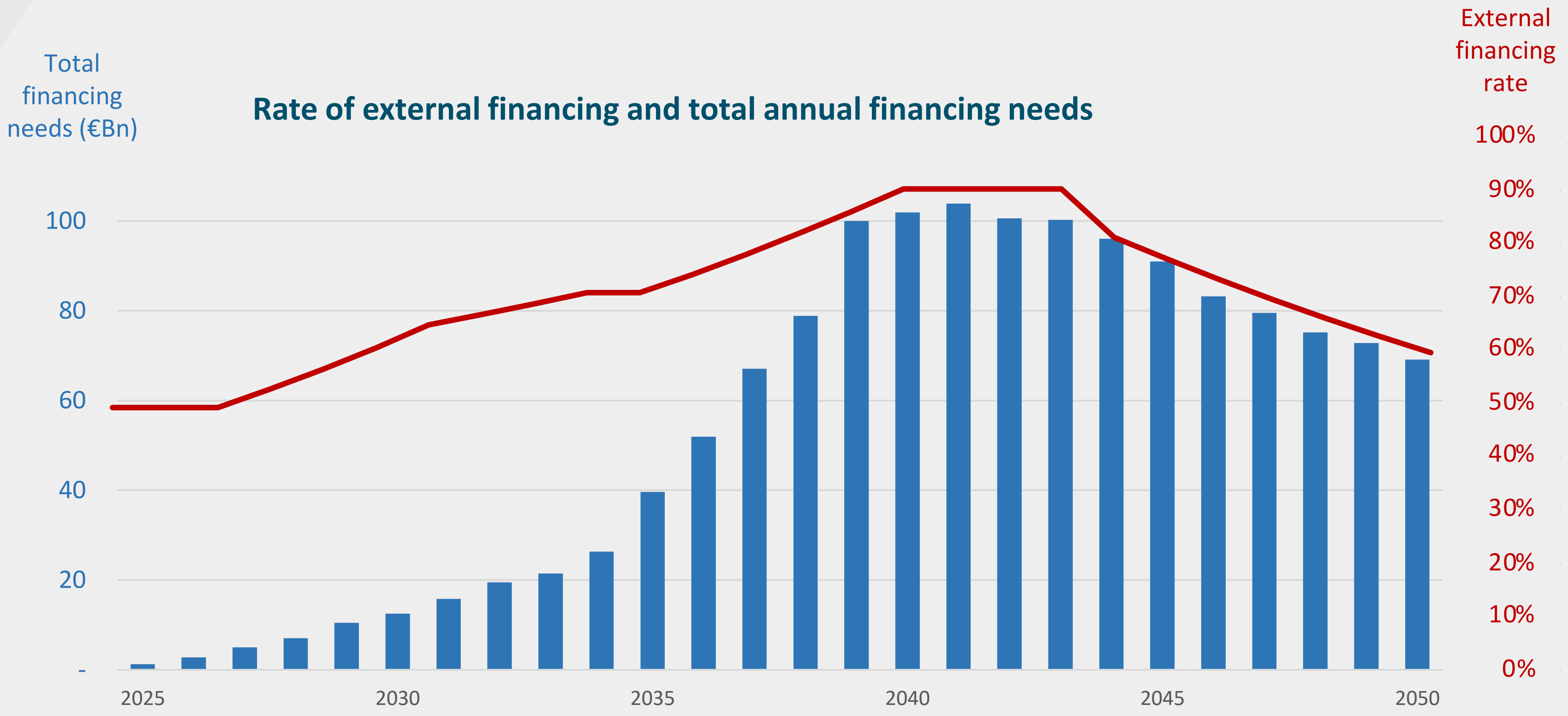
E-retrofit market size in value (order of magnitude)



The market size is based on the average revenues per retrofit (kit, batteries, installation), excluding VAT and the cost of donor cars. At its peak, the market represents about **13% of the current used car market in volume.**

High Adoption Scenario

Financing



Formula

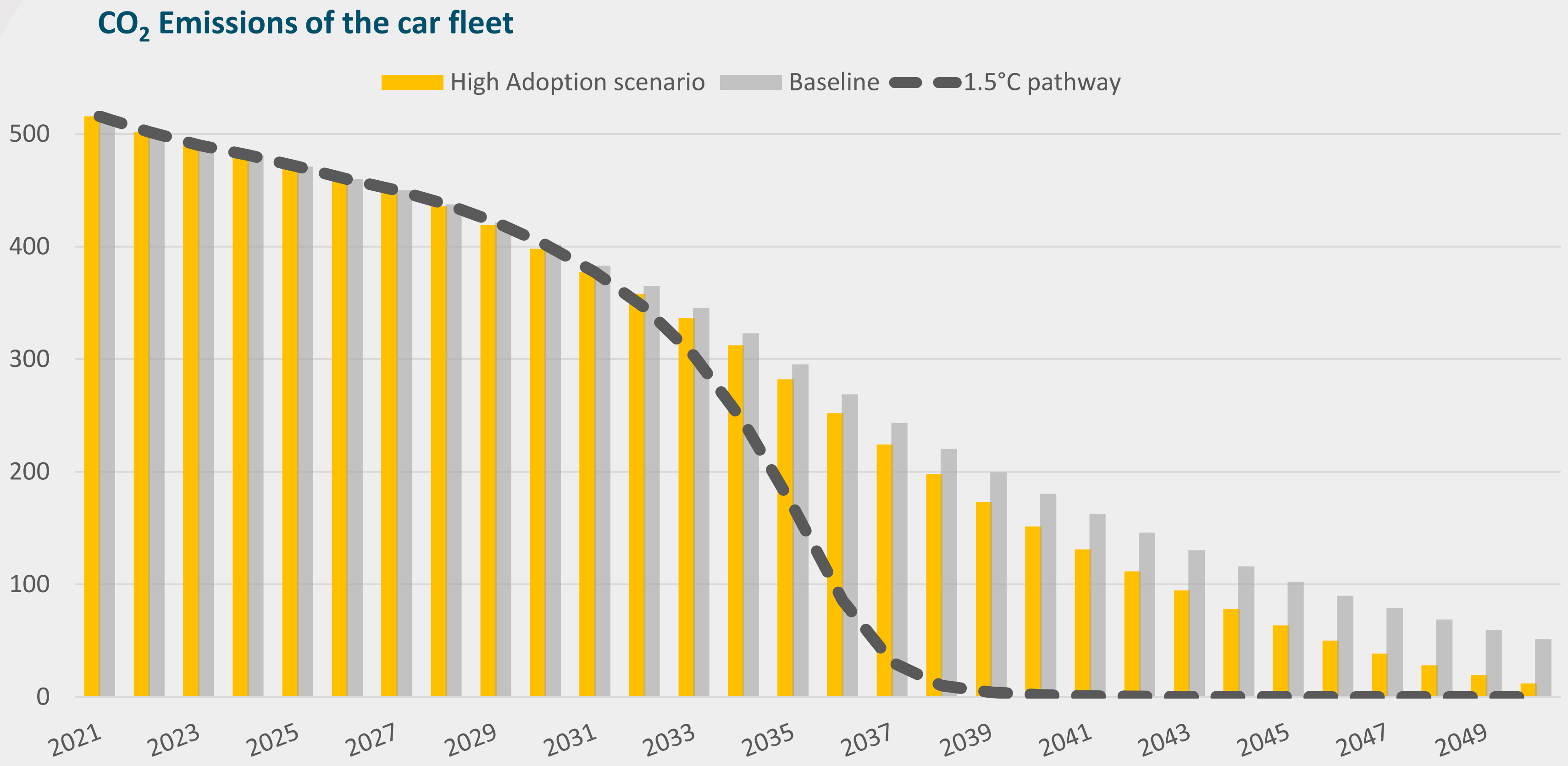
Financing needs

=

(Number of cars x Average net price paid by consumers + Average cost of a glider – Subsidies) x External financing rate

High Adoption Scenario

Impact on the car fleet CO_2 emissions



Over the period 550 Mt of CO_2 are avoided thanks to early retirements (scrapping and e-retrofits).

High Adoption Scenario

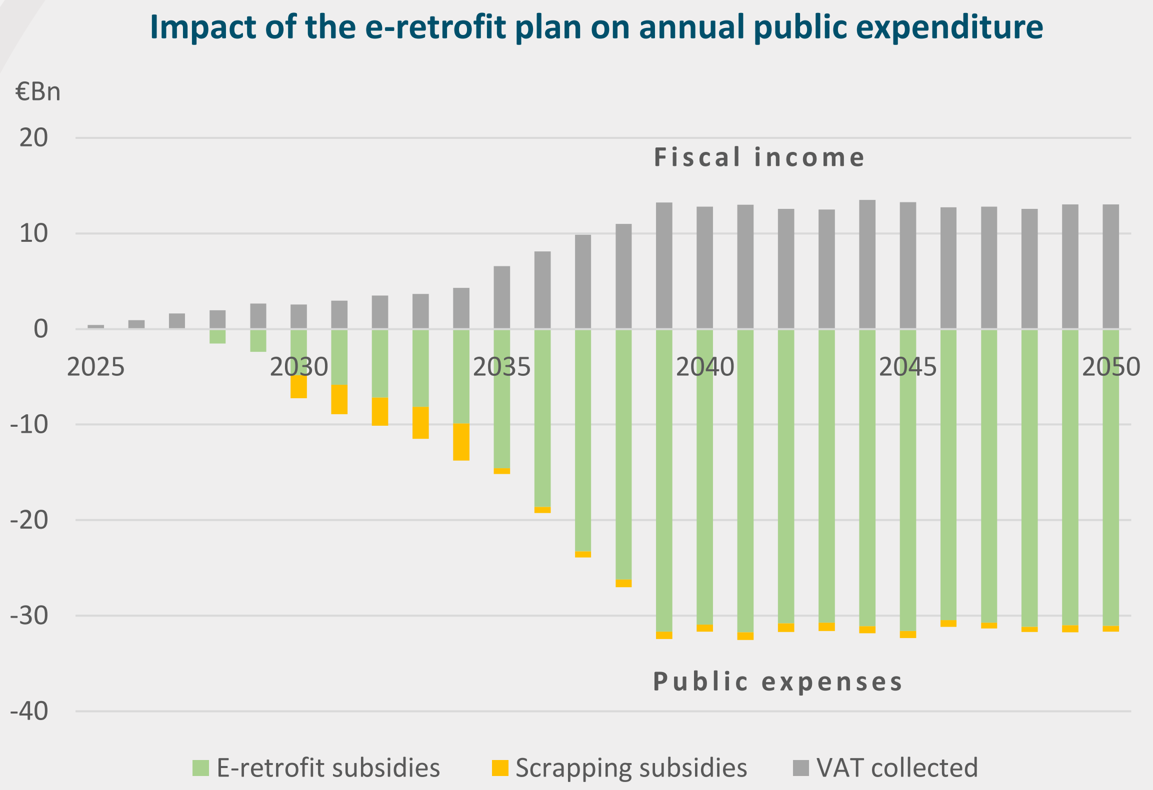
Impact on the car fleet CO_2 emissions

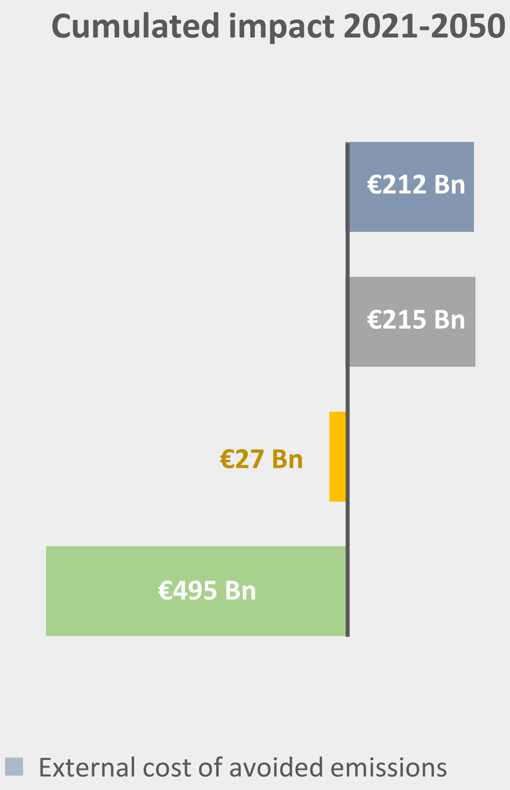
Scenario emissions compared to the 2021-2050 carbon budget

The fleet emissions are aligned with a pathway betwee 1.6°C and 1.7°C.

