ENDING THE ICE AGE

CAN E-RETROFIT HELP EUROPE PHASE-OUT FOSSIL FUEL CARS?

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About this report

This report has been commissioned by Transport & Environment. The objectives of the study are threefold:

- Mapping the problems associated with the legacy fleet of fossil fuel cars post-2035 in Europe,
- Understanding how scalable the different electric retrofit solutions are, and
- What regulatory, financial, or other barriers exist to realize their full potential in accelerating Europe's transition to zero-carbon road transportation?

This report complements the paper « Clean solutions for all - How to clean up the entire car fleet in Europe » (T&E, June 2023), which discusses the other decarbonizaton options, including faster BEV uptake, demand management, and e-fuels.

Key terms and concepts

- Unless otherwise specified, “Europe” or “European market” covers the 27 member states of the EU, Norway, Switzerland, and the UK.
- We use four powertrain categories: Battery Electric Vehicles (BEV or simply EV), Internal Combustion Engine (ICE- petrol & diesel), Hybrid (HEV), and Plug-in-Hybrid (PHEV). The terms “fossil cars”, “fossil fleet,” and “legacy fleet” covers all cars banned in 2035 (ICE, HEV, PHEV).
- The terms “cars” and “passenger cars” cover all categories of passenger cars, including SUVs and minivans. They exclude light-duty commercial vehicles (vans), trucks, and buses.
- The concept of “affordable electric car shortage”, (defined in chapter 1.2.) describes the gap between the demand of third-hand and older affordable cars and the stock of used electric cars, in case fossil cars become too expensive to operate or banned in certain areas.

Data sources

The report combines third-party data and data from a proprietary model. Third-party sources used are mentioned in the technical annex or as footnotes. Unless otherwise specified, historical fleet and sales data come from ACEA and Eurostat, sales forecast from LMC Automotive’s Global Hybrid & Electric Vehicle Forecast (Q2 2022), and BEV uptake scenario from T&E other forward-looking data come from the model described in the annex.

Authorship

This report was researched and written by Stan Dupre (Electrify®), with technical inputs from Alexandre Allard (Algoé) and Yoann Gimbert (Transport & Environment).

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About Electrify®

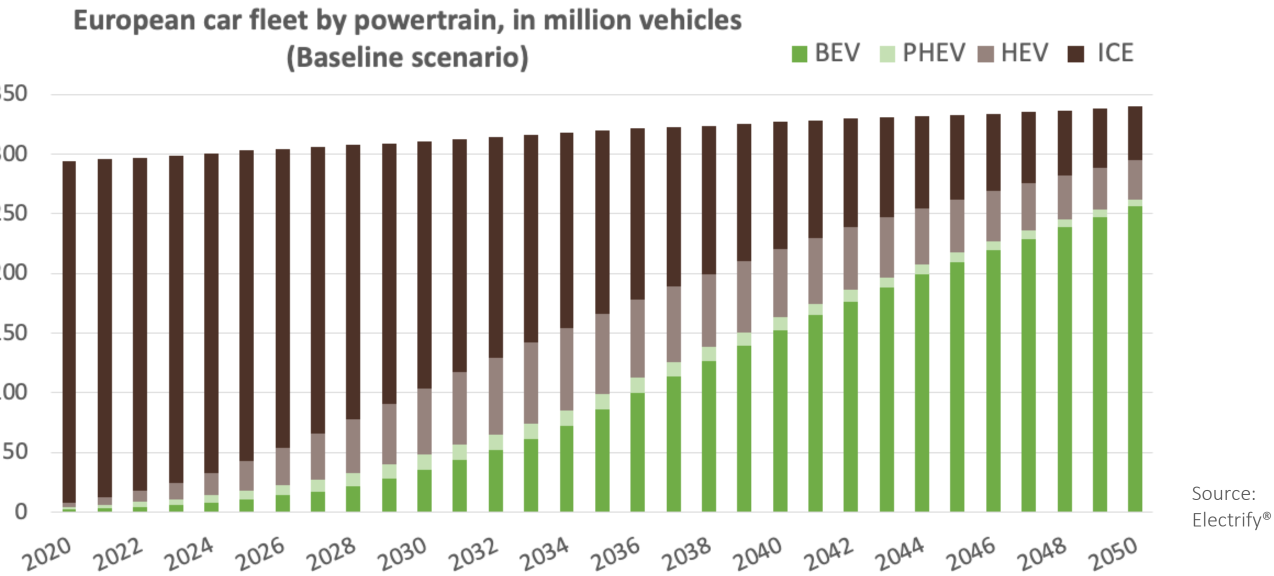
Electrify® is the first information website dedicated to e-retrofit, the industry outlook, and related social, economic, and environmental issues.

Visit **ELECTRIFY•cars** to download the Technical Annex and access the report’s data.

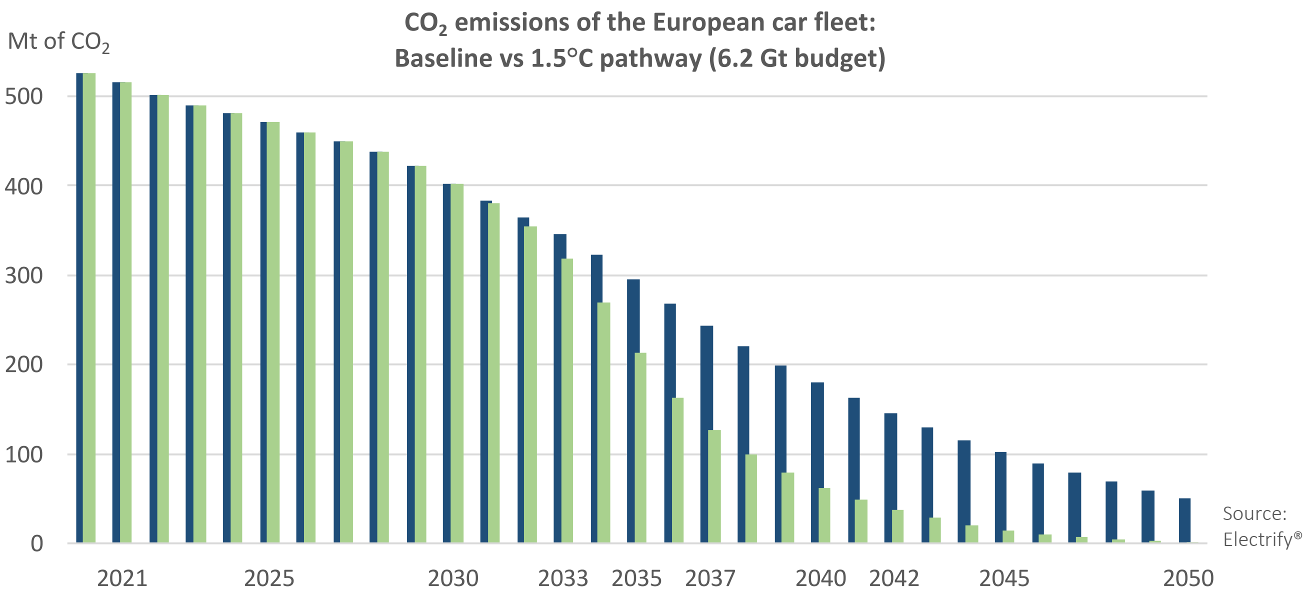
ENDING THE ICE AGE - EXECUTIVE SUMMARY

1. SHORTAGE OF AFFORDABLE ELECTRIC CARS IN A 1.5°C SCENARIO

Climate challenge. By 2035, car manufacturers will only be allowed to sell electric vehicles (EVs) in Europe. As a result, the share of fossil fuel-powered cars will gradually shrink and reach 0% around 2070.

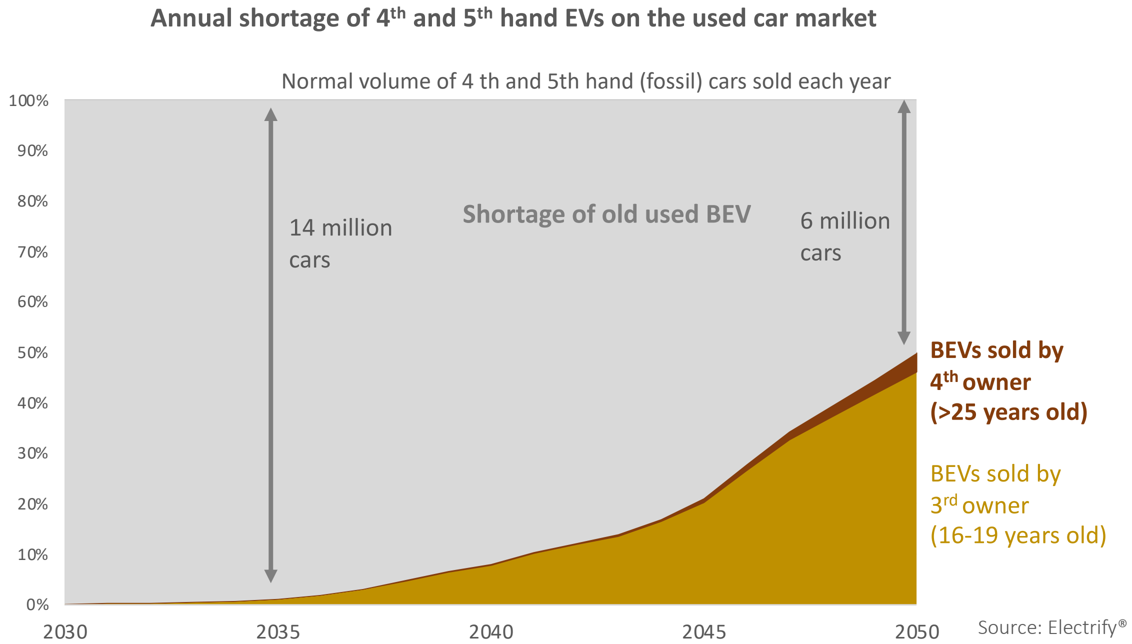


However, our analysis shows that more is needed to align the European car fleet's carbon emissions with the Paris Agreement. There will still be 240 million fossil cars on European roads in 2035 and 85 million in 2050. Factoring used car exports, the fleet will emit twice the 1.5°C carbon budget, generating an external cost of up to €2Tn for the economy due to pollution and additional decarbonization efforts required.



Social challenge. To avoid such a scenario, fossil fuel-powered cars should be retired by 2050 through policy measures such as removing old internal combustion engine cars from the road and increasing ownership and fuel taxes to force early retirements.

However, such measures will lead to a second problem: a need for more affordable used electric cars. In 2035 it is expected that there will be a shortage of around 14 million BEVs, and the average used BEV will be four years-year-old and cost 20,000€



Sources: Electrify.Cars based on Transport & Mobility Leuven for low-income household ownership.

The report assesses how retrofitting fossil cars to battery electric vehicles might help address both challenges by accelerating the phase-out of fossil cars, while generating affordable used electric cars to meet the demand for electric cars.

2. WHAT IS ELECTRIC RETROFIT?

“E-retrofit” involves replacing the internal combustion engine (ICE) and fuel tank of a used vehicle with an electric engine and battery (or a fuel cell and hydrogen tank).