High Adoption Scenario

Public expenditures





Over the period the net cumulated impact for taxpayers, factoring the external cost prevented (pollution and climate change) is -€95 Bn. These estimates are based on the central value for external costs (source: EC guidance). Using the high value for external costs, the impact is slightly positive: +€86 Bn.

1. Review of third-party forecast
2. Technology adoption curves

3.1 Low Adoption Scenario

3.2 High Adoption Scenario

3.3 1.5°C Scenario

3.4 Comparing scenarios

1.5°C Scenario

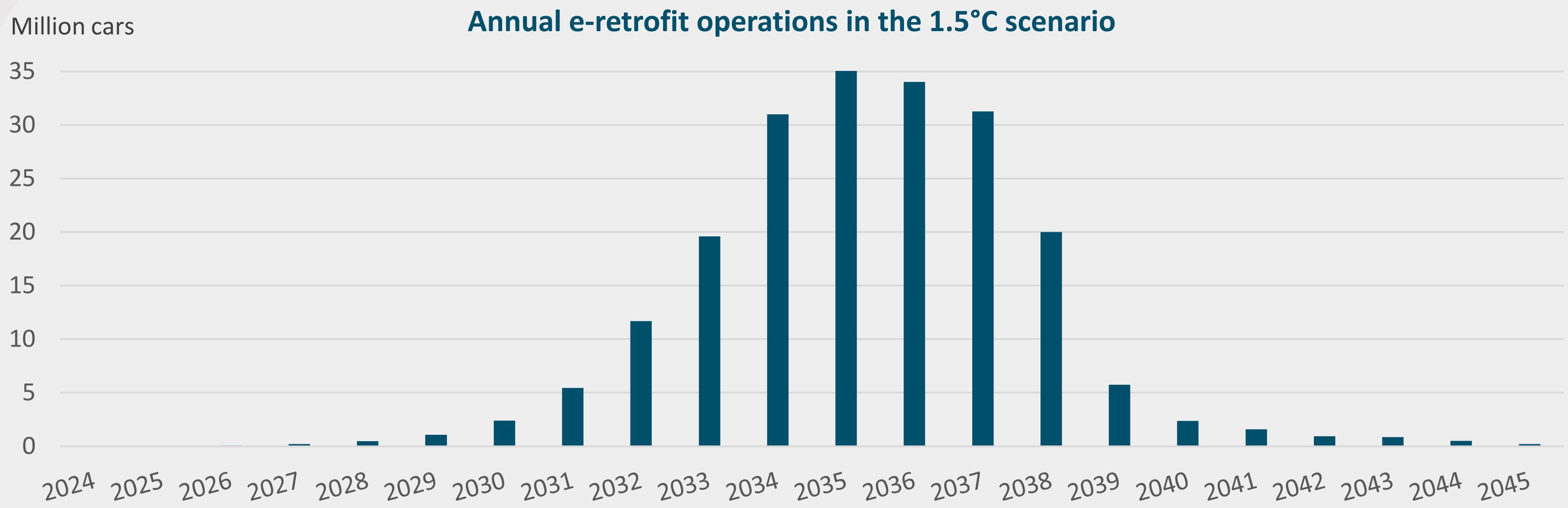
Drivers

This scenario is policy driven : the primary goals is to align emissions with a 1.5°C pathway, while bridging the affordable electric used car gap. It is based on a European plan to phase out all fossil cars from the roads between 2030 when e-retrofit becomes economical and 2045 when the decarbonization window closes.

Policy instruments (fictional)	Implementation	Implications
Additional subsidies specific to e-retrofit	None until 2028 2,700€ from 2028 to 2030 5,000€ from 2030 to 2033 2,700€ from 3024 to 2035 1,500€ from 2036 to 2040	€545Bn of public expenditures (assuming no subsidies for new EVs and limited to no subsidies for the purchase of an old EV).
Early retirement regulation and scrapping subsidies	In cities and suburbs, cars older than 35 years must be retired by 2035. Scrapping subsidy of €1,000 from 2030 to 2032, €500 from 2033 to 2035 and €300 from 2036 to 2040.	€17 Bn of public expenditure (which overlaps with existing scrapping schemes). Residual value destruction remains limited.
Contraints on fossil car use	In key Western European markets, a 10 to 15 years “expiration date” is introduced for fossil cars sold after 2023, with an obligation to scrap or retrofit the car.	The policies trigger a drop in fossil cars’ residual value in 2028 (up to -20% relative to the baseline) and then a complete collapse after 2032 (up to -80%).

1.5°C Scenario

Drivers

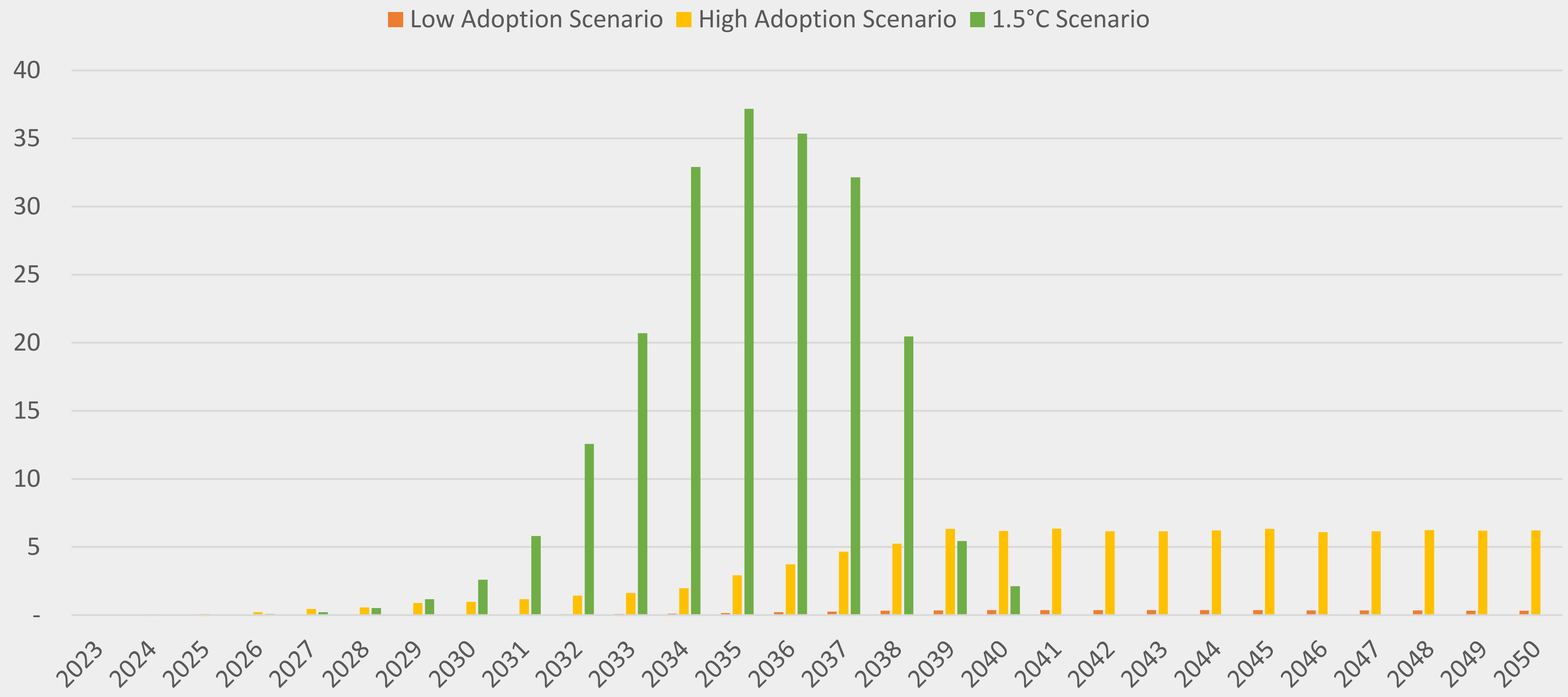


Phase	Period	Volume retrofitted	Target segment	CAGR
Vintage	2023-2027	360,000 cars	19-25 years old vintage cars	+150%
4rd hand cars	2028-2031	10 million cars	16-20 years old cars, low-cost conversions	+125%
3rd hand cars	2032-2035	100 million cars	Program focused on cars > 12 years old	+63%
2nd hand cars	2036-2040	100 million cars	Mandatory phase-out: all cars > 5 years old	-33%

1.5°C Scenario

Number of cars retrofitted

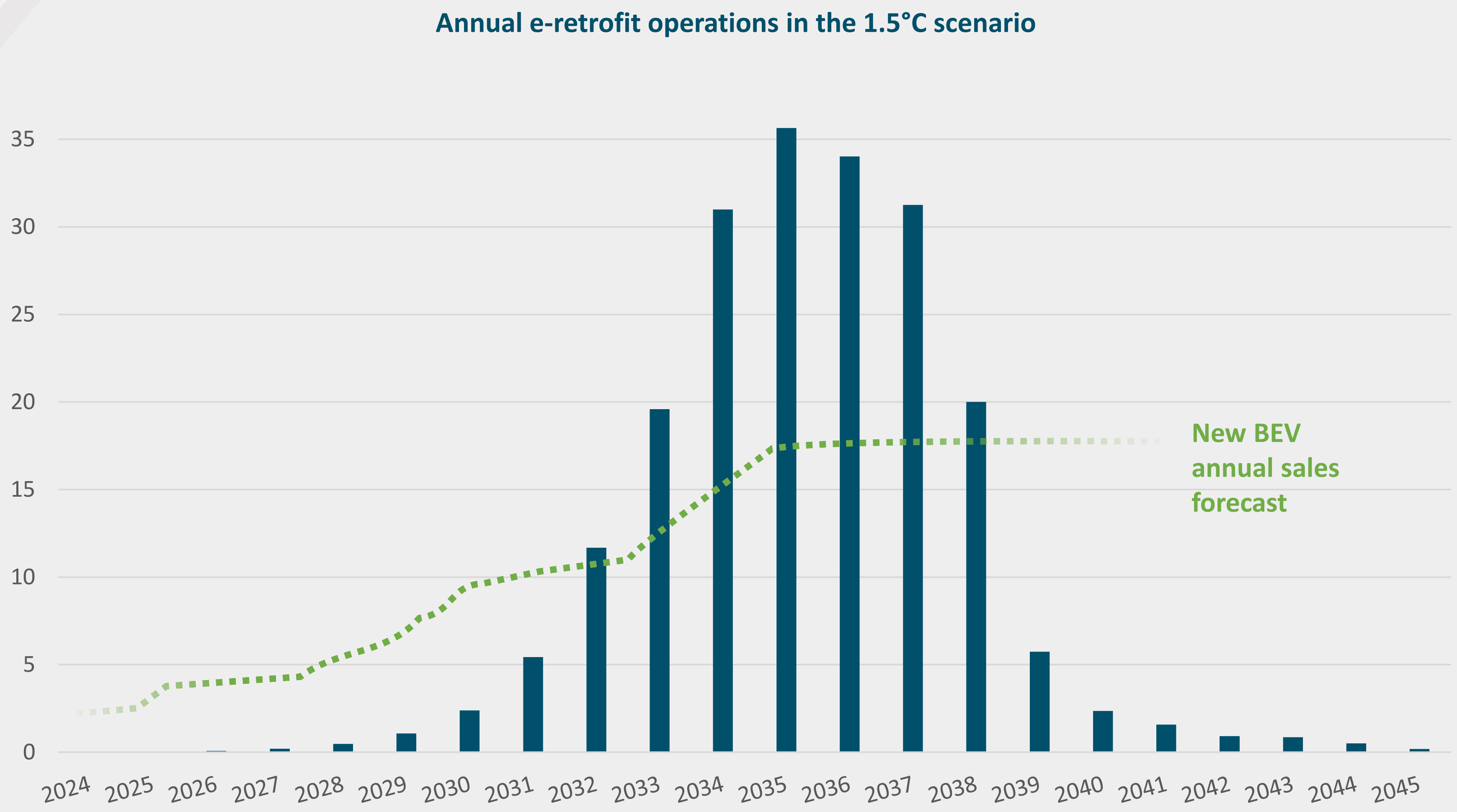
E-retrofitted cars in the 3 scenarios (million units)