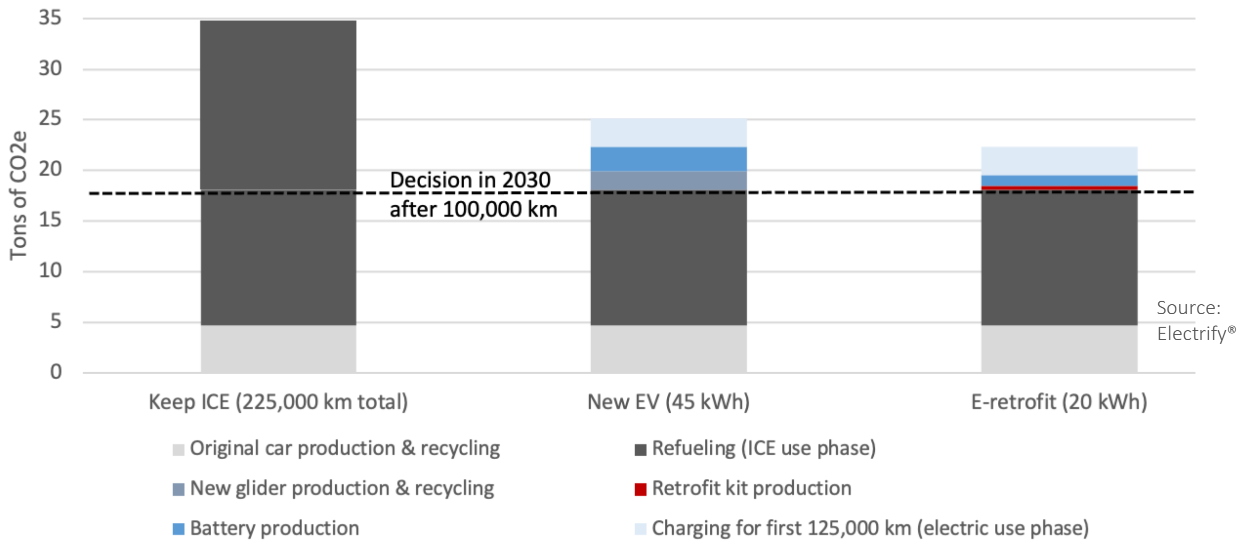
Regulation. Currently, the EU regulatory framework is ill-suited for e-retrofits: it requires an agreement from the manufacturer and regulatory approval for each vehicle. However, some countries have already simplified their approval processes (Netherlands, Germany, UK) for individual conversions, and France has even introduced the world-first regulation for series e-retrofit in 2020, giving birth to a new industry. Building on this initiative, the EU decided to assess the ways to deploy e-retrofit across Europe.

Series e-retrofit, as tested in France, requires regulatory approval of a e-retrofit prototype of a car model known as a type-variant-version (e.g., VW Golf VII). Once approved, dedicated companies manufacture the retrofit kit and battery in factories. Each manufacturer then trains and approves a network of installers, usually repair shops, to install the kit in the donor car, replace the ICE. The operation takes at least a week of work and could be associated with repairs and refitting of the donor vehicle.

3. THE ENVIRONMENTAL AND SOCIAL BENEFITS OF E-RETROFIT

From a sustainability perspective, e-retrofitting is an ideal solution: it generates 70% fewer CO_2 emissions than keeping the original fossil car, and 40% less than purchasing a new EV.

Lifetime emissions for a decision made in 2030 (use phase: average European electricity mix)



It is also a job-intensive industry: we estimate that up to 900,000 jobs can be created if the e-retrofit sector reaches its full potential in Europe (see 1.5°C scenario in chapter 8): 15% in manufacturing to produce the kits, and 85% in mechanical and maintenance for the installation.

4. THE E-RETROFIT MARKET AND ITS POTENTIAL

The e-retrofit market today. E-retrofit constitutes an emerging market for heavy trucks, buses, and vocational vehicles, with market leaders being early-stage startups (Series A or B) delivering their first vehicles. For light commercial vehicles, the key players are at an earlier stage, having raised seed rounds, and demonstrated prototypes. They are now taking pre-orders. However, the pool of vehicles eligible for e-retrofitting in these segments is limited, with 34.7 million vans, 7.1 million trucks, and 0.8 million buses and coaches on European roads in 2020.
The big challenge is the car market, with a huge pool of vehicles but with e-retrofits still in its infancy. Today, there are only a few startups, raising venture capital money to scale up fast and deliver economies of scale. Most of them are French due to the improved regulatory framework and are waiting for their first approval. Their offer focuses on vintage cars due to the emotional value and high resale price attached to these vehicles. Established car manufacturers are largely absent from the market, with only small-scale initiatives, also focused on their vintage fleet.

The potential size of the car market. If the market remains focused on vintage models, we estimate that e-retrofit potential is limited to a pool of 10 million cars or 3% of the total fleet. However, the most ambitious startups plan to retrofit everyday cars and exceed a billion euros of sales by 2030. If they succeed, the potential pool of fossil cars to be retrofitted is about 236 million vehicles in 2030, with emission mitigation potential of up to 4.8 Gt of CO_2. In such a scenario, the use case for e-retrofitted cars is likely to focus on households' second and third cars used for short local trips (about 40-50 million vehicles), as well as affordable (below €9,400) and very affordable old vehicles (below €4,200), which represent a fleet of 180 million cars in Europe. The second part of the report explores under which conditions the e-retrofit industry can reach this potential.

5. POTENTIAL DRIVERS OF ADOPTION

Several factors are likely to boost the demand for e-retrofit in the coming decade:

Zero and Low Emission Zones are expected to prevent dozens of millions of Europeans from using fossil cars in their everyday life. Several member states have integrated Low Emission Zones (LEZ) into their climate regulations and plans, including France, Spain, the Netherlands, and Poland. The number is expected to exceed 500 zones in 2025 with a potential for growth remaining significant. Many LEZs are expected to be converted into Zero Emission Zones (ZEZs) the most ambitious plan being the Paris metropole which affects a local fleet of more than 2 million vehicles.

Subsidies. Subsidies have played a critical role in triggering the electric car market and are expected to be equally critical for the e-retrofit market. Most European countries, provide subsidies for scrapping an old fossil car and purchasing of a new low-emission vehicle instead, with higher levels for electric cars (up to €12,000 in France and Romania, €9,000 in Germany, and €6,000 in Poland). Based on carbon emissions avoided, our analysis suggests that e-retrofitted vehicles would be entitled to an additional €1,500 subsidy in France and €2,700 in Germany relative to standard EVs. If it proves to be a viable solution at scale, a possible scenario would involve a gradual shift of remaining subsidies from old car scrapping and new EV purchase to e-retrofit.

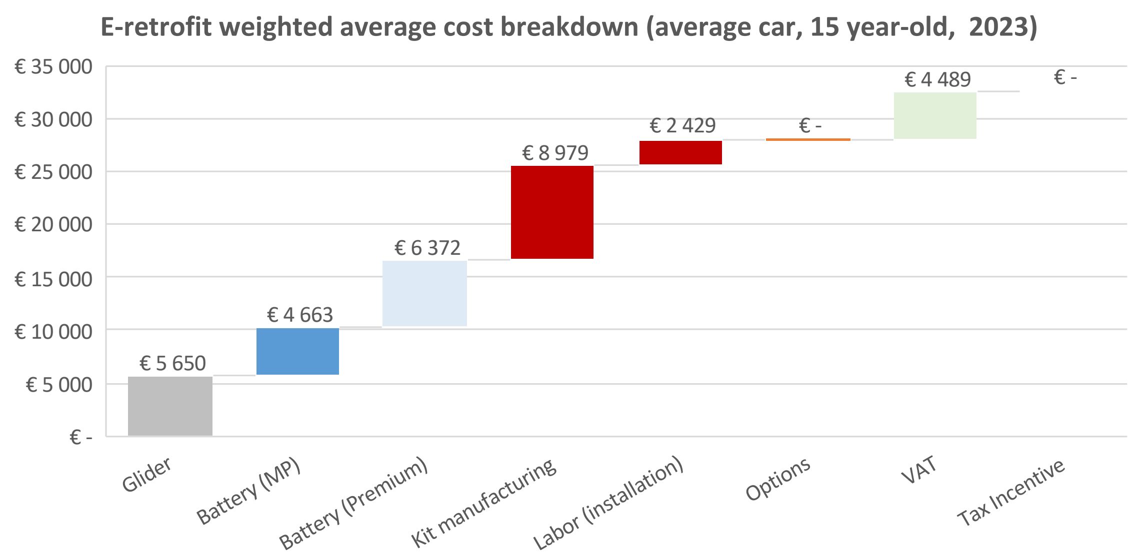
Interest from early adopters. The history of EVs shows that early adopters driven by environmental values and technology enthusiasm have played a critical role in triggering a mass market long before EVs reach cost parity with fossil cars. E-retrofit seems to benefit from an even higher level of interest: a 2022 IPSOS survey found that it is preferred to purchasing a new EV in key European markets.

European carbon reduction strategy. To meet the Paris Agreement objectives, the EU must phase out its legacy fossil car fleet by 2050, requiring action from 2030 onwards. Until 2022, new sales were prioritized in policy debates, but going forward, we expect questions on vehicles-in-use emissions, manufactured extended responsibility, and exported pollution to move up on the policy agenda.

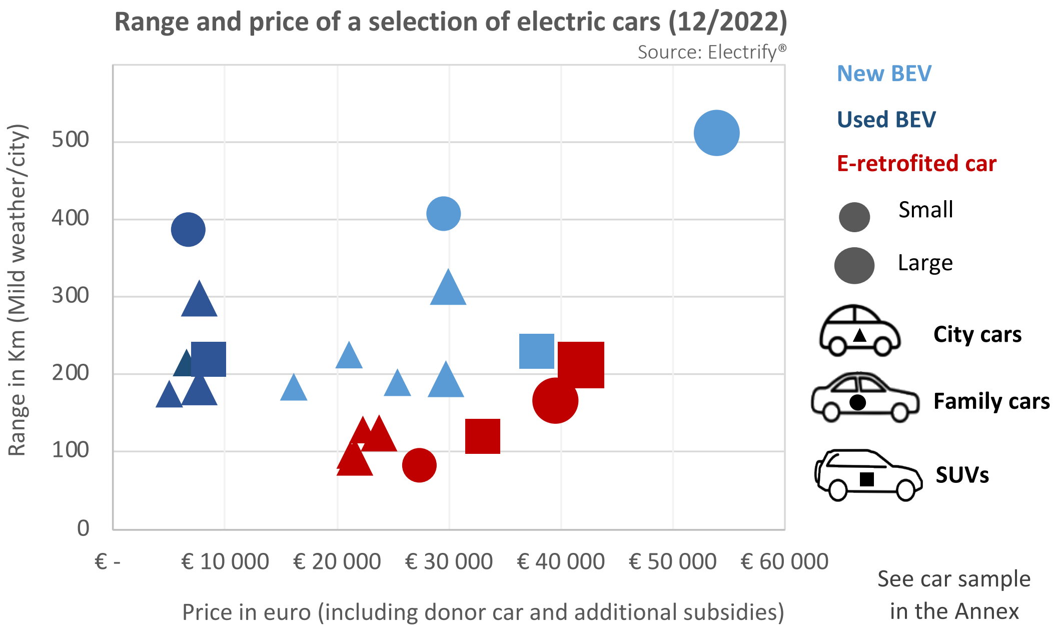
E-retrofit for cars might be at the dawn of a major boom and become the main solution to bridge the affordable car gap during the transition to zero mobility, first in Europe and then in other markets.

6. SOLVING THE ECONOMIC EQUATION OF E-RETROFIT

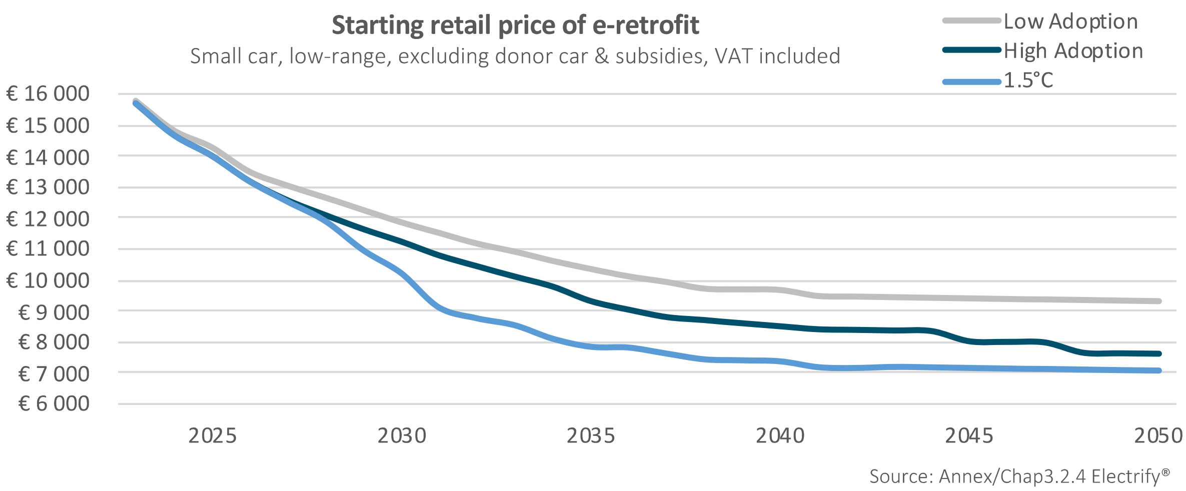
As of today, e-retrofitted is too expensive to provide an affordable solution to the electric used car shortage. Today, the retail price of e-retrofit starts at €16,000 (VAT included) for a small car such as the Renault Twingo, without factoring in potential subsidies and the cost of the donor car.



Due to the high upfront investment, the total cost of ownership (TCO) of an e-retrofitted car remains higher than maintaining its internal combustion engine. Therefore, the decision to retrofit a vehicle must be driven by non-economic factors such as regulation, social status, or environmental targets for organizations. However, the high price of e-retrofitted cars put them in the range of same-size new EVs, and way above equivalent used EVs, for a much shorter range. To buy a new or used BEV, the ICE owner would need to sell his old ICE first. The donor car residual value is included in the whole retrofit price to have a fair comparison as the ICE owner would not sell the old car if they convert it to electric.



Cost outlook. For e-retrofit to take off beyond the niche vintage cars market, the economic equation will need to improve dramatically. Our analysis suggests that only a perfect storm of cost reduction factors (e.g. falling battery prices, economies of scale, and reduced residual value of donor cars), propelled by aggressive environmental policies and dedicated additional subsidies (up to €5,000) can align e-retrofit net prices with the level required to become the affordable car solution. With such reductions, e-retrofitted cars produced in large series would quickly become cheaper than new EVs, with a gross starting price dropping **below €8,000 between 2035 and 2045** (VAT included, subsidies and cost of the donor car excluded) depending on the scenario.



However, reaching price parity with used EVs would remain a challenge. Our findings suggest that the e-retrofit market can only reach scale if significant inflation (+20% to +70%) occurs in the old (> 15-year-old) used EV market, triggered by a **shortage of affordable used electric cars**. The upper range could appear as unlikely, but it is in line with the inflation (up to 70%) in used car prices observed during the COVID crisis.

7. TECHNICAL ROADBLOCKS

If e-retrofit manages to become affordable, it will still have to address a few technical roadblocks to reach its full potential of 200+ million cars converted:

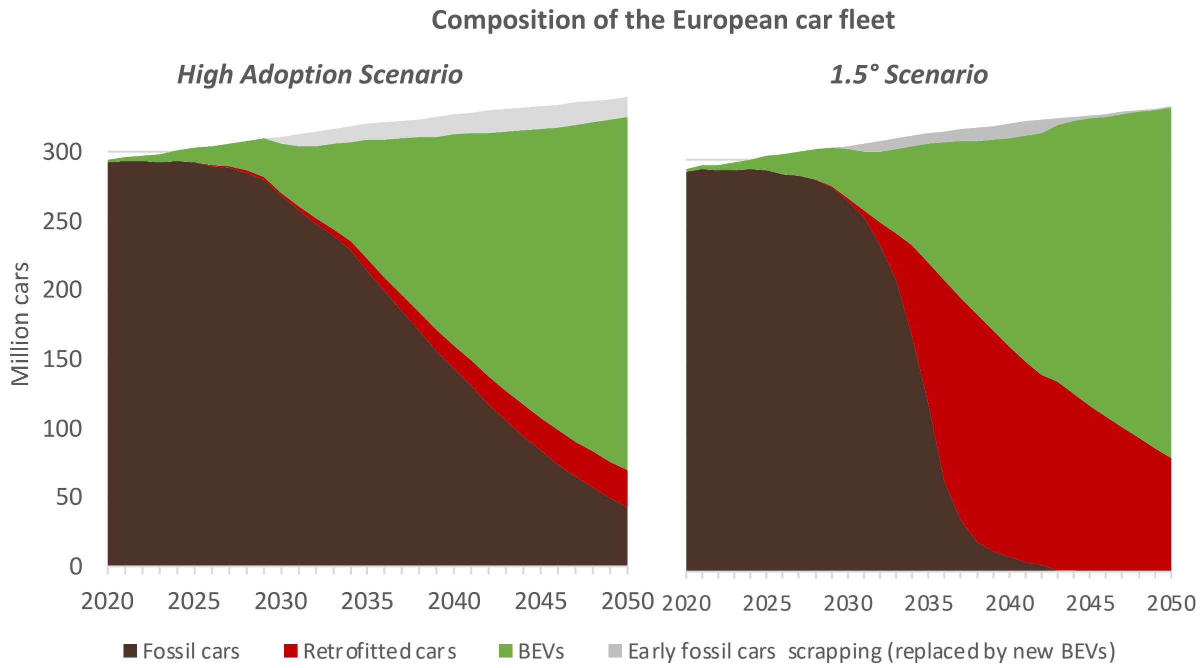
- **Low range.** Due to technical constraints and higher prices, current e-retrofitted cars include much smaller batteries than equivalent EVs, limiting their range to 100 km for small cars and 200 km for larger vehicles. Although usage statistics suggest that such a low range matches the needs of 90% of users for daily trips, it requires destination charging infrastructure and consumers who overcome their range anxiety. Major improvements in the energy density (kWh/size and weight) of batteries could solve this problem, but unlikely to materialize at the necessary scale before 2030 or 2035.
- **Mechatronics**. Vintage cars are quite easy to retrofit since they are not equipped with electronic systems. Dealing with the complexity of mechatronic systems such as electric power steering (EPS), advanced driver assistance systems (ADAS), and hybrid powertrains are the other make-or-break challenge for e-retrofit. If this challenge is not addressed only the past generation of cars will be eligible for retrofit reducing the pool to 70 million vehicles in 2030 and 25 million in 2035.

8. E-RETROFIT OUTLOOK

This chapter presents three scenarios for e-retrofit market uptake to 2050.

- **The Low Adoption Scenario** could see 8 million cars retrofitted, most conversions taking place after 2045 when economic and regulatory pressures on fossil car use intensify. In this scenario, e-retrofit remains focused on vintage cars and niche low-range use cases. E-retrofitted cars benefit from the same subsidies as all EVs, and never reach price parity with comparable used EVs. The market size reaches €6 Bn in 2040.
- **The High Adoption Scenario** envisions 50 million e-retrofitted cars from 2023 to 2050, all of them older than 10 years. The market size reaches 3 million vehicles retrofitted per year, and 25 €Bn of annual revenues by 2040, representing about 8% of the used car market in volume. The industry creates about 60,000 jobs from 2037 to 2050. In this scenario, adoption is driven by the deployment of Low and Zero Emission Zones across Western Europe, combined with social leasing programs and subsidies targeted at low-income households. Restrictions on fossil car ownership accelerate their depreciation and inflate the resale value of used EVs, making e-retrofit more competitive. Factoring in subsidies, the starting price for retrofitting drops below €4,500 in 2035, or about €6,600 including a donor car.
- **The 1.5°C Scenario** could see 210 million cars retrofitted. This scenario is policy-driven, aiming to align with the 1.5°C pathway and bridge the affordable electric used car gap. Europe deploys a plan to phase out all fossil cars from the roads between 2030 and 2045. The residual value of fossil cars approaching their expiration date collapses and the resale value of old used EVs rises. With the additional effect of subsidies, the net starting price of e-retrofitted cars drops below €3,600 without donor car and €5,000 with the donor car in 2033. The market size exceeds 35 million cars and $350 bn of annual revenue at its peak in 2035s, roughly the size of the current used car market.

Cumulative CO_2 emissions (2021-2050) from the European car fleet are reduced by 0.3 Gt (-4%) in the High Adoption Scenario and by 2.3 Gt (-27%) in the 1.5°C Scenario. Subsidies of €275 billion and €560 billion are respectively distributed in the High Adoption Scenario and the 1.5°C Scenario. In the latter scenario, the net economic impact on public expenses is largely positive when factoring in VAT and external costs.



9. CONCLUSIONS

Key finding. Policymakers in Europe will have to choose between letting the emissions of the legacy fossil cars fleet exceed the 1.5°C carbon budget and triggering a shortage of affordable used electric cars by pushing for early retirement of fossil cars. E-retrofit could constitute a solution to this dilemma, but it would require aggressive policy actions implemented in a short period of time.

Recommendations. Whatever the scenario favored by policymakers for e-retrofit, our findings call for immediate actions by public authorities in Europe:

- The study revealed major gaps in public statistics regarding the age structure of the current car fleet and the whereabouts of old cars, as well as a lack of research on the shortage of affordable used EVs in a scenario of transition to full electric road mobility. This gap can be bridged by EU-funded research such as the Horizon Europe program.
- With 2035 approaching, a structured policy debate on how to end the ICE age while addressing the affordability challenge would be needed. A High-Level Expert Group at EU level could help pave the way.
- Even in the low adoption case, harmonization of regulations on e-retrofit across Europe would be needed, with the EU providing at least guidance to member States on how to develop national regulation and potential tax incentives schemes.
- The business model of e-retrofit for passenger cars is yet to be demonstrated, and the market outlook heavily depends on the introduction of public policies. Such a situation does not create favorable conditions for raising private capital. Public funding would be needed to finance large-scale demonstration projects.
- If e-retrofit takes off, car manufacturers could play an important role. Potential short-term actions include sharing the detailed specifications of the vehicles and providing access to the software components of mechatronics systems. They can also support e-retrofit by designing the last generation of fossil cars in a way that makes it easier. Beyond this, policymakers can request car manufacturers to come up with objectives and roadmaps regarding the mitigation of existing cars' emissions, in the context of their climate disclosure obligations.

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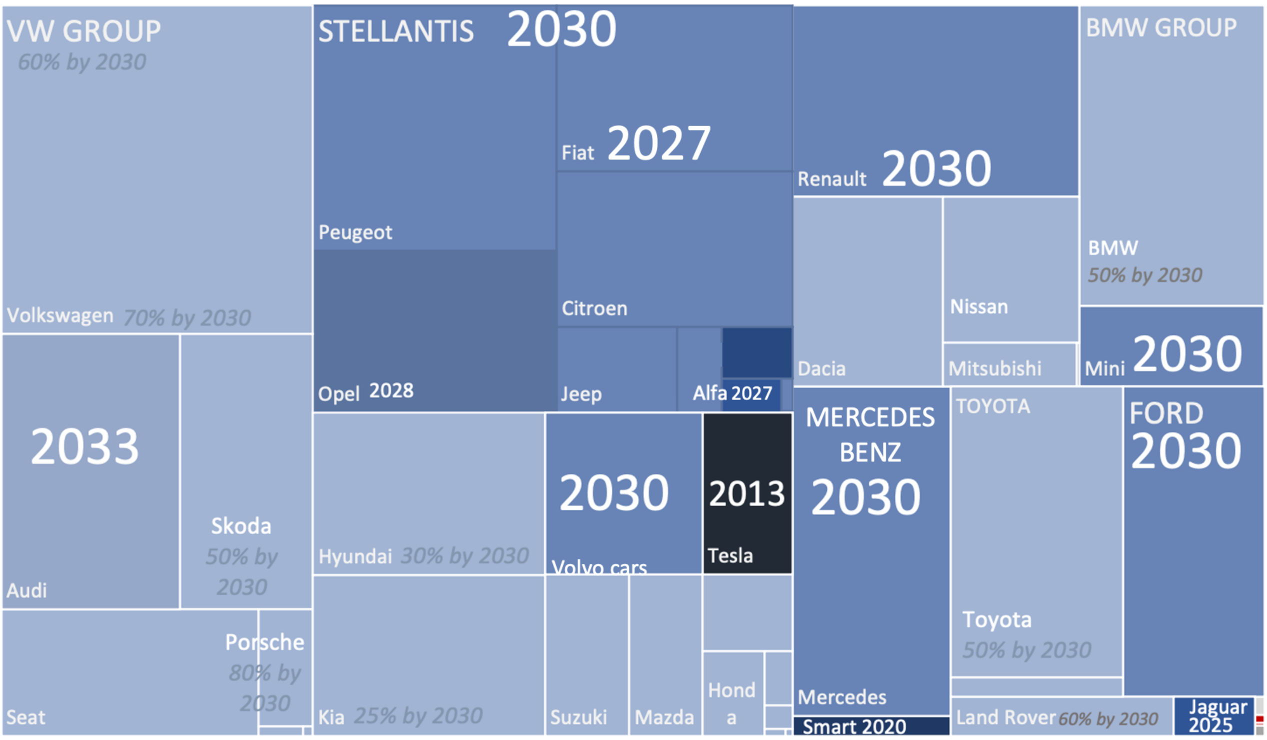
1. JUST TRANSITION CHALLENGES IN THE CAR MARKET

1.1. MEETING CLIMATE TARGETS

ICE Phase-out. As part of its FitFor55 regulatory package, the EU agreed on a full phase-out of new ICE by 2035 for cars and vans[1]. Some countries have set more ambitious non-binding targets involving a phase-out of ICE LDVs by 2025 to 2030[2]. So far trucks are not affected, but a coalition of 38 environmental NGOs including T&E advocates for an extension of the 2035 phase-out to this category.