Overall, about **210 million cars are retrofitted**, which is close to the total technically eligible fleet (236 million in 2030).

1.5°C Scenario

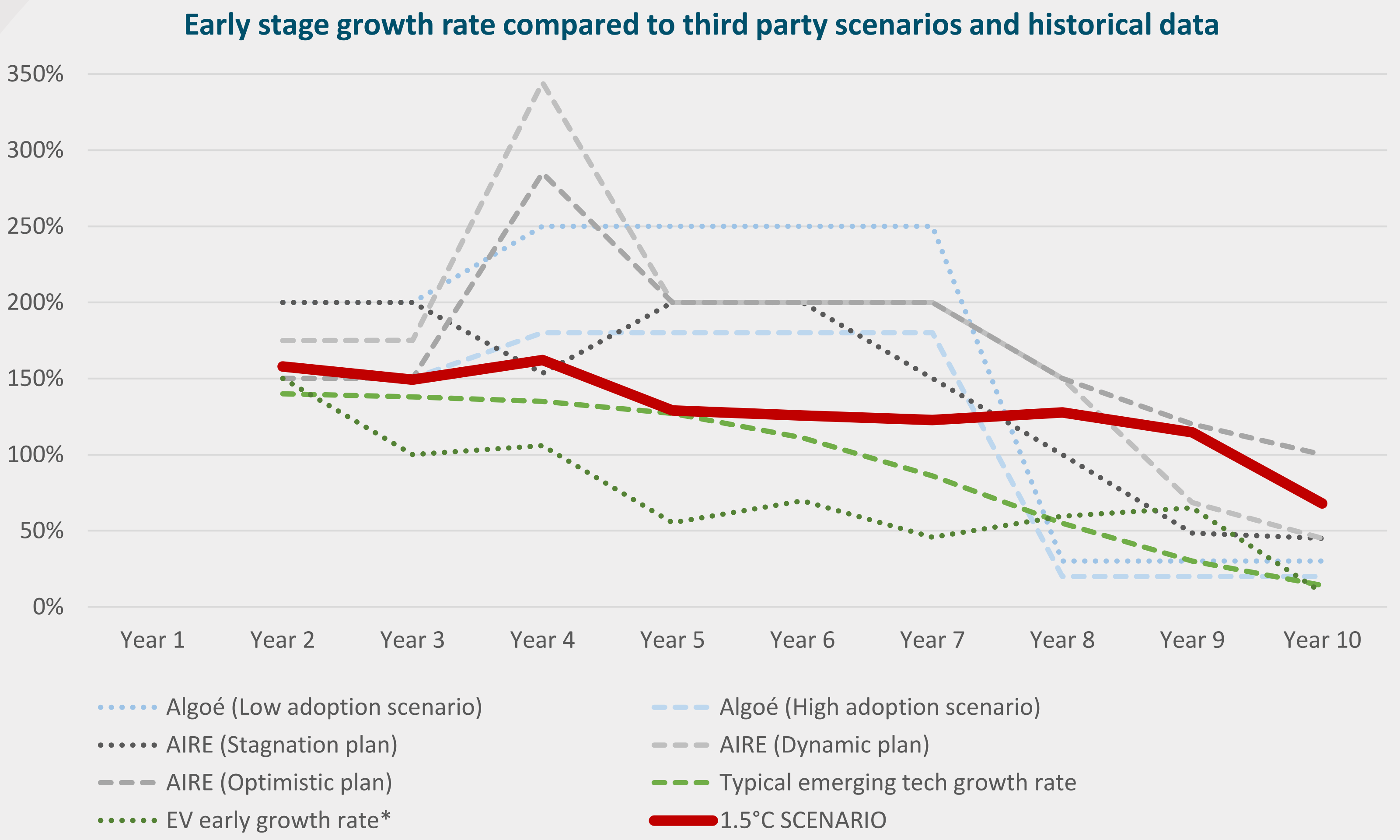
Number of cars retrofitted



Most cars are retrofitted after the high growth period. The number of cars retroffited exceeds the volume of new EV sales in the early 2030ies, for a few years. At its peak, the annual volume corresponds to the **size of the used car market**, which is logical given that every used fossil car sold during this period must be retrofitted.

1.5°C Scenario

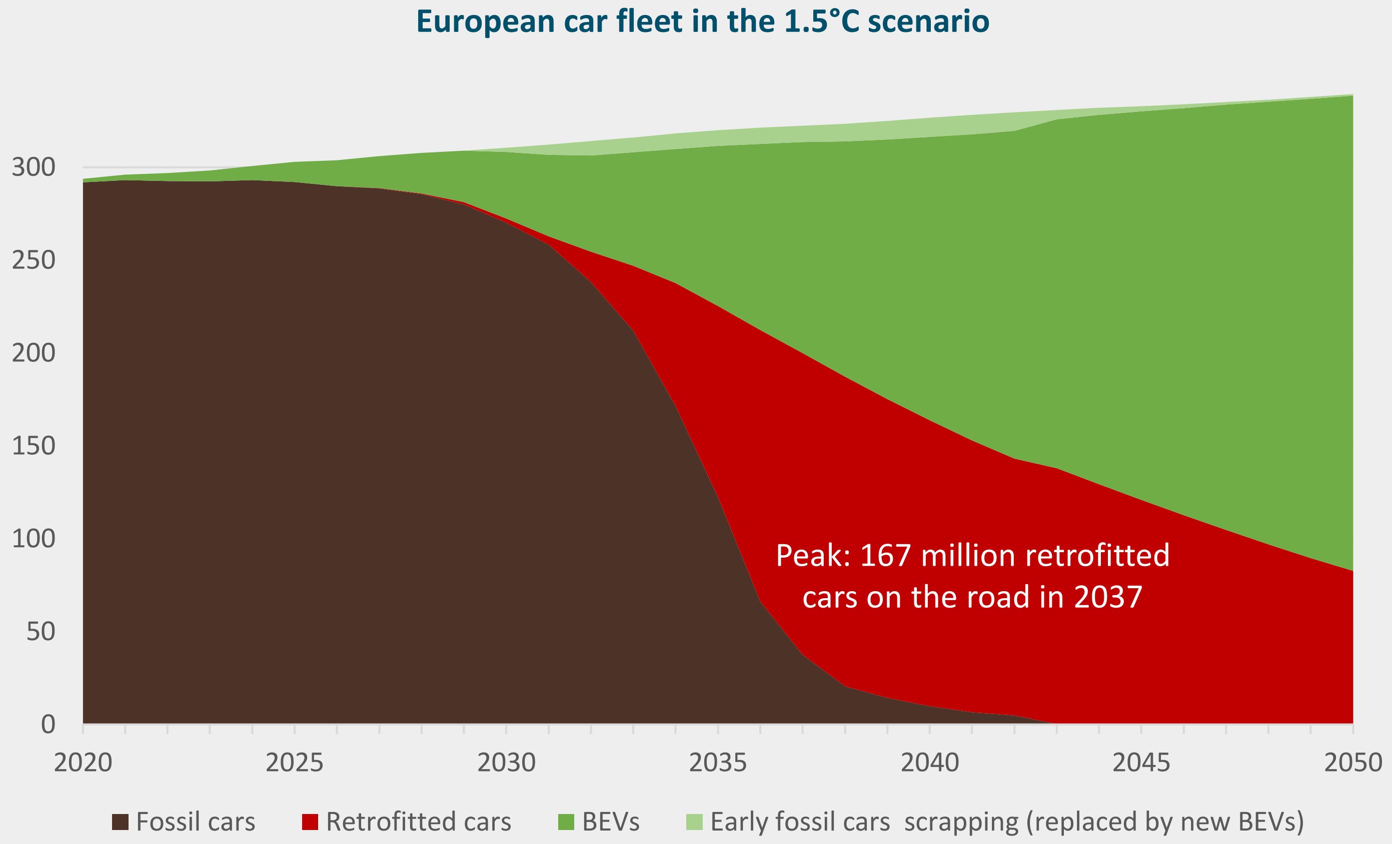
Early-stage growth rate



In this scenario, the number of retrofits peaks in year 11 and then declines sharply.
The early stage growth rate is above the typical new tech adoption curve and the historical data for EVs, due to several years of growth above 100%, at the beginning of the period. The growth rates at the beginning are lower than those used in previous scenarios (Algoé, AIRE) though, but they decline in year 10, instead of year 8 in other scenarios.