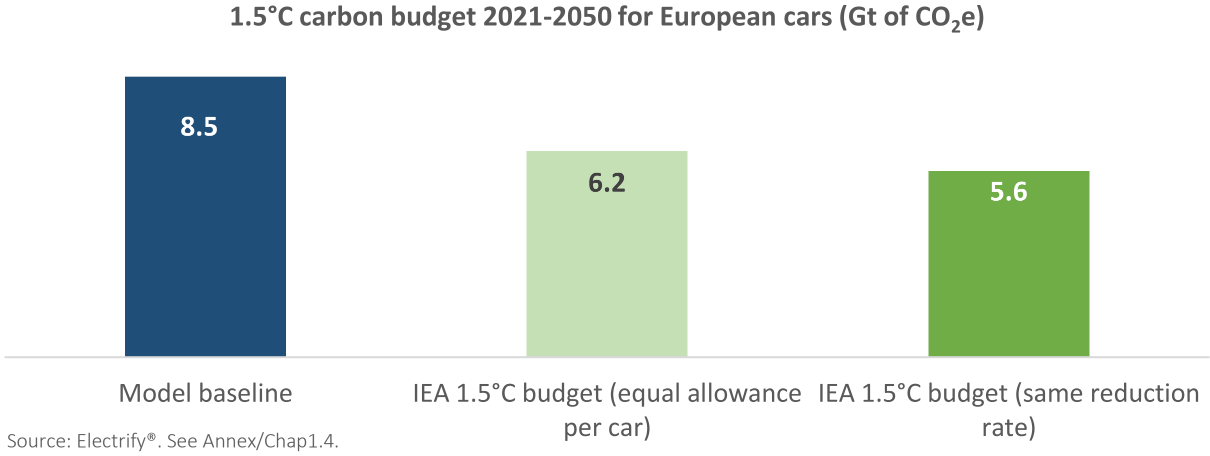
Voluntary targets. Some Manufacturers responded by adopting slightly more ambitious targets at the brand or group level (see chart below[3]). Overall, as of April 2022, voluntary commitments to 100% BEV sales by 2030 sump up to 55% market share[4].

Manufacturers target years for 100% BEV sales of LDVs and vans in Europe (Dec 2022)



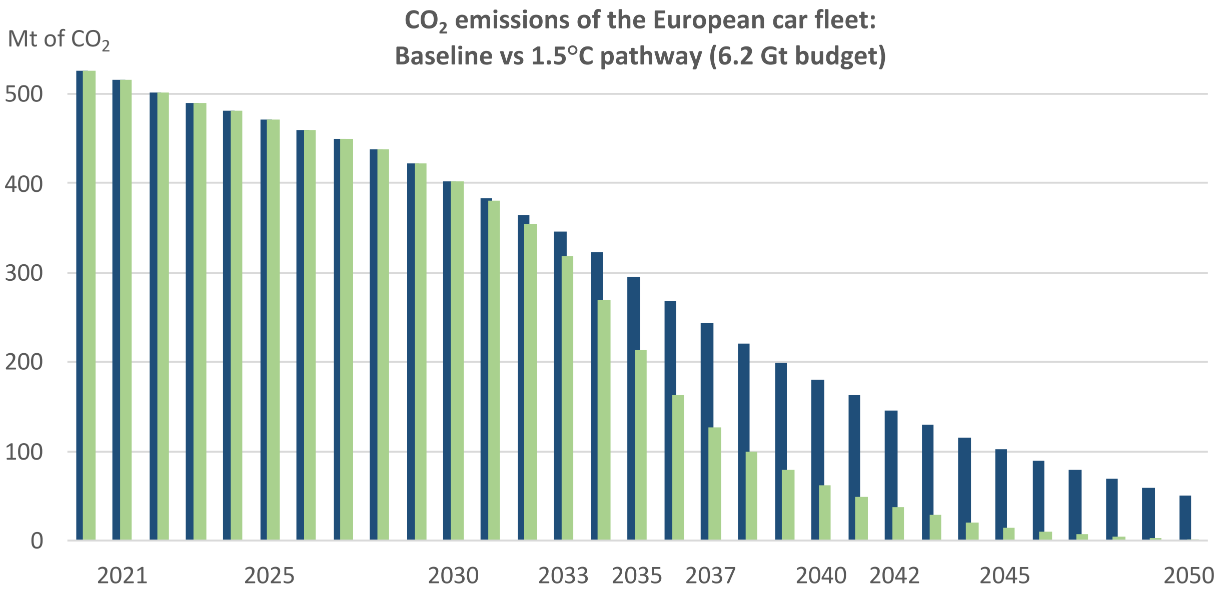
Size of the squares proportional to 2022 EU sales by brand (ACEA) Source: Electrify®

Preventing a carbon budget overshoot. The EU adopted a binding economy-wide target of reaching carbon neutrality by 2050[5] and set the intermediate target of reducing net GHG emissions by at least 55% by 2030, relative to 1990 levels[6]. However, stricter tailpipe emissions standards for new vehicles and the 2035 ICE ban will not suffice to put the EU on a path compatible with the objectives of the Paris Agreement.
In its 1.5°C scenario[7], the International Energy Agency (IEA) has estimated that the total carbon budget left for the global passenger car fleet over the period 2021-2050 is about 33 Gt of CO_2e. It would require a global fossil ban for new cars by 2035, and a near-complete phasing-out of ICE from fleets by 2050 for all road vehicles.
The chart below shows the EU-27 “fair share” of this global carbon budget available for the EU-27 passenger car fleet. Depending on how this fair share is defined, the budget ranges from 5.6 Gt of CO_2e to 6.2 Gt (see methodology in the Annex/Chap.1.3). The first approach consists in allocating the global carbon budget estimated by the IEA based on the projected size of the fleet in each region, over the period (2021-2050). The second approach assumes that Europe reduces its emissions at the same rate as the rest of the world every year. These budget estimates are consistent with a 50% probability to achieve the 1.5°C target[8].



Source: Electrify®. See Annex/Chap1.4.

However, according to our estimates (see Annex), the European car fleet is expected to emit 8.5 Gt of CO_2e by 2050, consuming a third of the global carbon budget allocated to passenger cars, with only 17% of the global car fleet. On its current path, Europe will overshoot its 1.5°C carbon budget between 2033 (low budget estimate) and 2035 (high budget estimate). To get back on track with a 1.5°C pathway, Europe would have to retire all its fossil cars (petrol, diesel, hybrids, and plug-in hybrids) by 2050, with most early retirements taking place by 2040. This conclusion does not factor in potential demand reduction measures[9].



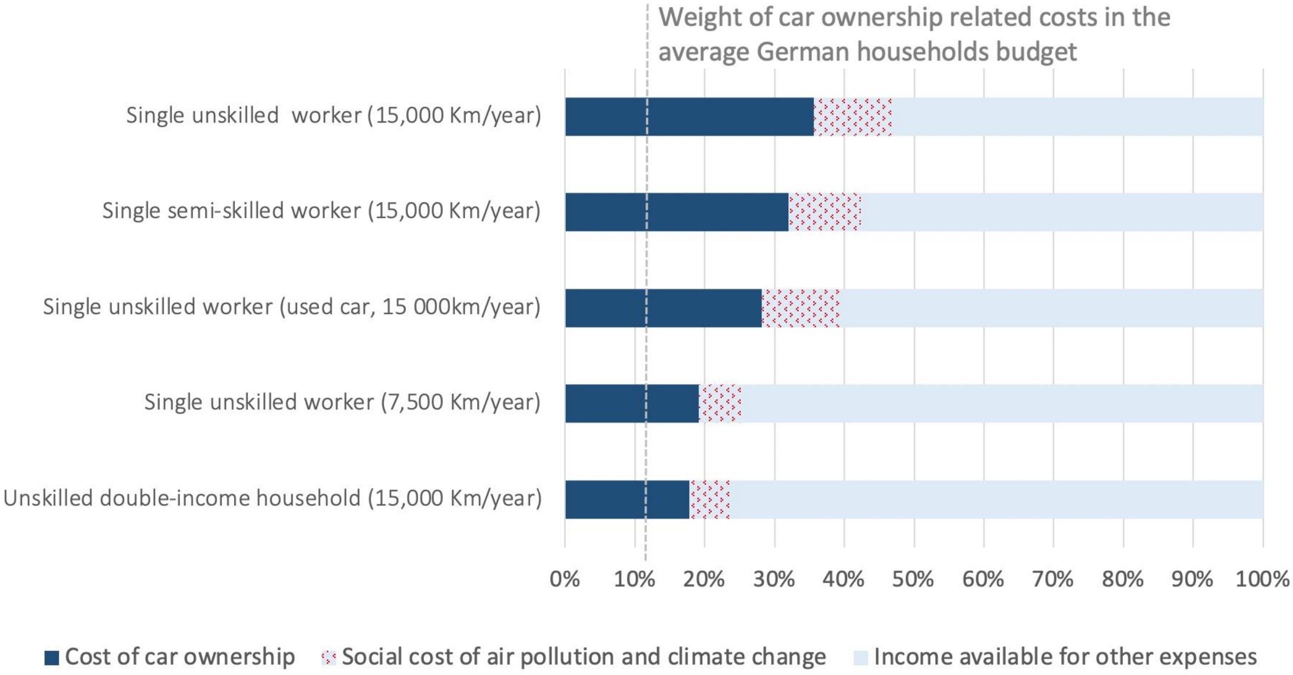
Source: Electrify®. See Annex/Chap1.4.

1.2. MAKING ELECTRIC CARS AFFORDABLE TO LOW-INCOME HOUSEHOLDS

Affordability gap. Car ownership represents on average 10.6% of European households' expenditures (Eurostat 2021), including 3.6% of the car price and 7% of operating costs. However, the burden could be much higher for low-income households: a 2021 study for Germany[10] concluded that the extended cost of ICE car ownership can represent up to 36% of net income for single-person low-income households (see chart below). If not properly managed, the transition to zero carbon road transportation could increase this affordability gap: if external climate and air pollution costs (red dots on the chart) were fully internalized through higher taxes this share would jump to 47% for single low-income Germans driving a small ICE car (see Annex for calculation).

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

Source: Electrify®, adapted from Gössling (2021). Se Annex/Chap1.6.



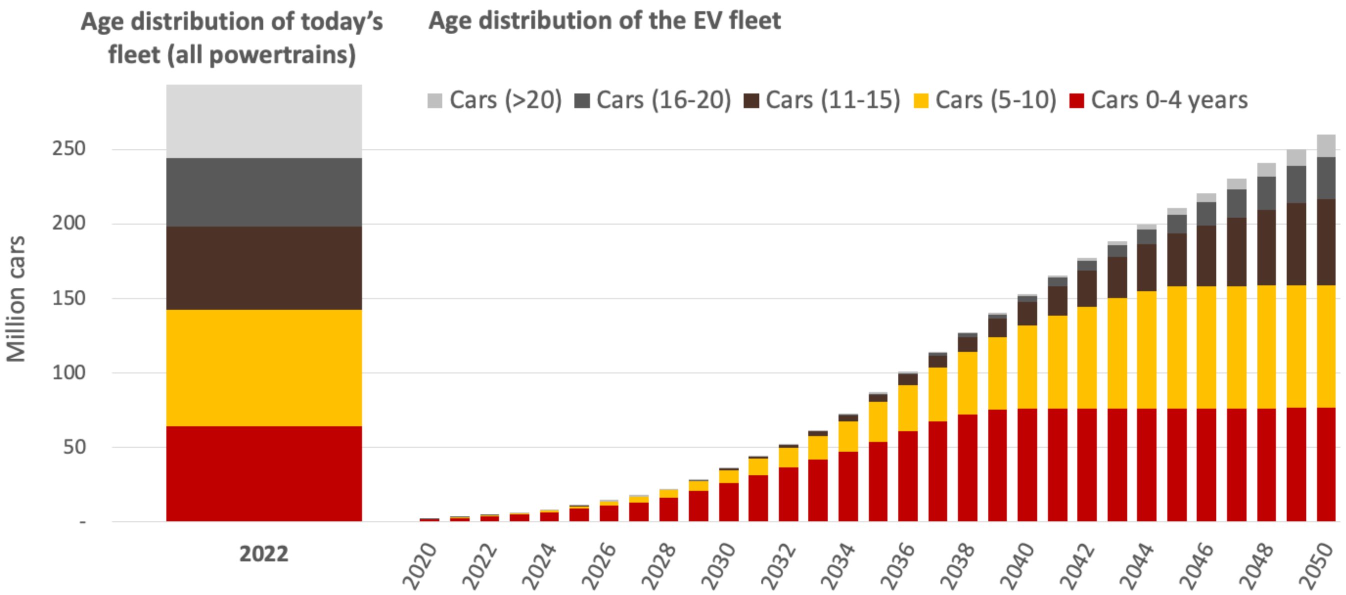
The scale of this problem makes it a major challenge for the transition to low carbon mobility in Europe: about 95 million Europeans (21%) are at risk of poverty in 2021, including 57 million (13%) in rural and suburban areas where car ownership is often a necessity to personal mobility (Eurostat 2021). 11 million European households (5.7%) cannot afford a personal car (see chart below for data per country).