1.5°C Scenario

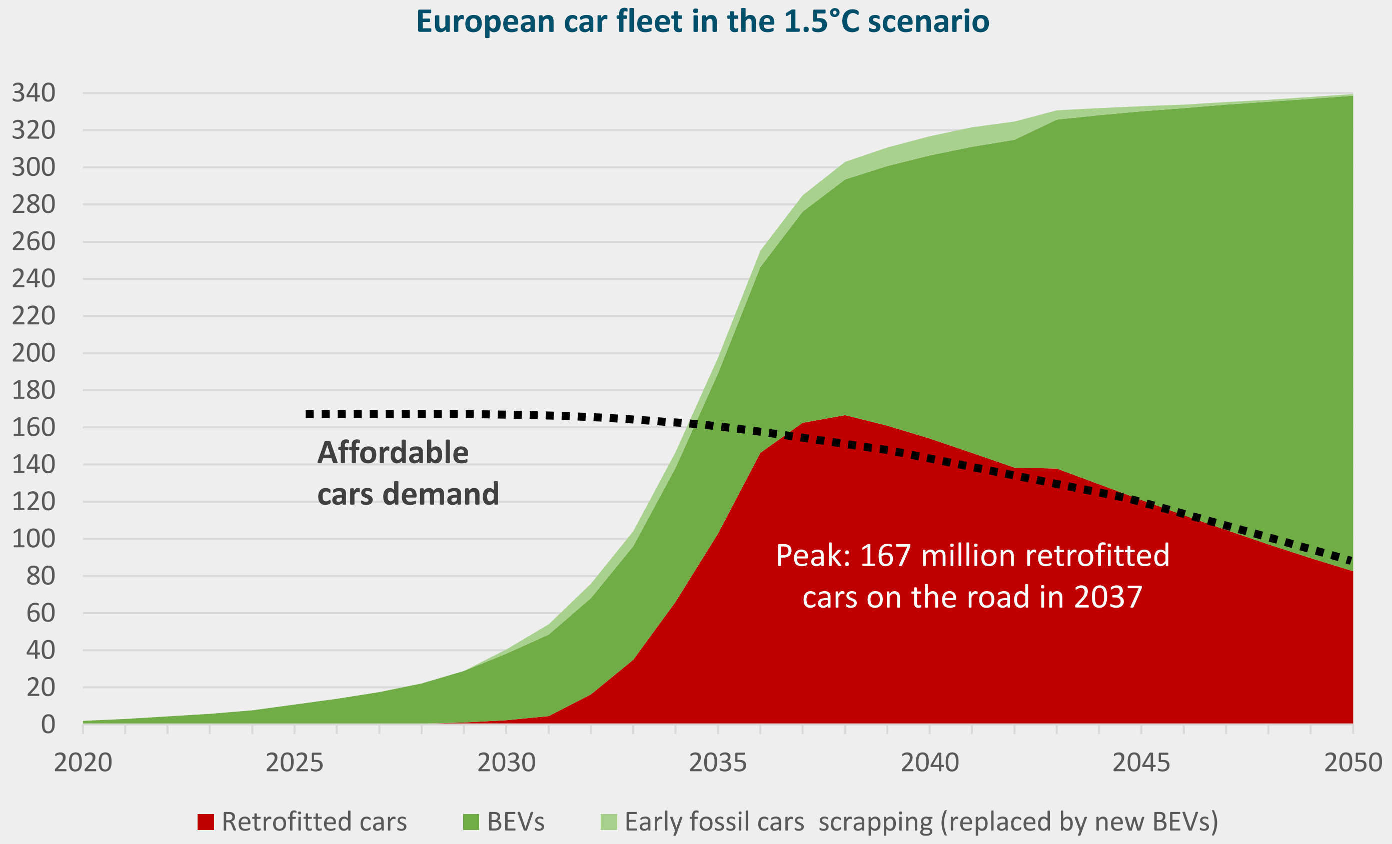
Impact on the car fleet composition



E-retrofitted cars become the dominant powertrain between 2035 and 2040, replacing old fossil cars on the affordable used cars segment. From 2040 onwards, used BEVs gradually replace e-retrofitted cars on this segment.

1.5°C Scenario

Impact on the car fleet composition

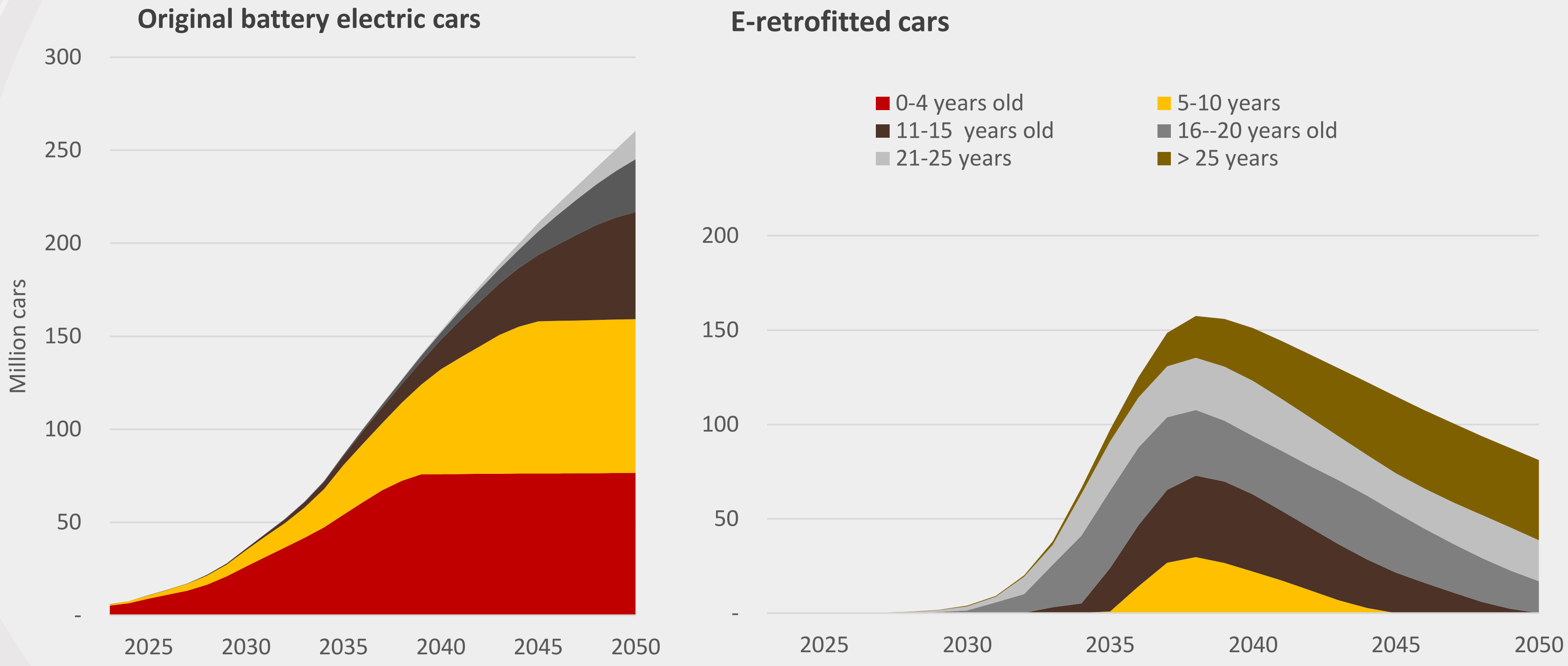


The e-retrofit market bridges the affordable used electric car gap in 2035 when the pressure increased on low-income car owners. Retrofitted cars replace affordable old fossil cars on the used car market, notably in eastern Europe, until BEVs take over at the end of the period.

1.5°C Scenario

Impact on the availability of affordable used electric cars

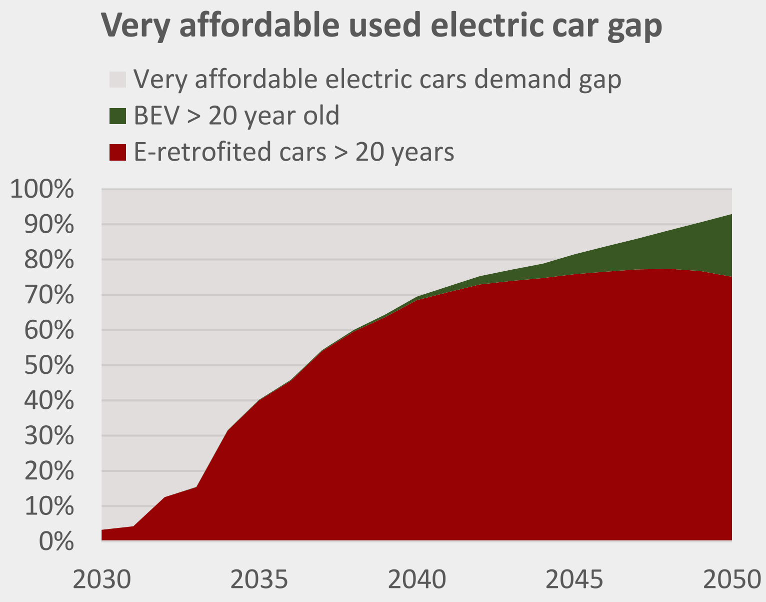
Distribution of the electric car fleet by age

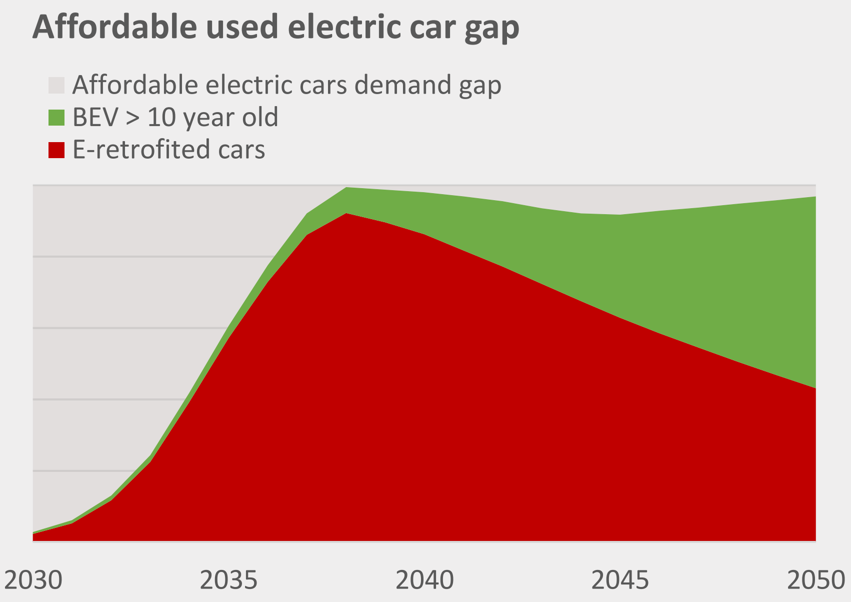


E-retrofitted cars and BEVs compete on completly different segments of the used car market: the average age of used BEVs rise from 3 year in 2030 to 9 years in 2050, while the average age of e-retrofitted car over the period is above 20 years old, and never below 16 years old.

1.5°C Scenario

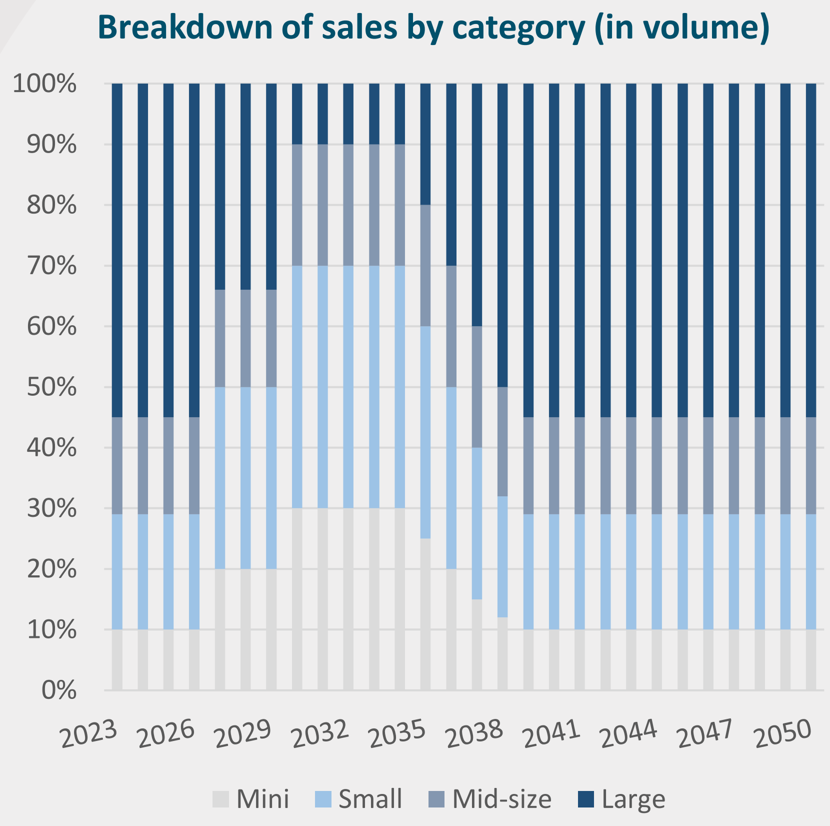
Impact on the availability of affordable used electric cars

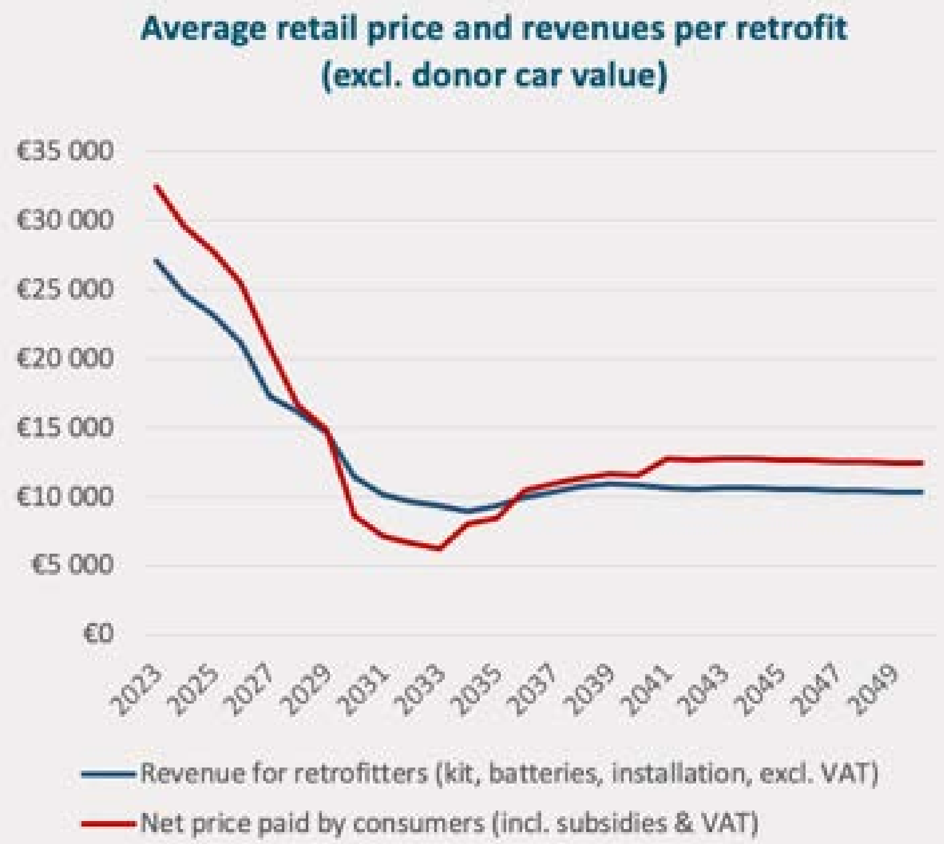




In this scenario, e-retrofitted cars help bridge the affordable electric car gap in 2038.

Revenues of the e-retrofit sector

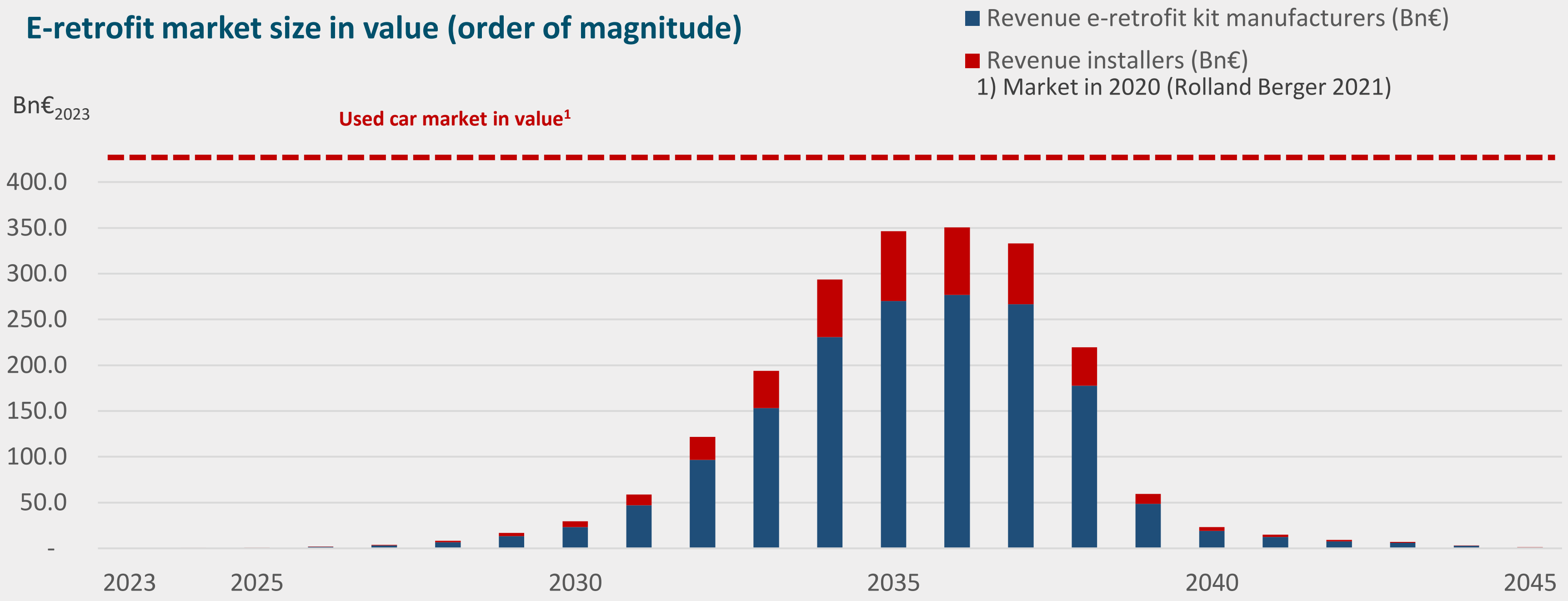




The category mix evolves over the period: it is aligned with the fleet mix at the beginning when vintage cars are converted and the end of the period, when retrofit become mandatory. During the peak (2030-2035), mini and small cars (more affordable) are overrepresented in retrofits and heavily subsidized. The average retrofit price is calculated based on the mix of size category, battery capacity and standard of retrofit (low cost on average).

1.5°C Scenario

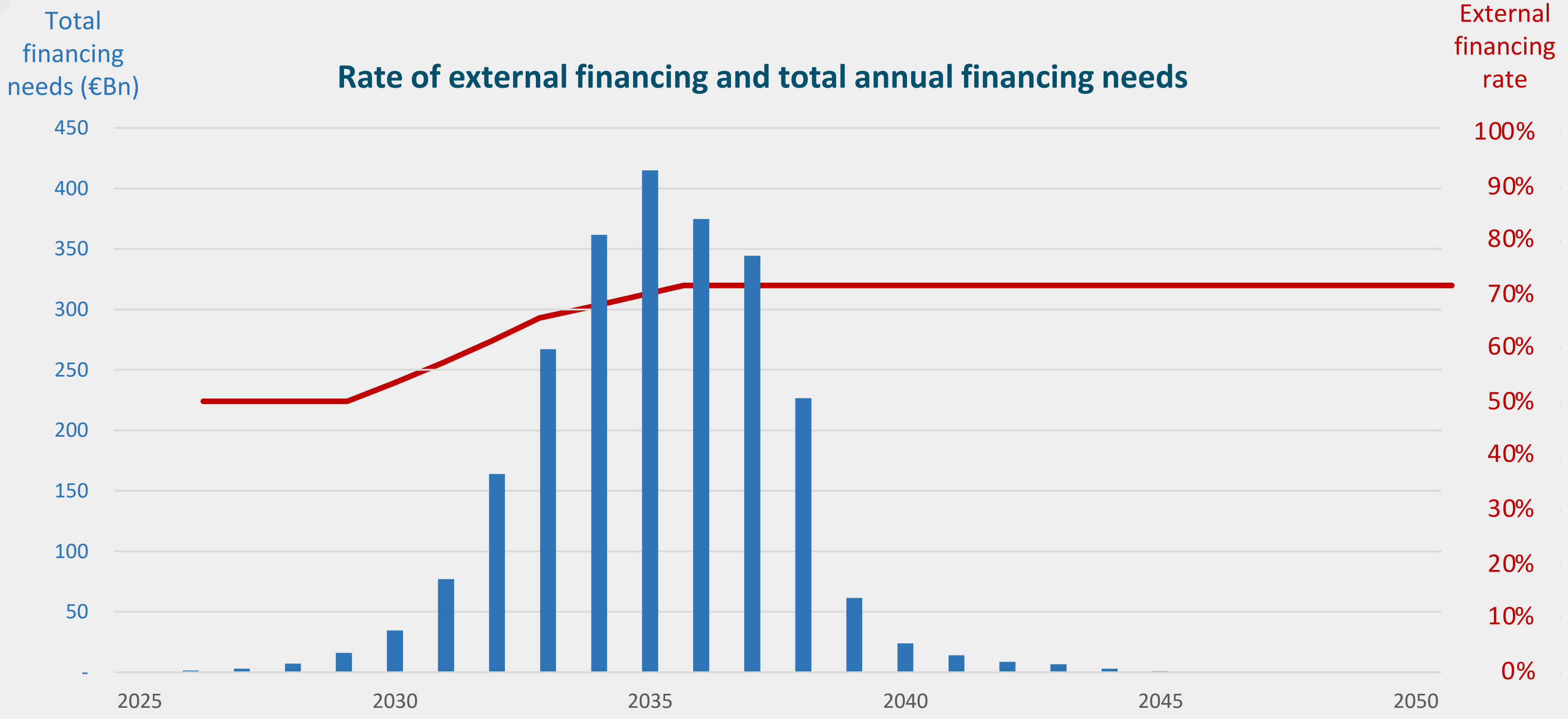
Revenues of the e-retrofit sector



The market size is based on the average revenues per retrofit (kit, batteries, installation), excluding VAT and the cost of donor cars. It represent the revenues of manufacturers and installers.