Risk of being priced out of car ownership. In France, where access to car ownership is relatively high, a recent study finds that 20% of the population is “vulnerable”, including 14% who struggle to pay for fuel, and 7% who have limited access to transportation[11]. 28% of unemployed people have been prevented from accepting a job due to transportation-related hurdles, and many lower middle-class households have cut transportation costs in 2021 by reducing trips (18%), using public transport instead of their car (9%), or using car-sharing (6%)[12]. As a result of this affordability gap, the social acceptance of higher taxes on fossil fuels and cars, stricter environmental regulations, and Zero Emission Zones are becoming a major concern for policymakers. The 2018 “Yellow Vests” violent protests in France were sparked by the introduction of a new environmental tax that was supposed to increase the cost of fuel by 3% and inflate the cost of ownership by 0.8% for a small car, to be compared to +32% if the external cost of tailpipe emissions was to be fully internalized (Gössling et al).

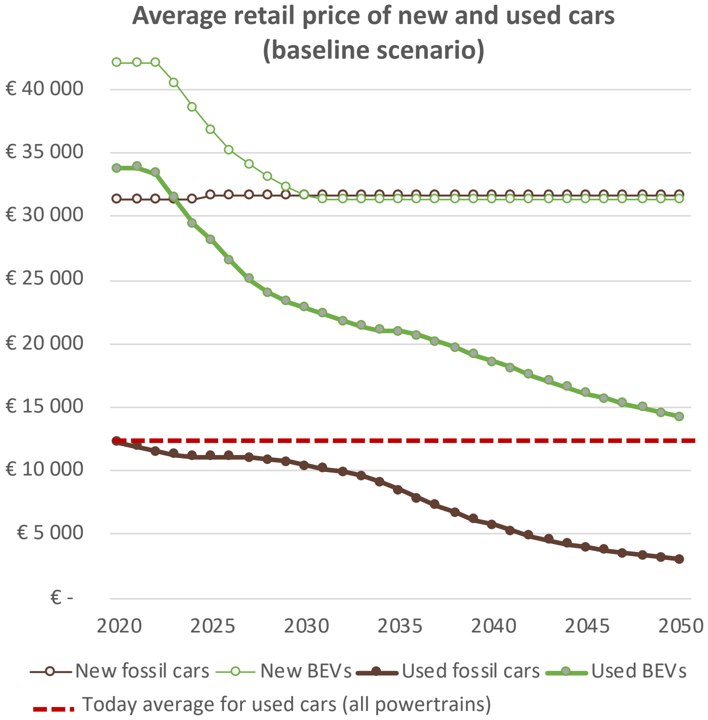
Total Cost of Ownership. Switching to EVs eliminates most external costs related to air pollution, and therefore reduces the exposure of low-income drivers to potential fuel and road taxes increases. On the other hand, new EVs are still significantly more expensive to purchase (+33% to +55% depending on sources[13]) which increases the depreciation cost, which represent up to 50% of the total cost of ownership (TOC).

Evolution of retail prices. According to production cost-based studies, EVs are expected to become less costly to own than ICE cars in the late 2020ies[14], although there is no consensus on when the tipping point will be reached for each European country and car category, notably due to the impact of subsidy levels[15]. A factor of uncertainty relates to the fact that many EV manufacturers tend to sell their vehicles below their production cost (notably in the context of the Q1-2023 price war) and might recover their investment costs when the production cost will drop. As a result, retail prices might not decline as fast as production costs and battery prices.

Shortage of old EVs. More critically for low-income households, used EVs are expected to remain less affordable than the current used fossil cars, due to their higher original price, as well as the shortage of old cars (> 10 years).

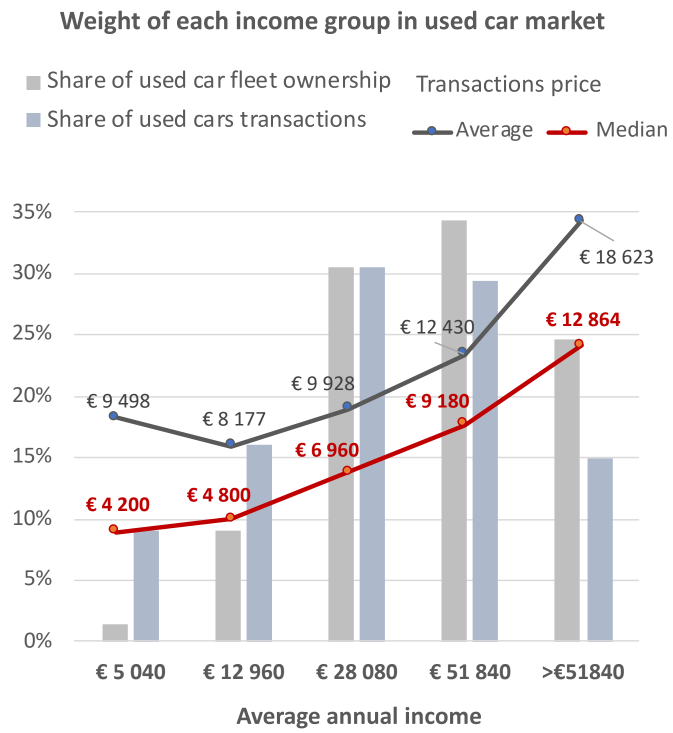


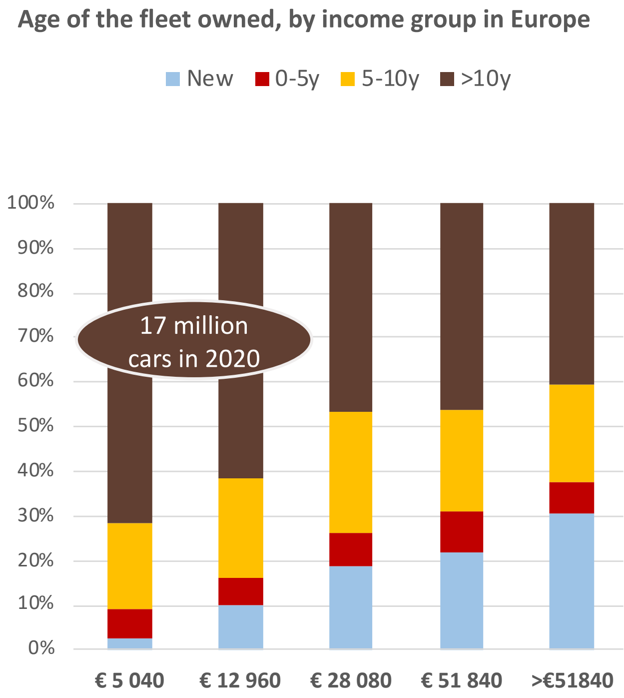
Source: Electrify®



As shown on the chart (left), it will take more than thirty years for the average resale value of EVs to converge with current average resale values of the used car market (according to our model). Partly because new EVs will remain more expensive until the end of the 2020ies, but more critically because used EVs will remain much younger.

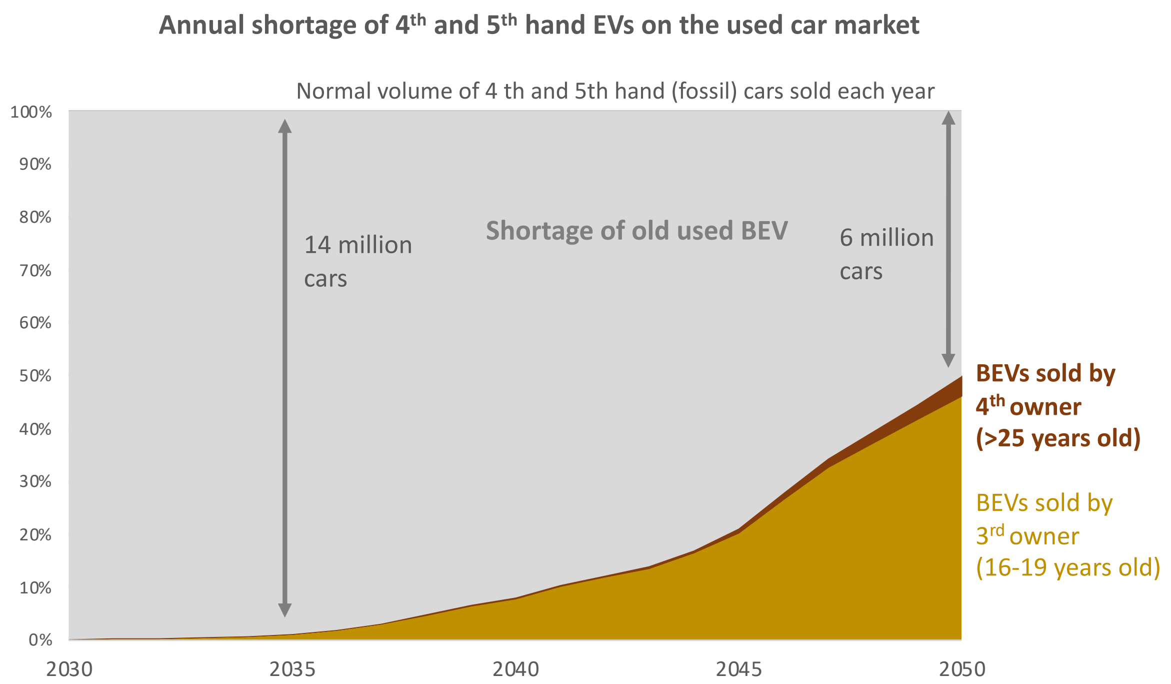
Today affordable old used cars play a critical role in the access to road mobility for low-income households (figures below) and constitute a significant share of the car market in volume.





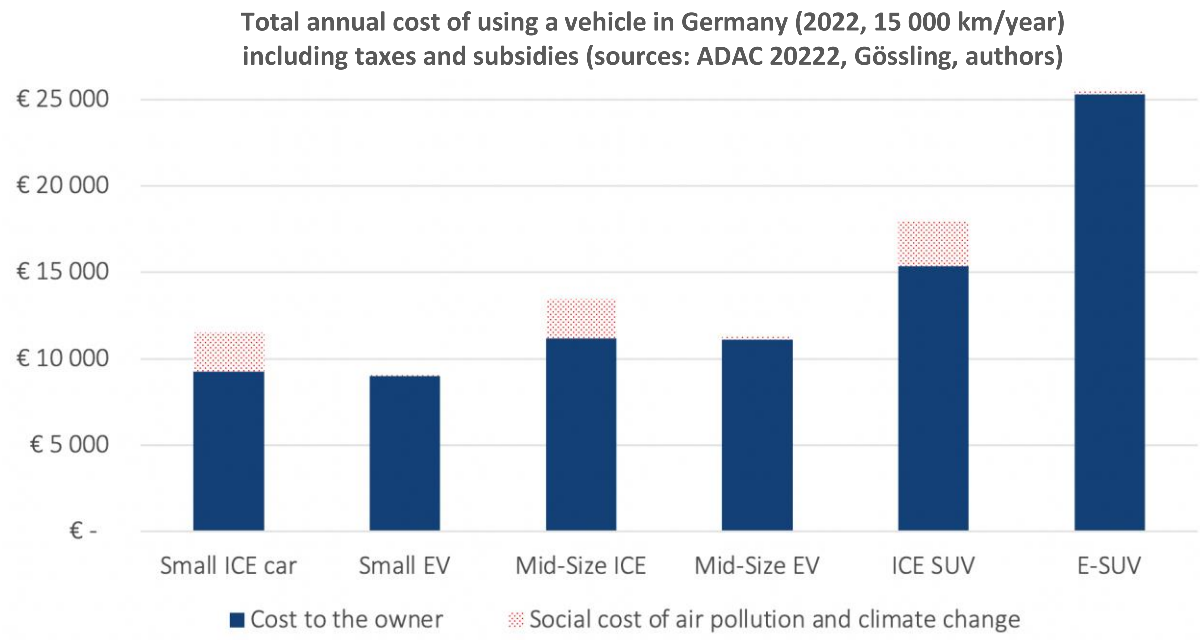
Sources: Transport & Mobility Leuven (2016), Eurostat (2022). Market data for 2016 extrapolated to the 2020 fleet. Prices and income levels converted in $€_{2023}$. (See annex for details). "Low-income households" are constituted by the first two income groups.

If ICE cars become uneconomical to use (due to fuel prices and taxes) or banned (for environmental reasons), the stock of old used EVs (> 15 years) will not be large enough to sustain the flow of cars necessary to meet the annual demand for "very affordable" used cars (4th and 5th hand prices below €9,000 and €5,000).



Sources: Electrify® based on Transport & Mobility Leuven for low-income household ownership.
Other values are the outputs of the model used for the study. See the annex for details on the methodology.

Social transfers. Several countries provide higher tax incentives for small affordable EVs, which can compensate for the 30-50% premium paid by the first owner but does not bridge the above-described affordability gap for low-income households. This gap has, on the contrary, increased in 2022 due to inflation affecting both the minimum price of new EVs (e.g., Dacia Spring) and the residual value of used cars.



The response to this problem, notably adopted in France after the Yellow Vests backlash, is to increase tax incentives for low-income households exposed to upcoming Zero Emission Zones[16]. To go further, the French president, Emmanuel Macron, has promised to make electric cars available to low-income households for less than 100€/month, through a public social leasing scheme. The 100€/month public scheme confirmed in 2022 will only kick-off in 2024. In the meantime, French car manufacturers such as Renault and Stellantis have announced their social leasing programs: factoring the maximum level of subsidies, the monthly cost amounts to an upfront payment of 2,100€ and then 110€ plus 0,07€ per km for a Peugeot e-208, and a more attractive 40€ per month for a Dacia Spring with no upfront payment.

Subsidies for used EVs. Another lever to bridge the affordability gap is to extend subsidies to used EV purchases, which has recently been done in Germany (€6,000), the Netherlands (€2,000), and France (1,000€).

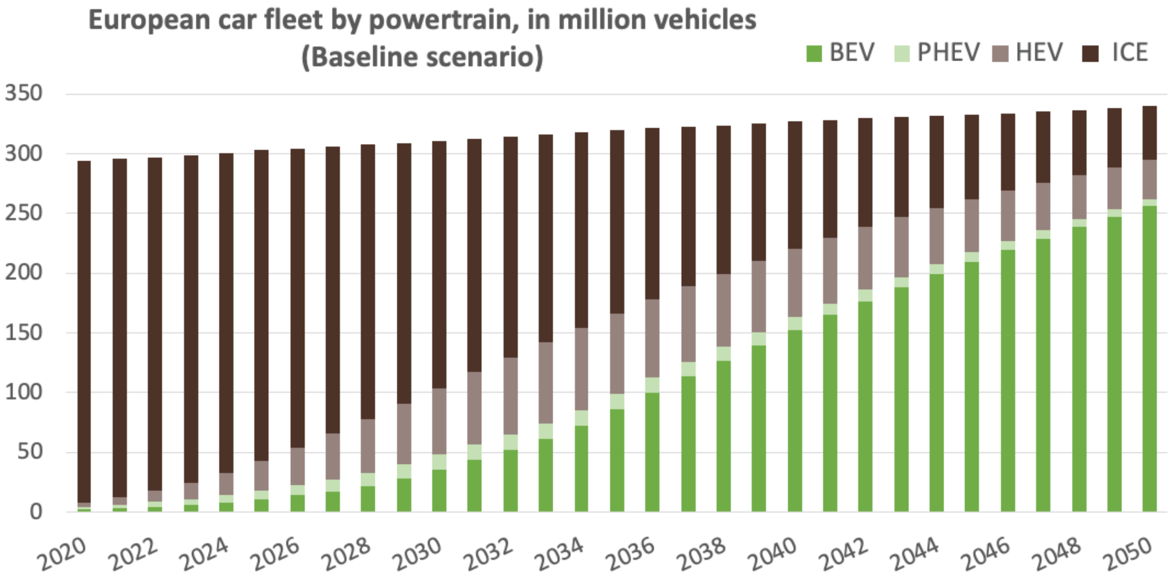
Sales data from selected European countries[17] suggest that 90% of recent EV registrations relate to new cars. However, the EV used market will organically get bigger in the next 5-6 years given the current rise in EV sales.

Tax incentives are traditionally reserved to new cars or significantly higher. However, low-income households tend to purchase mostly used cars. The impact on the resale value of the car, which determines how the tax benefit is transferred to the second and third owners, depends on various factors and tends to evolve. Once again, there is no consensus among TOC studies: some conclude that second owners will benefit more than first owners, while other reach the opposite conclusion[18].

1.3. THE €2 TRILLION DILEMMA

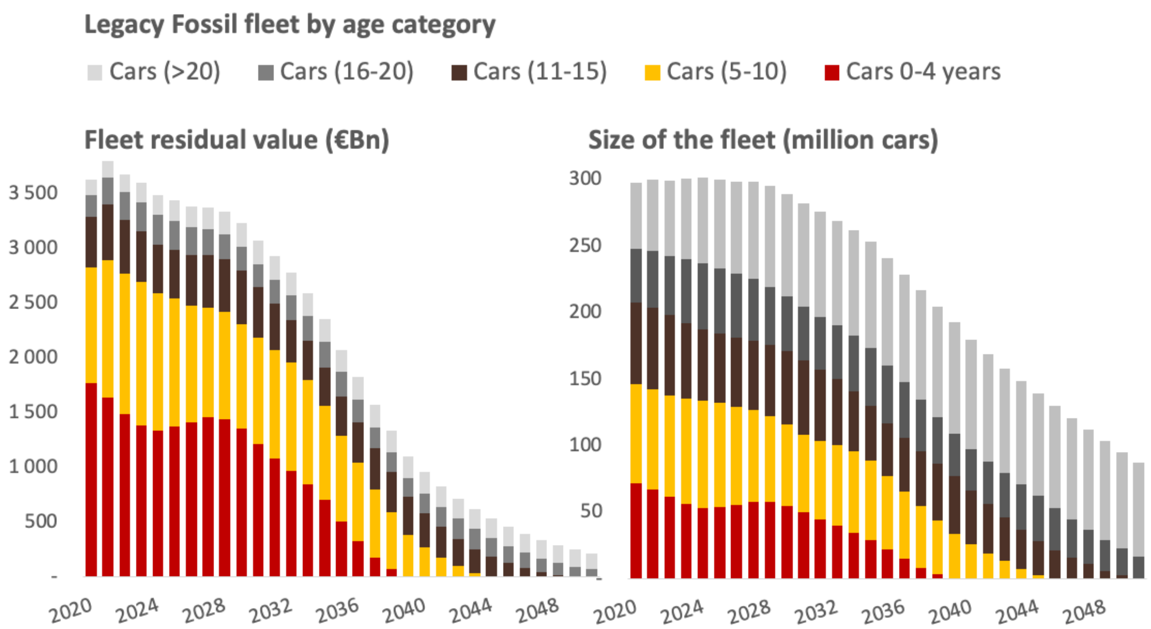
THE LEGACY FOSSIL CAR FLEET

ICE fleet inertia. Assuming the EU ICE ban is implemented as planned, no new ICE car will be sold in Europe beyond 2035. At this time there will be close to 90 million BEVs on the roads, but fossil cars will still dominate with a legacy fleet of about 240 million vehicles with a residual value of about €2 Trillion.



Source: Electrify®. See Annex/Chap.1.2

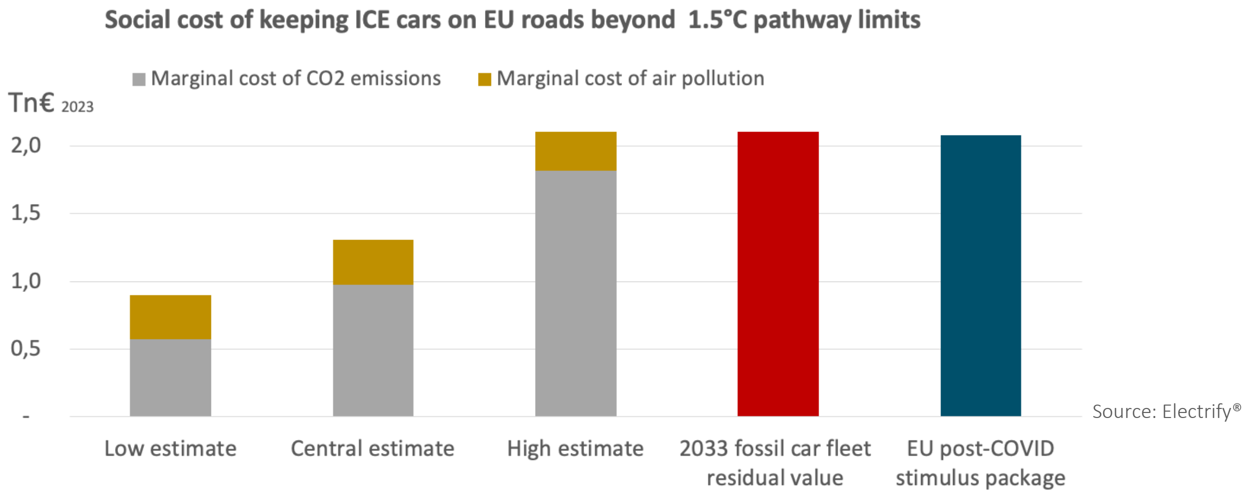
Based on current sales forecasts (2022-2035 and our aging model – see Annex), we estimate that, without any policy intervention, the fossil car fleet will take another 30 years to be phased out completely and emit 2.5 Gt of CO_2 above the 1.5°C carbon budget.



Source: Electrify®. See Annex/Chap.1.2

INCURRING €2 TRILLIONS OF EXTERNAL COSTS

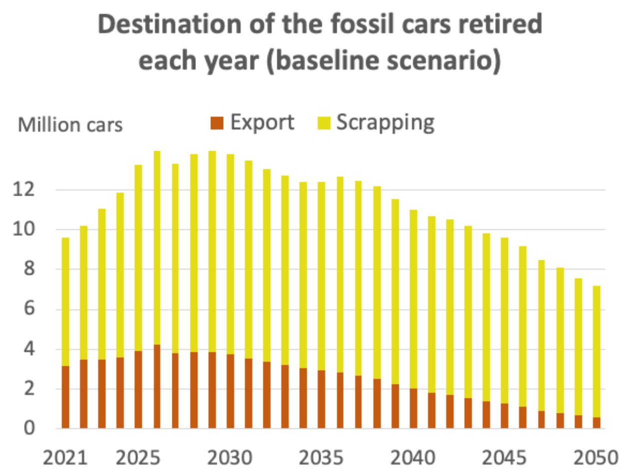
External cost of fuel consumption. The EC provides estimates (high, central, low) of the external cost of CO2 and air pollution related to passenger cars[19]. Based on our estimates of the fleet CO_2 emissions (2021-2070), and using the EC guidance, we estimated the "absolute" external cost of the European fossil car fleet fuel consumption over its lifetime (see Annex for details): it ranges from €1.8 to €4.2 Tn. The scope is limited to the cost of CO_2 (climate change) and air pollution (health impact notably), excluding noise, infrastructure use, and a range of other externalities that are not specific to fossil cars (and therefore are not reduced with EVs).