1.5°C Scenario

Financing



Formula

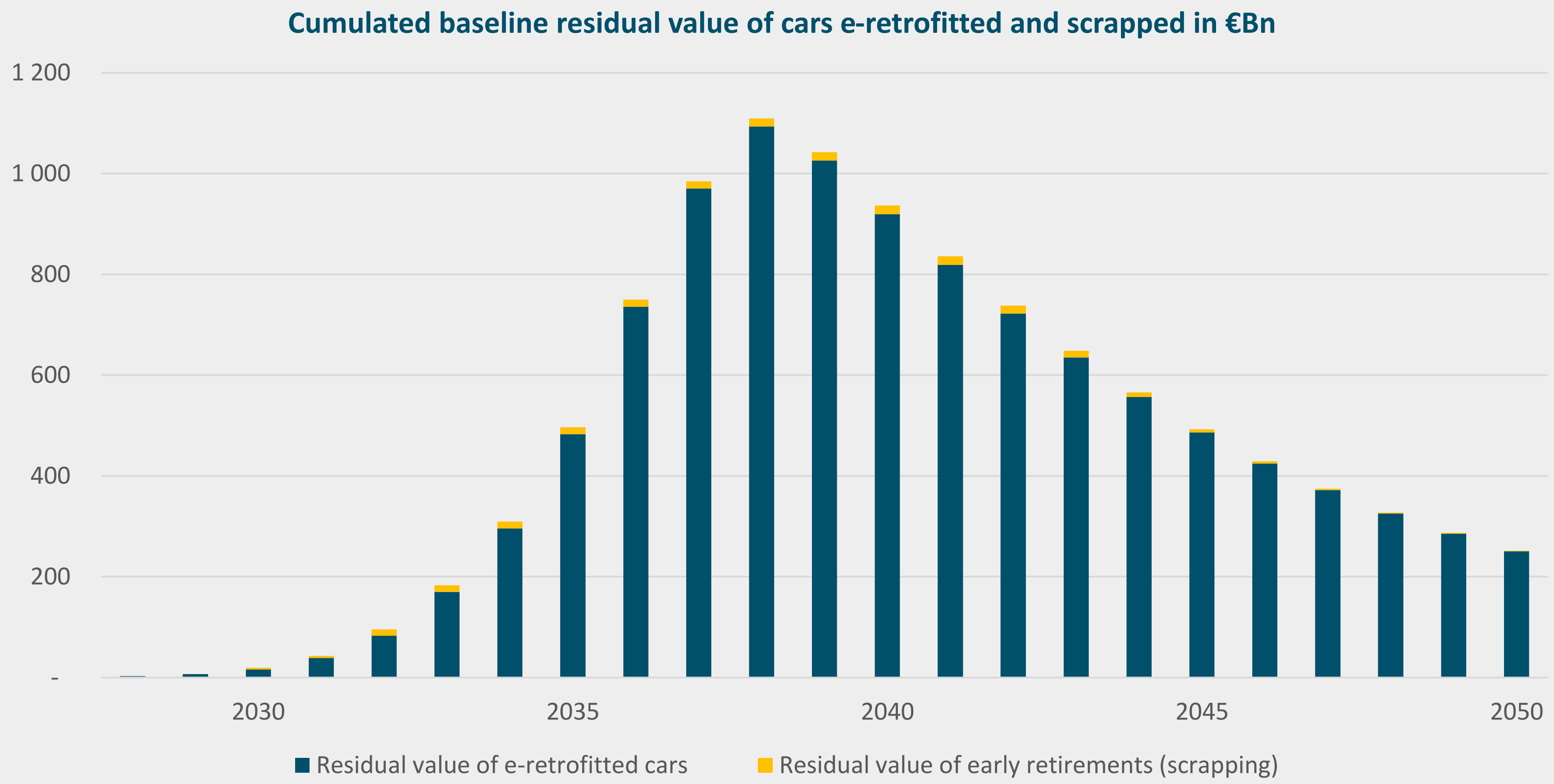
Financing needs

=

(Number of cars x Average net price paid by consumers + Average cost of a glider – Subsidies) x External financing rate

1.5°C Scenario

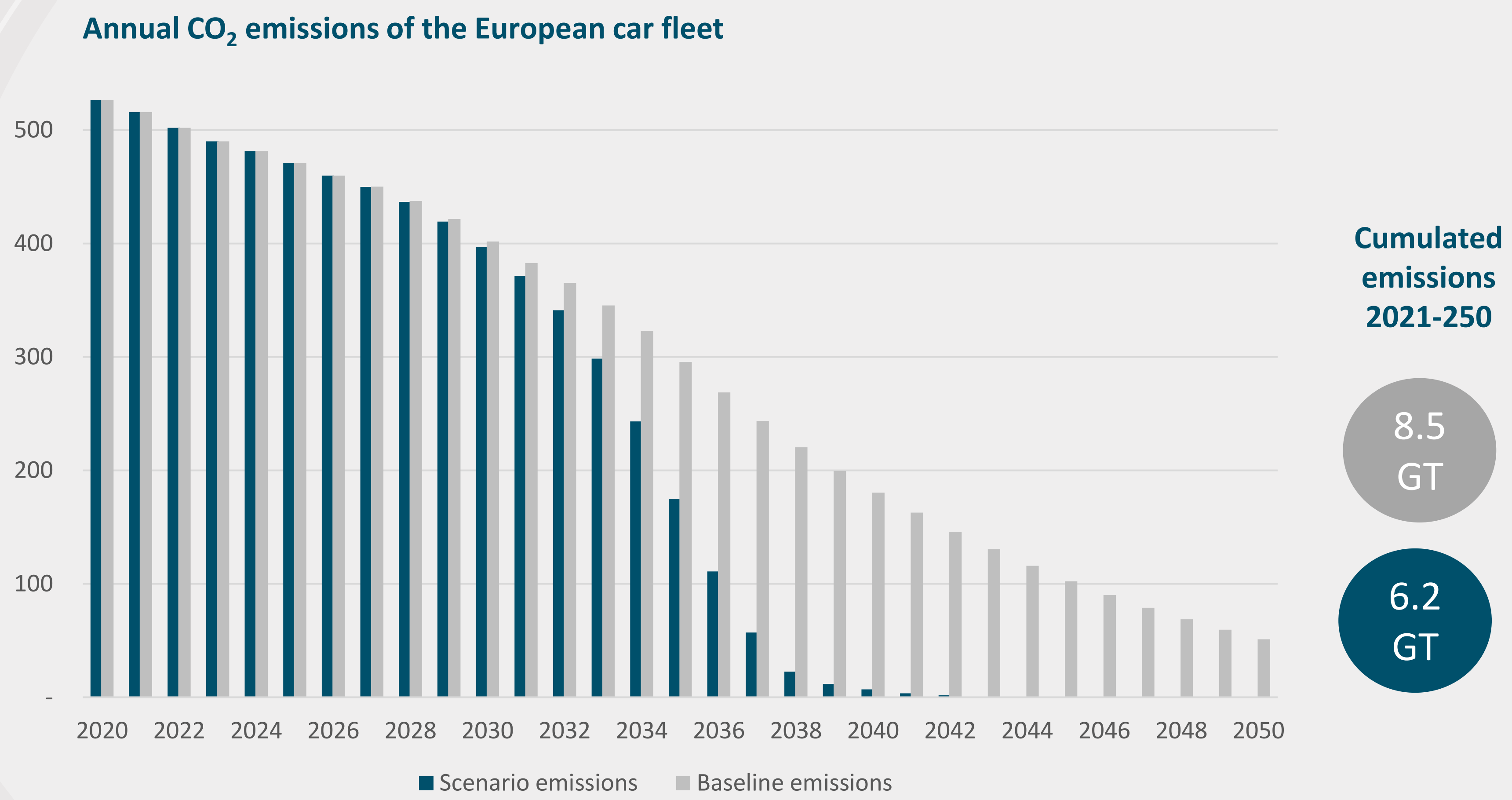
Financing



This chart shows the original residual value (in the baseline scenario) of the cars retrofitted. Assuming e-retrofitted cars keep a similar resale value, the chart provides an estimate of the resale value of retrofitted cars.

1.5°C Scenario

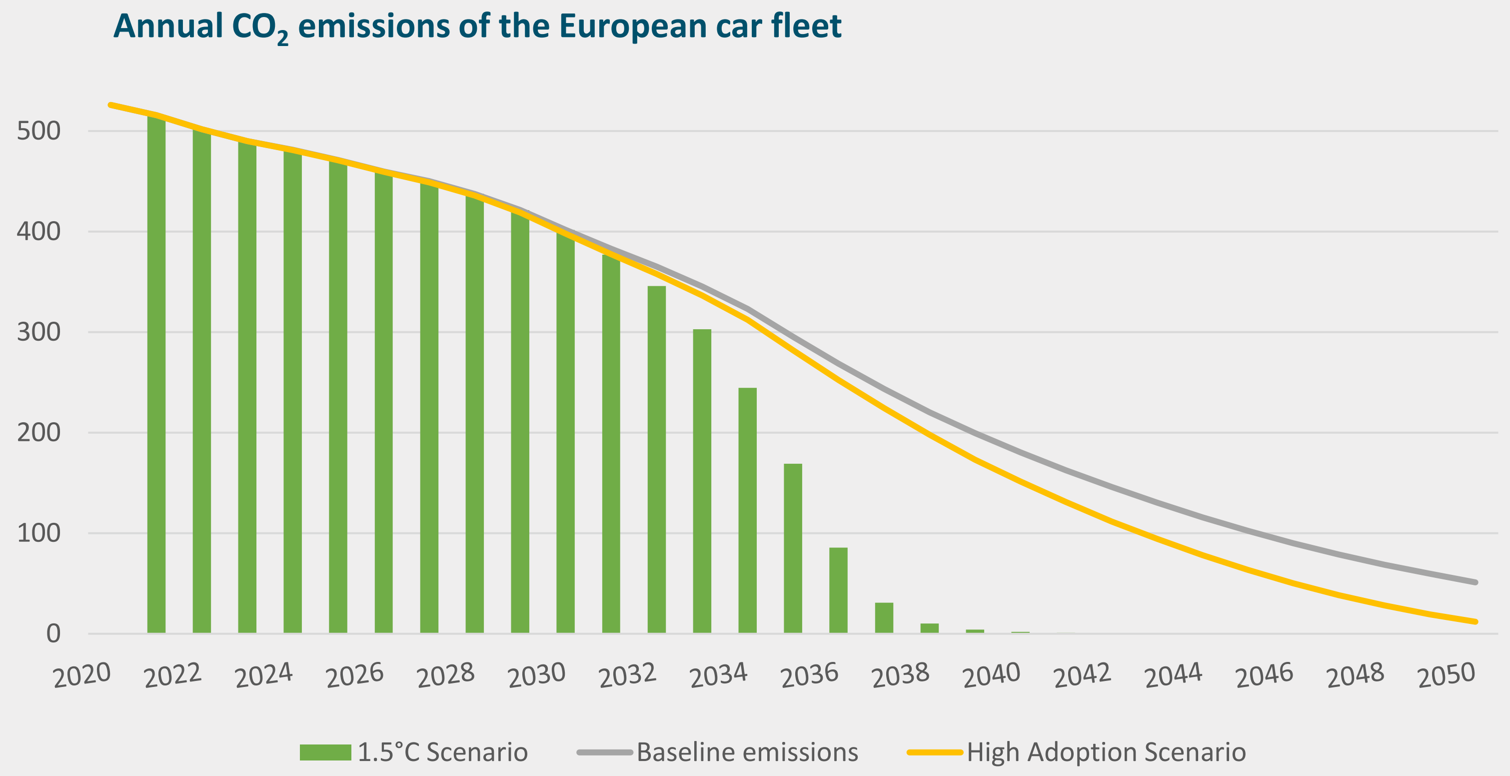
Climate change



This scenario is designed to align the car fleet CO_2 emissions with the 1.5°C pathway (defined in chapter 1). The fleet reaches zero emissions in 2040. The decarbonization effort takes place between 2030 and 2040.

1.5°C Scenario

Climate change

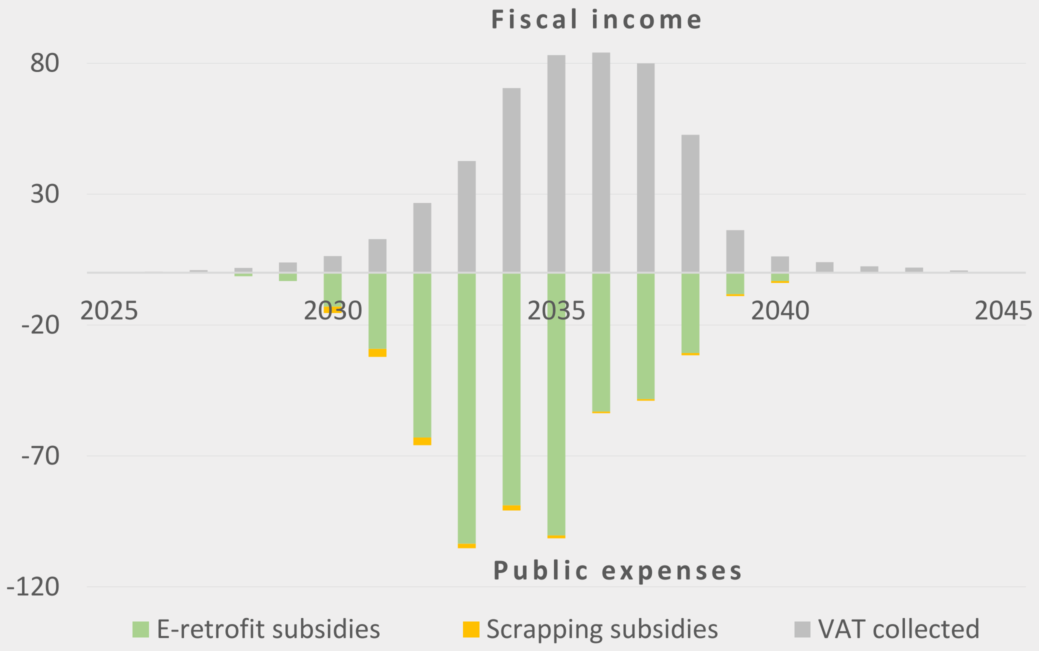


This scenario is designed to align the car fleet CO_2 emissions with the 1.5°C pathway (defined in chapter 1). The fleet reaches zero emissions in 2040. The decarbonization effort takes place between 2030 and 2040.

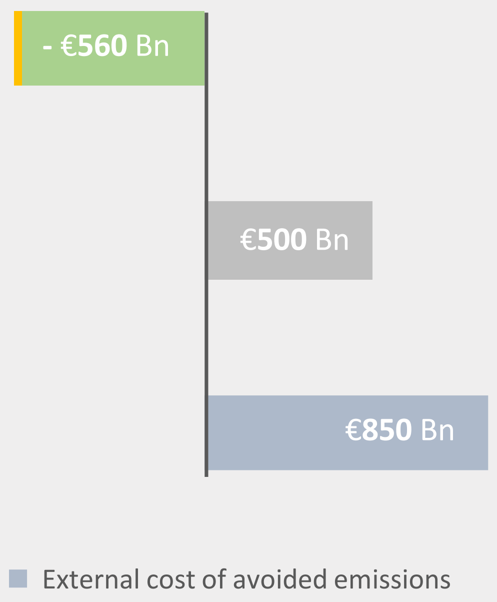
1.5°C Scenario

Public expenditures

Impact of the e-retrofit plan on annual public expenditure



Cumulated impact 2021-2050



Over the period the additional subsidies distributed are partly offset by the VAT collected, due to the limitation of subsidies after the expiration date of fossil cars.

- 1. Review of third-party forecast
- 2. Technology adoption curves
- 3.1 Low Adoption Scenario
- 3.2 High Adoption Scenario
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- 3.4 Comparing scenarios

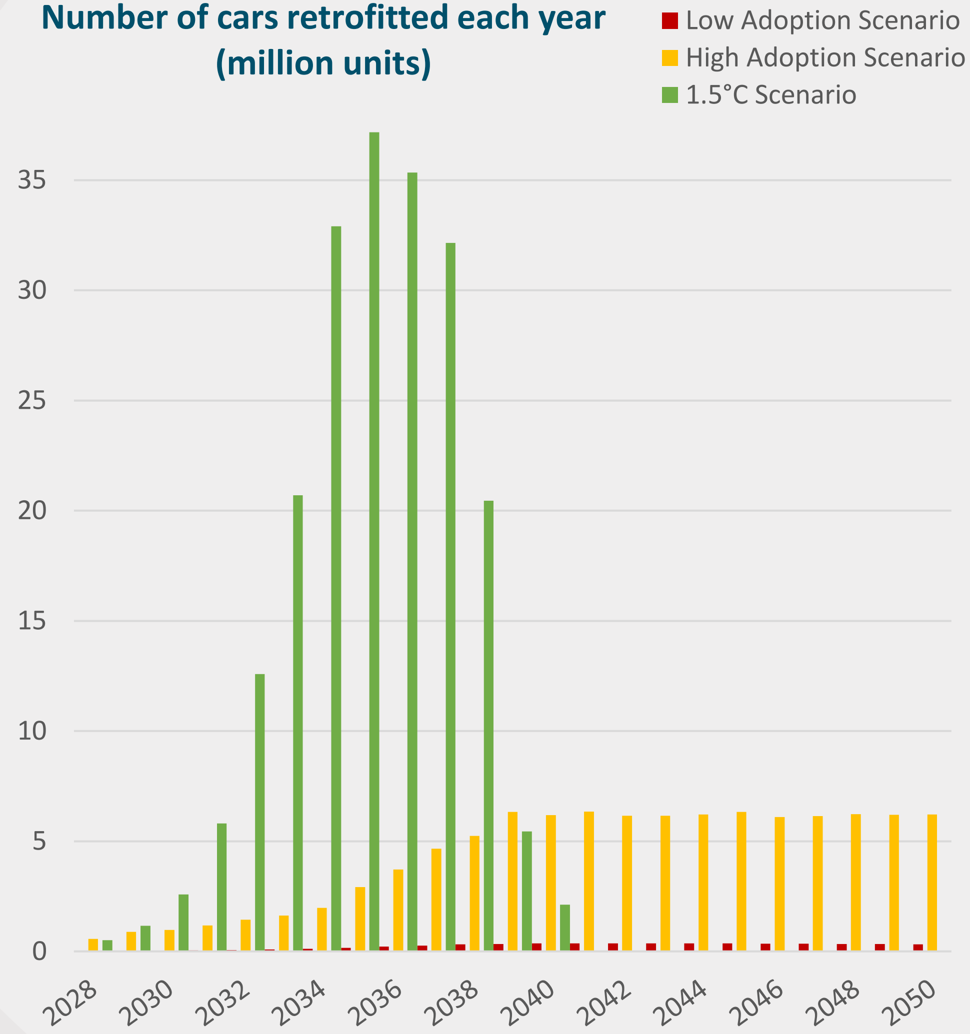
Prices

Date	Scenario	**Retrofit** (Kit, battery, installation)		**Retrofitted car** (donor car included)	
		Without subsidy	*With subsidy*	*Without subsidy*	*With subsidy*
2023	Baseline	€15,700	-	€18,500	-
2030	Low adoption	€11,900	-	€14,700	-
	High adoption	€11,300	€6,248	€13,500	€8,500
	1.5°C scenario	€10,300	€5,251	€12,500	€7,500
2035	Low adoption	€10,400	-	€13,200	-
	High adoption	€9,400	€4,400	€11,600	€6,600
	1.5°C scenario	€7,900	€5,200	€9,000	€6,300
2050	Low adoption	€9,300	-	€12,100	-
	High adoption	€7,600	€2,600	€9,900	€4,900
	1.5°C scenario	€7,100	€7,100	€7,700	€7,700

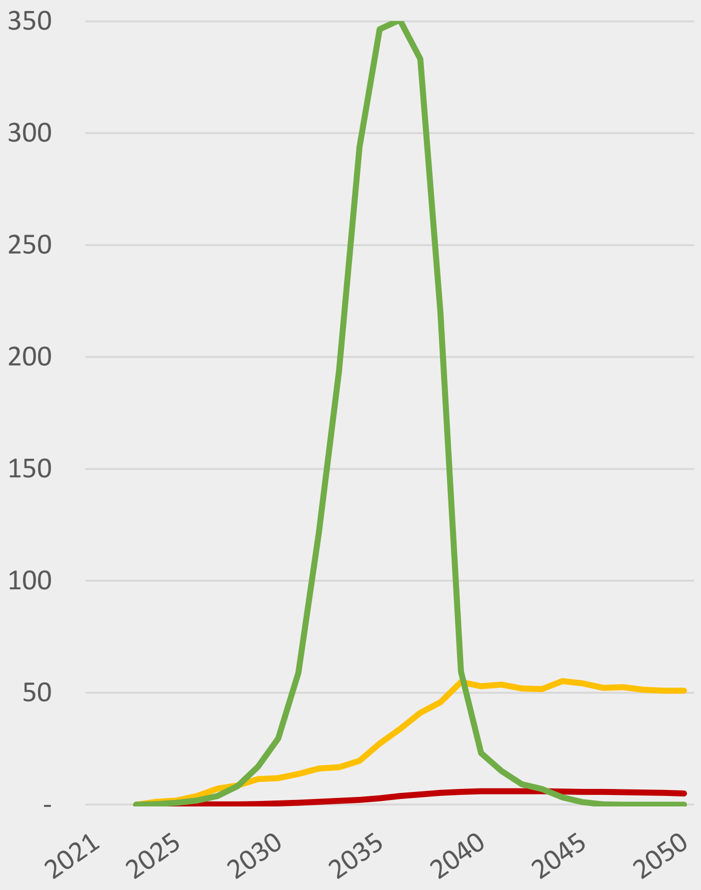
X.