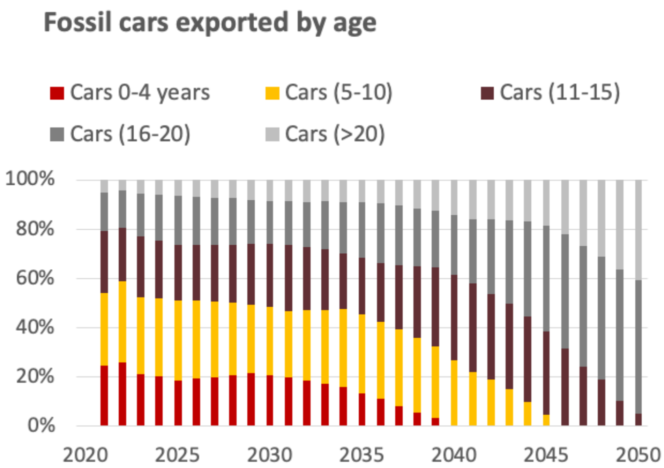


The "marginal cost" only covers the emissions beyond the 1.5°C carbon budget (we used the low estimate of 5.6 Gt of CO_2 based on IEA NZS): if the legacy ICE car fleet remain on the road until the end of its normal lifetime and fuel taxation remains at current levels, the well-to-wheel emissions will generate an additional social cost of €0.9 to €2.1 Trillion euros by 2070, with a central estimate of €1.3 Tn. It is comparable to the residual value of the legacy fleet at the date of the 1.5°C carbon budget overshoot, or the cost of the EU post COVID stimulus package.

EXPORTING THE SOCIAL COST TO EMERGING ECONOMIES

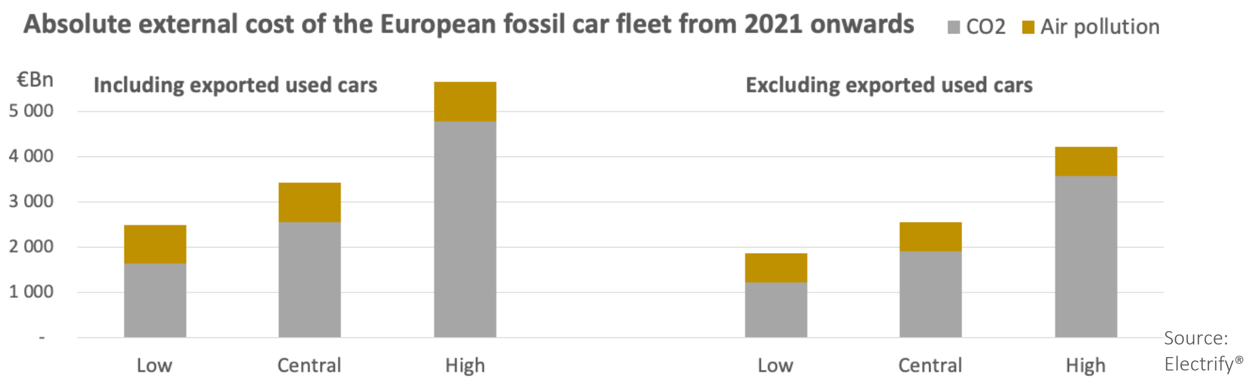
For Europe to avoid these costs, a possibility consists in exporting them. About 6 million vehicles are legally disposed each year in the EU (Eurostat), and another 3.4 to 4.7 million deregistered vehicles with unknown whereabouts[20], mostly illegal scrapping and exportation[21]. According, the UNEP data[22], the EU is the biggest exporter of used vehicles, with 7.5 million cars and 250,000 trucks exported over the period 2015-18. In 2018, the EU exported 1.9 million cars, which is more than USA and Japan combined. The main destinations for EU used vehicles are Eastern Europe, Central Asia, and Africa. In 2018, the EU exported one million used cars to Africa, which represented 2/3 of Africa used cars imports and 40% of new registrations. Germany is the biggest exporter with about half of total EU exports. The UNEP identified significant environmental problems associated with this trade since many exported vehicles do not meet modern air pollution and carbon emissions standards and are operated in countries with weak or non-existent regulations (see map).





Nb: The breakdown of export/scrapping is defined by age, based on an adjusted version of the survival probability curve. The unknown whereabouts are allocated at 40% to exports and 60% to illegal scrapping. Source: Electrify®

In our baseline scenario (which does not factor the above-discussed potential additional exports), the normal flow of used car exports generates an estimated 2.5 additional Gt of CO_2 emissions from Europe which translates into an external cost of 0.8 €Tn (central value in the estimates).



This problem is due to increase in the future: the global car fleet growth by 2050 will mostly be fueled by new registrations in non-OECD economies, and the climate constraints targeting European drivers (taxes on gas and ICE vehicles, ZEZs, etc.) will create an incentive to export used ICE cars that become stranded in Europe. Europe "exported environmental cost" will more than double if the above-mentioned legacy fossil fleet is exported to meet the 1.5°C target in Europe. Given the necessity to fully decarbonize all car fleets by 2050 in a 1.5°C scenario (see discussion above), such an option would be fundamentally at odds with the objectives of the Paris agreement for Europe.

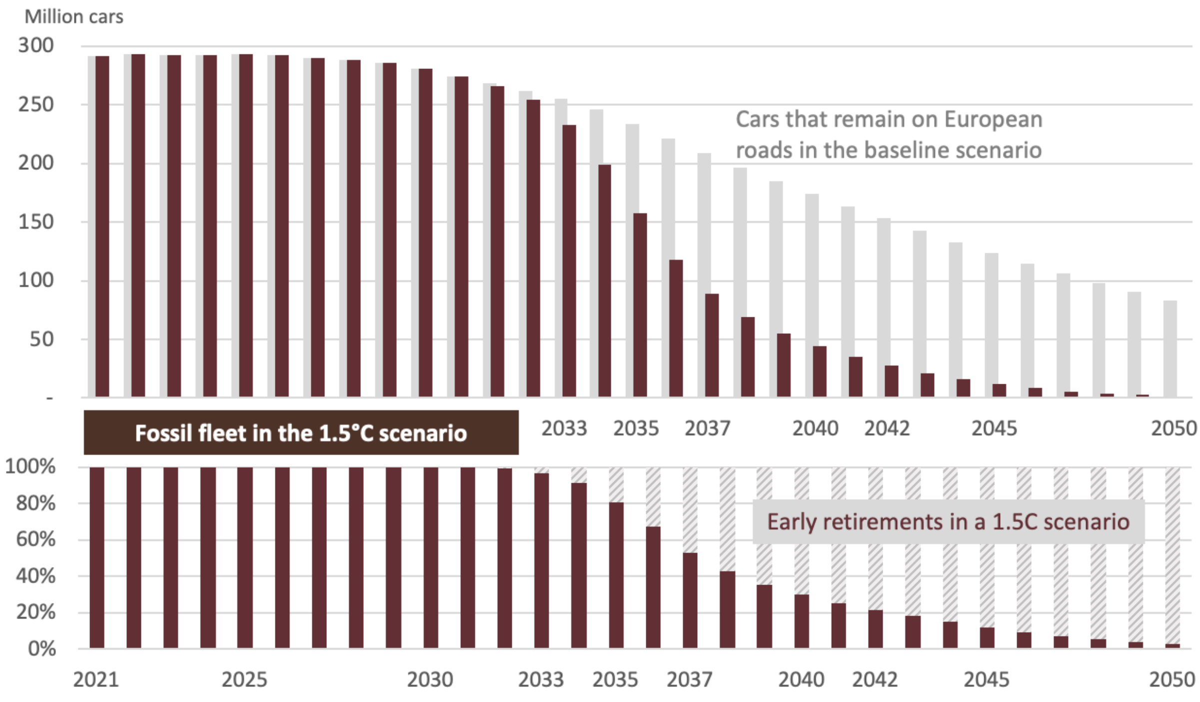
EARLY RETIREMENT OF THE FOSSIL FLEET

Policymakers will face the choice to accept this social cost or to prevent it. Beyond its external cost, and the obstacle it represents to meeting the objectives of the Paris Agreement, the legacy fossil fleet is likely to eventually become a burden, since it will necessitate to maintain an aging fuel refining and distribution infrastructure for many years, while modernization investments will not be profitable. The EU will likely look for cost-effective solutions to accelerate the phase out of this legacy fleet.

Used fossil cars phase out. It can be done by significantly increasing fuel and ownership taxes to make fossil cars cost of use uneconomic, or by subsidizing the early retirement of ICE vehicles and their replacement by

EVs, through tax incentives. In one case, the tax revenues will increase, at the expense of ICE vehicle owners, which might be highly unpopular. In the other case, public spending will increase significantly. The phase out can also take other forms like mandatory "expiration dates" associated with different age, fuel efficiency and price categories of vehicles.

Fossil car fleet size: baseline vs 1.5°C scenario*



Source: Electrify®

Scrapping or retrofitting? The common denominator of these scenarios however is a destruction of economic value: we estimate the remaining residual value of the European car fleet north of €2Tn in 2035 and will take another 20 years to naturally reach zero (see figure page 12). If an early retirement of fossil vehicles is implemented, it will involve an accelerated depreciation of the vehicles, in a few years instead[23]. Scrapping these vehicles would be both sub-optimal from an environmental perspective and extremely costly: in addition to the economic value destruction, it would require the replacement of a large parr of the used fleet with new cars. In this context, retrofitting fossil cars to turn them into battery electric vehicles appear to be a potential solution to this trilemma. The purpose of this paper is to explore how realistic would be such as solution.

2. E-RETROFIT TECHNOLOGY AND REGULATORY FRAMEWORK

2.1. ELECTRIC RETROFIT TECHNOLOGY

E-retrofit concept. The electric retrofit of vehicles (e-retrofit) consists in replacing the Internal Combustion Engine (ICE) and fuel tank of a used vehicle by an electric engine and battery (or a fuel cell and hydrogen tank). The process is applied to passenger vehicles as well as vans, buses, trucks, specialty vehicles, motor bikes, etc. This report focuses primarily on passenger cars, but also discusses the other categories. It can be combined with a refit and retrofitting of the car with advanced driver assistance system and modern features.

<table>
<tr><th>Main components</th><th>Description (for cars)</th><th colspan="2">Typical cost</th></tr>
<tr><td>Donor vehicle</td><td>Used roadworthy ICE vehicle, 5 to 20-year-old</td><td colspan="2">1 500€ to 30 000€</td></tr>
<tr><td>Battery pack(s)</td><td>15 to 50 kWh battery</td><td colspan="2">4 500 € to 15 000 €</td></tr>
<tr><td>Electric engine(s)</td><td>50 to 120 kW engines connected to the drivetrain</td><td>Design</td><td>Production</td></tr>
<tr><td>Power control unit</td><td>Brain of the EV system, including converter</td><td rowspan="4">300 000€ to 2M€ for a new model</td><td rowspan="4">8 000€ to 30 000€</td></tr>
<tr><td>Wiring & charging port</td><td>To charge the battery at home or at public chargers</td></tr>
<tr><td>Dashboard instruments</td><td>Basic information such as battery capacity</td></tr>
<tr><td>Software</td><td>New software to manage AC, ADAS systems, etc.</td></tr>
<tr><td>Tablet (option)</td><td>Tablet integrated in the car dashboard</td><td colspan="2">500€ to 1 000 €</td></tr>
<tr><td>Refit (option)</td><td>Deep clean, fix or replace damaged parts, seats, etc.</td><td colspan="2">1500 € to 5 000€+</td></tr>
<tr><td>Paint job (option)</td><td>Complete repainting of the vehicle</td><td colspan="2">1 500 € to 4 000€</td></tr>
<tr><td>ADAS retrofit (option)</td><td>Hardware & software (level 3 or level 4 autonomy)</td><td colspan="2">1 5000€ to 3 000€</td></tr>
</table>

Source: Electrify®

Light e-retrofit. The e-retrofit operating could be 'Light', consisting in a replacement of the necessary parts, without altering the structure, weight, top speed, features, or appearance of the vehicle. The size of the battery (kWh) for retrofitted vehicles is usually smaller (15 to 40 kWh) than for the equivalent new EVs (40 to 100 kwh) and fits in the space freed up by the fuel tank and the ICE engine disposal. Some complexities need to be addressed involved to keep basic comfort features: in ICE cars, heating, AC assisted steering systems are powered by the engine. These systems therefore need to be powered by the battery in the converted vehicle.