Market size

Number of cars retrofitted each year (million units)

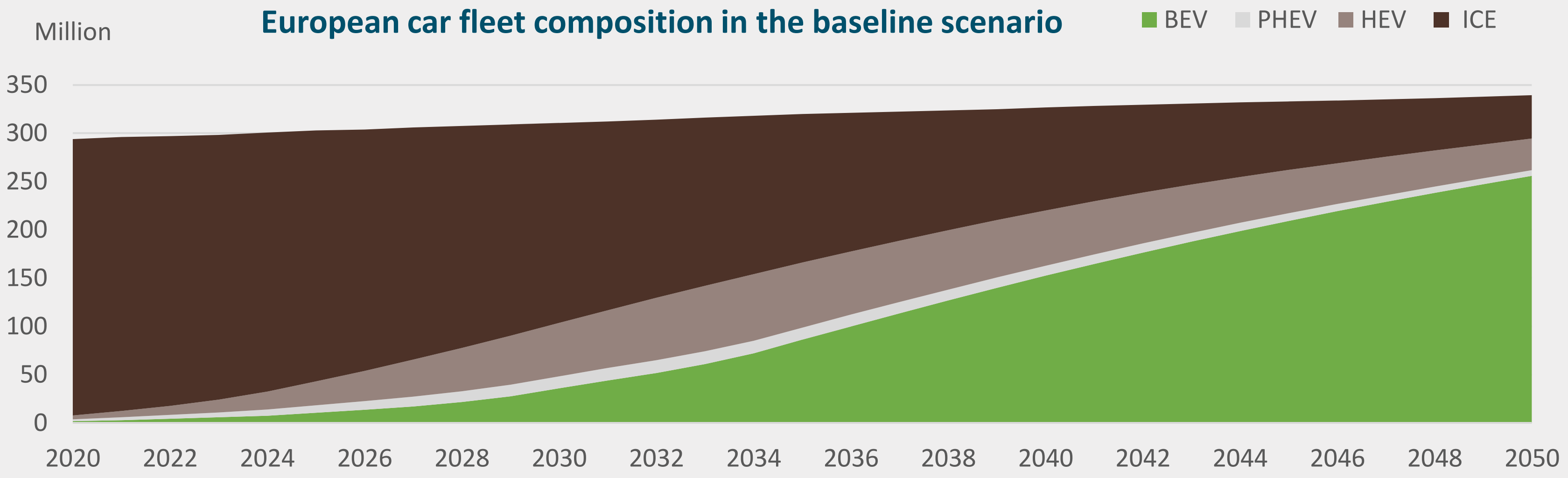


Annual sales in €Bn (kit manufacturing and installation)

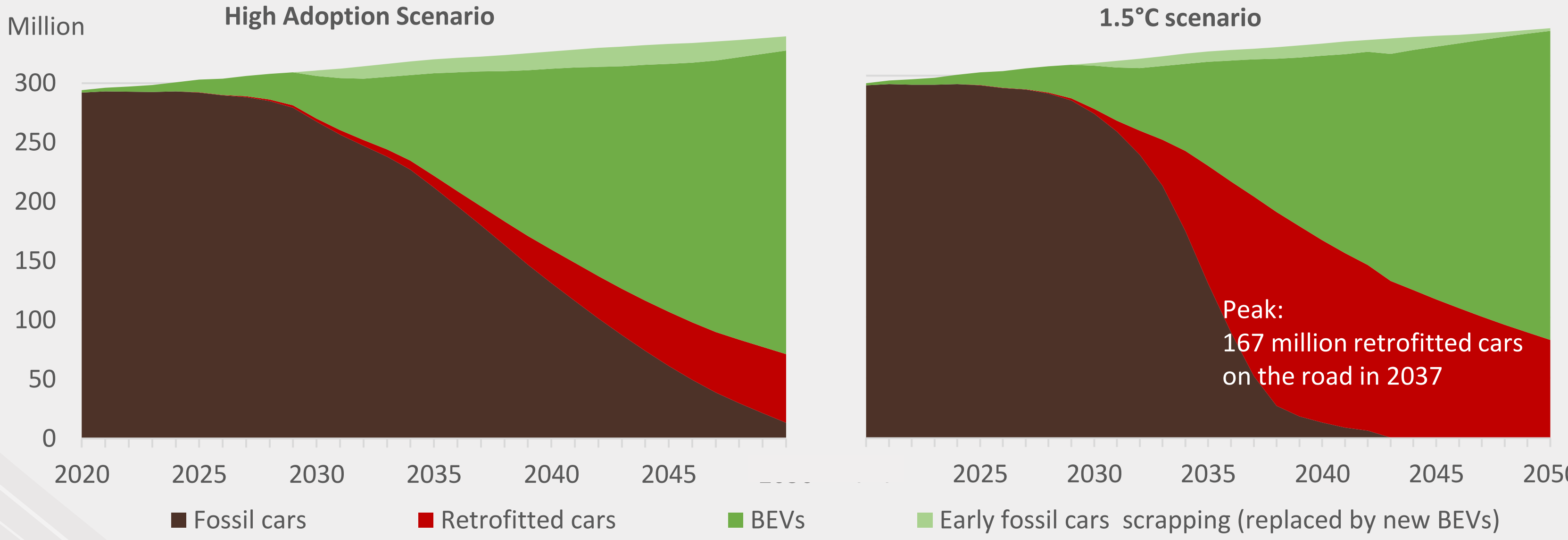


Source: Electrify®

Fleet composition

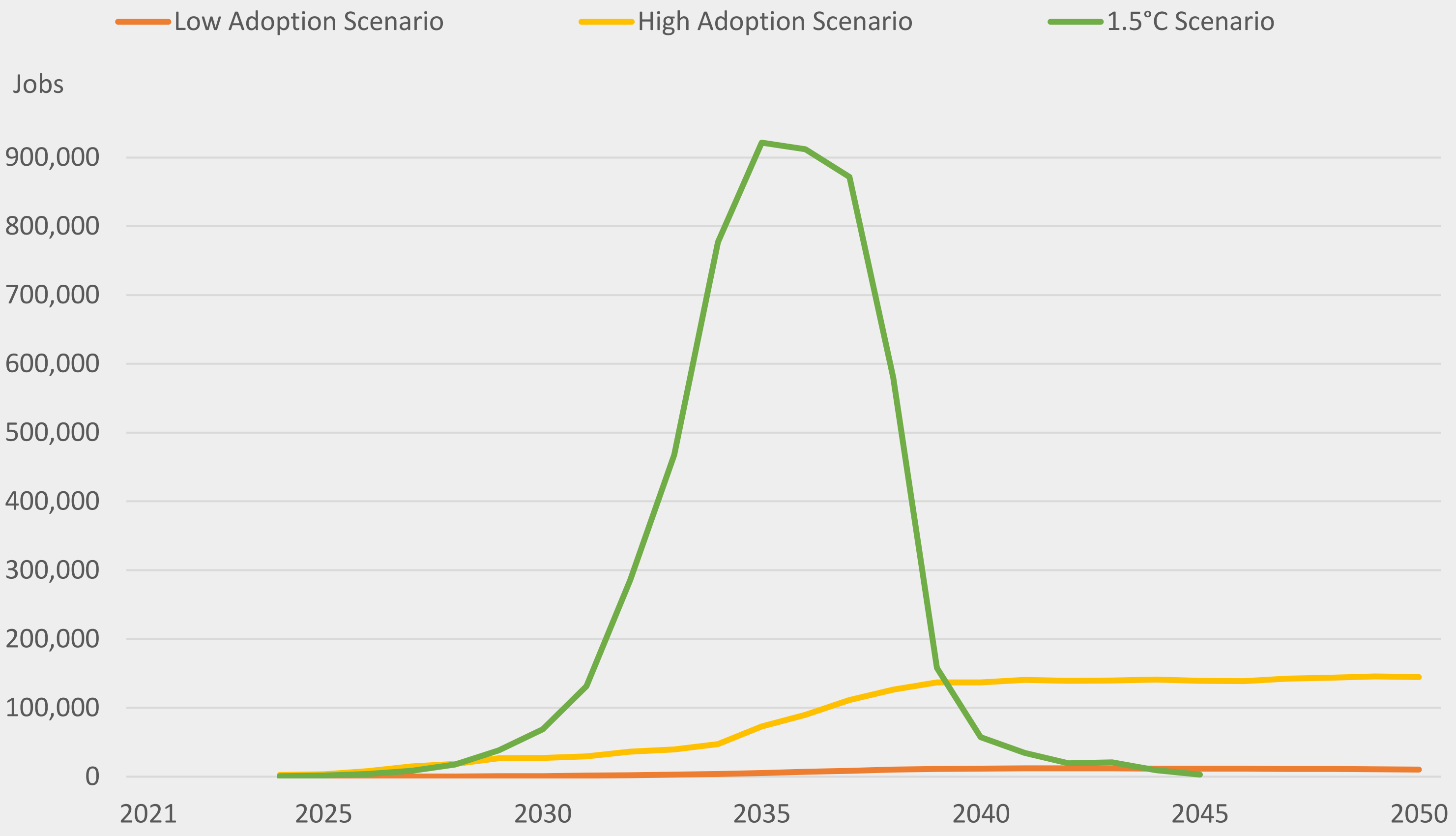


Scenarios

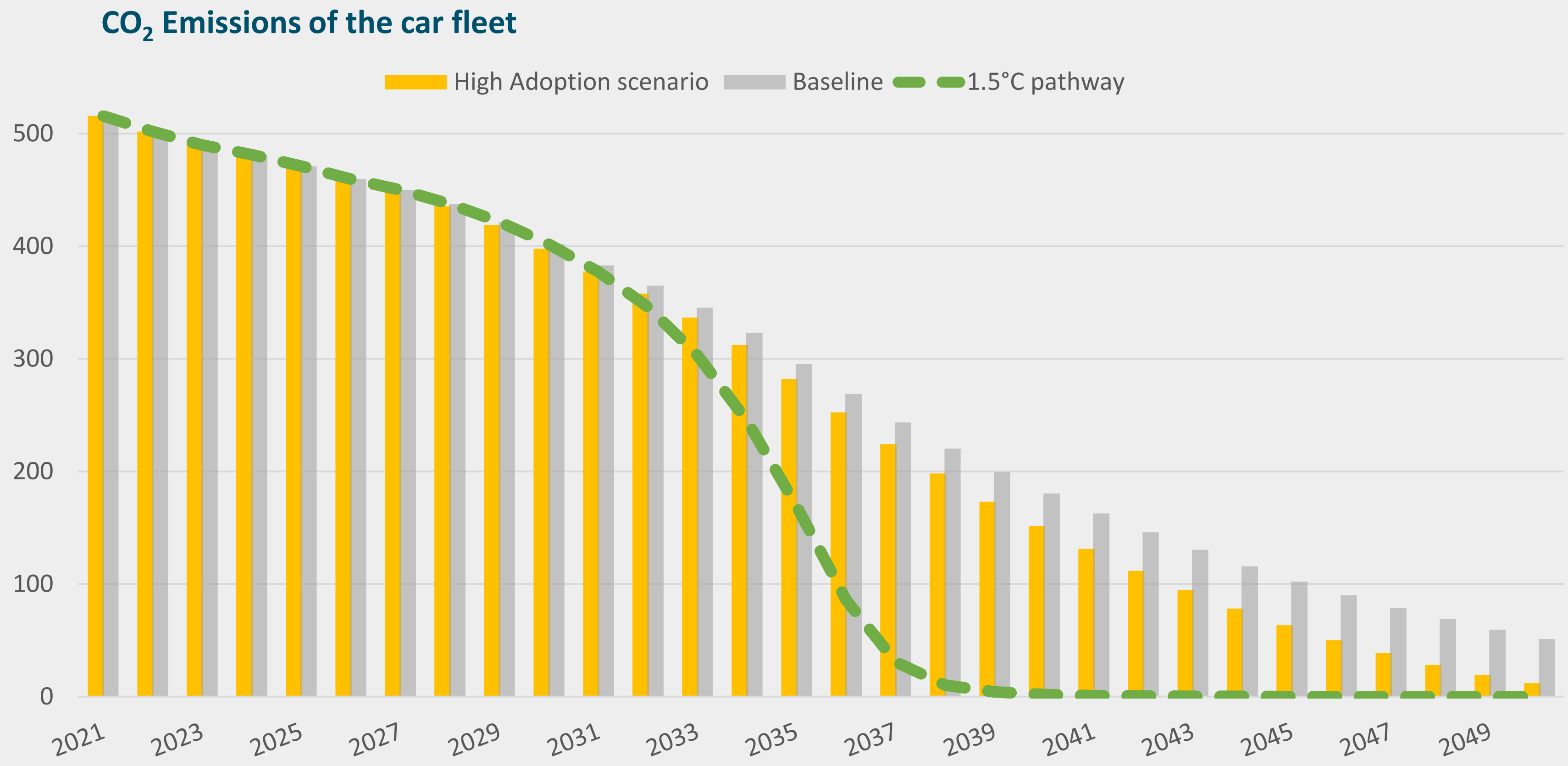


Employment

Employment in manufacturing and installation across scenarios



Carbon emissions

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