Heavy e-retrofit. Some companies offer 'heavy' retrofits, involving a replacement of the whole base frame, drivetrain, suspensions, brakes, improvement of soundproofing, integration of modern electronics and ADAS, full redesign of the interior, improvement of the general appearance. With such a transformation, the weight and power of the vehicle might increase significantly. Such a conversion could get closer to manufacturing a new model using reused parts, from both a technical and a regulatory perspective.

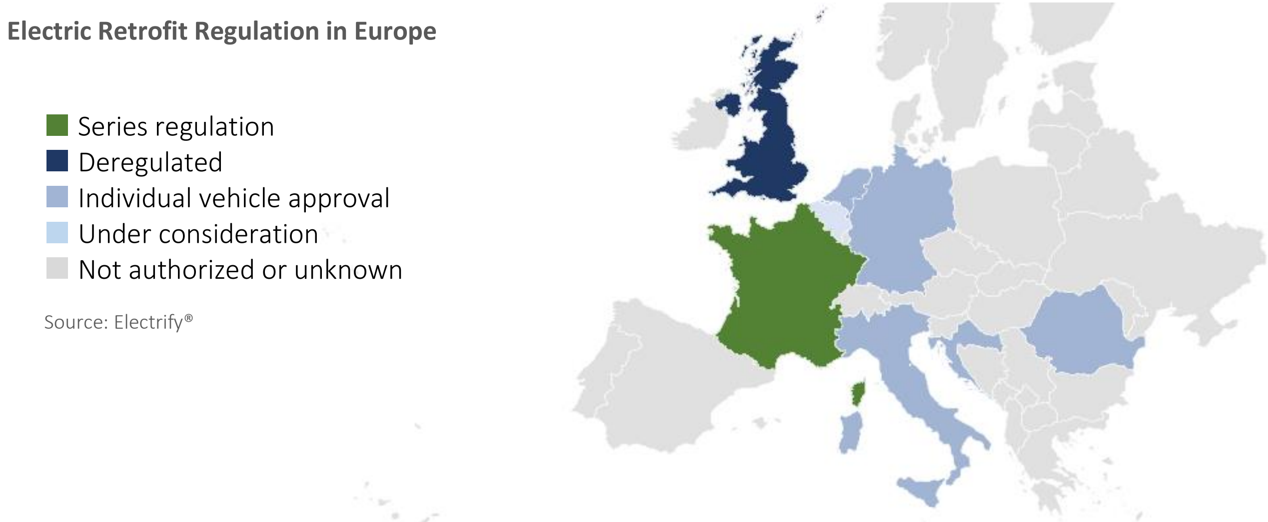
Basic eligibility criteria. From a technical perspective, almost any vehicle can be retrofitted.
The main technical constraints are:

- the roadworthiness of the vehicle and the expected remaining lifespan (for light retrofits),
- the room available for the battery, which in turns depends on the capacity of the original fuel tank and the size of the engine bay.
- The weight of the donor vehicle and the ability its base platform to handle extra weight, which in turn determines the size of the battery needed, the total weight and therefore the range delivered.

When extra space is available close to the chassis to host a part of the battery cells (it can be the case on vintage VW Beetles), it can help to lower the center of gravity of the vehicle and slightly increase the size of the battery. However, the conversion can be made more difficult and costly by a range characteristic of the donor vehicle (see discussion in Chapter 8).

2.2. REGULATORY FRAMEWORKS

Default situation. The EU has a strict regulatory framework that applies to the approval of new models of vehicles, systems, and components. An approval issued by a national authority is accepted in all the Member States. The rules focus on safety and environmental compliance[24]. Under the standard process, a dozen or more prototypes should be crash tested, which cost millions of euros for each approval. The EU regulation allows member states to apply simplified procedures for small series and individual vehicles, the latter category being exempt of crash test[25]. However, the approval is limited to domestic roads, and additional approvals need to be requested to each member state. This framework is not designed for aftermarket conversions and particularly ill-suited for electric retrofit: An agreement of the manufacturer is required to alter a vehicle, a regulatory approval is needed for each new model, and the process is long and costly, which would only work for the conversion of large series by a car maker. Companies that breach the regulation risk administrative fines of up to € 30 000 per vehicle. In the EU, national authorities are the competent level for all modifications to vehicles after their first registration, including e-retrofit[26]. However, only few member states have introduced dedicated regulations to simplify the administrative burden for e-retrofitting.



Individual Vehicle Approval. In Europe, most countries have simplified approval processes for individuals importing non-EU-approved vehicles, which requires a series of tests and approval for each vehicle. Certain countries have amended this framework to enable electric retrofitting, but an approval is needed for the conversion of each individual vehicle. This system costs a maximum of €2,000 and requires a few months. Several countries have introduced it such as Italy[27], Germany, Romania and Switzerland. It is also under consideration in Belgium, while the Netherlands accept vehicles approved in Germany. These regulations usually come with the adaptation of tax incentives schemes[28] related to the purchase of EVs and scrapping of vehicles, to subsidize retrofit operations. The main limitation of this approach is that it is ill-suited for standardization and industrial scale conversion programs since the administrative burden applies to each vehicle retrofitted.

Deregulation. Certain non-EU countries, such as the US and the UK have introduced regulations and or regulatory guidance that 'deregulate' after-market alteration, especially when it is performed by the owner or on small series. The approval process is affordable, and the tests very limited, the retrofitter guaranteeing compliance. For such markets, generic or model-specific "conversion kits" can be found online, for a range of models, to support DIY installation or retrofit by repair shops. The production of low-cost kits for these markets, is often based on the repurposing of existing components and does not require a lot of investments from manufacturers. On the other hand, generic kits take more time to install, each retrofit operation being bespoke. The regulatory framework also allows the conversion of larger series, but the liability in terms of safety and environmental compliance being transferred to the retrofitter, it comes with exposure to litigation risks and would therefore require specific insurance policies.

E-retrofit series regulation in France. To enable e-retrofit at industrial scale, France[29] has introduced a dedicated law in 2020, which addresses the limitations of Individual Vehicle Approval. The law also introduces tax incentives for each vehicle retrofitted. Under this new law, the approval is obtained for retrofitting a series of vehicles, assuming the same "type-variant-version[30]" (e.g. most versions of Golf VII) for the donor vehicle, limited changes in terms of weight (+20% maximum), power (+0% to -40%) and size (similar), and standard specifications (battery size, weight, power, top speed, etc.) for all retrofitted vehicles in the series.
The law creates two categories: the e-retrofit "manufacturer" and the "installer". The "manufacturer" which designs the system and process, obtains the approval for a prototype, and then produces the "kit" (components) and produce the specifications for the standard conversion process. The manufacturer then approves and controls a series of accredited local "installers" (usually repair shops) and provides the manufacturer guarantee. This framework is currently pilot tested by a dozen of companies, which are required to report annually to the government a the number of key metrics including customer satisfaction.

Batteries approval. A significant difference between countries approval frameworks for retrofit relates to the type of the stress-tests required for batteries approval: certain countries require the R100 regulation version 1 that only mandates testing the basic safety of the battery, while the version 2 requires a series of crash-tests (fire, impact, etc.), which significantly increases the cost. Another difference relates to the constraints associated with series approval: to be approved retrofitted vehicles need to mimic the prototype, which prevent from using recycled battery packs (e.g. from crashed cars) that are not identical to the one approved.

Potential European regulation. In the context of the new EU climate regulation for vehicles, the parliament has introduced an amendment requesting the harmonization of the rules across Europe aligned on the French model, to allow series approval. The final compromise takes a step back and requests an assessment of the regulatory options available while supporting the general goal of retrofitting the existing ICE fleet.

Amendment 54 of the EU parliament[31]	Final compromise text, Recital 12a (Nov 11, 2022)
"6 months after the date of entry into force of this Regulation, the EC shall adopt a delegated act to harmonise the type-approval rules for vehicles with ICE converted to battery or fuel cell electric drive, in order to allow for series approval. The EC shall also assess the introduction of a rule for calculating the CO_2 equivalents of combustion engine vehicles converted to battery or fuel cell electric drive in the context of the application of this Regulation."	In order to protect the environment and health of citizens in all Member States it is important to also decarbonise the existing fleet. The market of second hand vehicles creates the risk of shifting CO_2 emissions as well as air pollution to less economically developed regions in the Union. To speed up the reduction of emissions from the existing fleet and to accelerate the transition to zero-emission transport it is of the utmost importance to encourage the conversion of internal combustion engine vehicles to battery or fuel cell electric drive, including an assessment of ways to facilitate the deployment of such solutions in the Member States;

2.3. MANUFACTURING OF A NEW MODEL

Steps of development. E-retrofit by individuals or small shops has been performed for more than a decade in unregulated markets, notably in the US. It involves purchasing or putting together a "conversion kit" and months of labor on a single vehicle. More recently, certain companies have been trying to develop small series and deliver economies of scale. This approach is limited to deregulated markets and France. The process applied in France, which is likely to inspire a potential European framework is described below.

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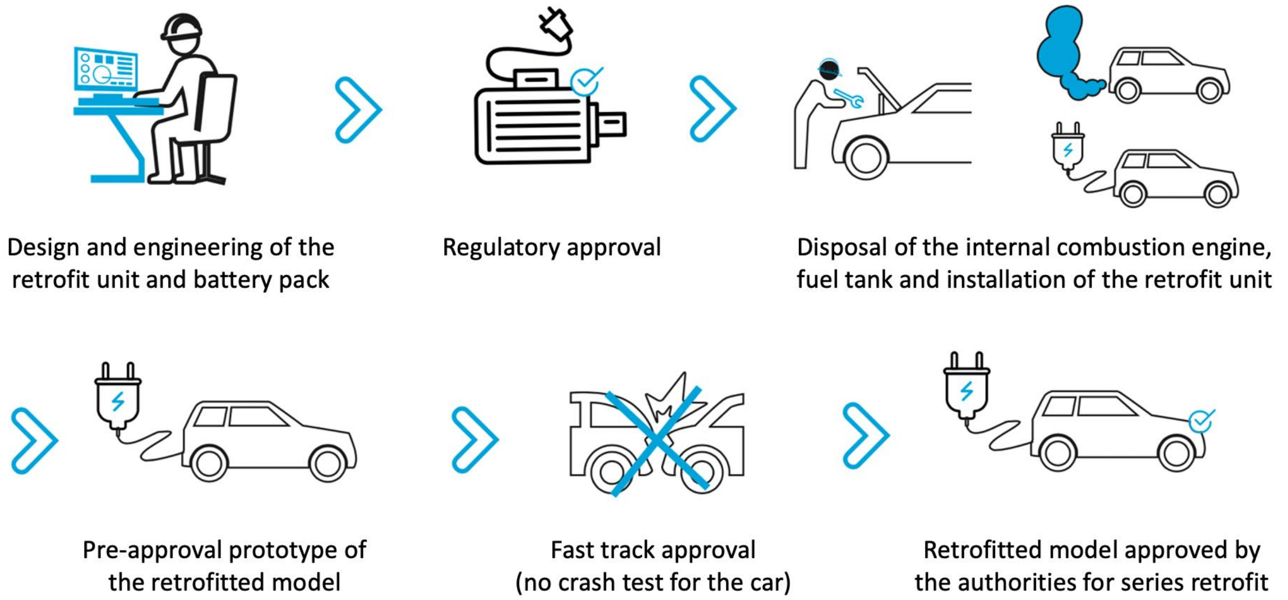


Simplified process for regulatory approval in France. Source: Algoé (2020)

Approval. As discussed above, if the EU aligns with the French model, it will likely require an approval for each "type-variant-version" (e.g. VW Golf VII), even though economies of scale are realized when obtaining approval for an other version of a model already approved (e.g. VW Golf VI). To limit the R&D investment required, e-retrofit manufacturers will focus on top selling types and versions. In a given year, 190 models are available for sale, and empirical analysis suggests that manufacturers upgrade to a new version every 5 years.

Production. The retrofit « kit » is manufactured in small factories or workshops. In non-regulated markets, kit manufacturers put together components from different third-party providers and sometimes produce generic kits that apply to a category of vehicles. In series production, the kit is tailored to each type of vehicle approved and manufactured centrally. The capital investment needed to start a retrofit activity is relatively limited (about 3M€), many of the costly processes such as testing being outsourced. The main fixed costs relate to R&D, approval, and marketing.

2.4. INSTALLATION OF THE RETROFIT UNIT

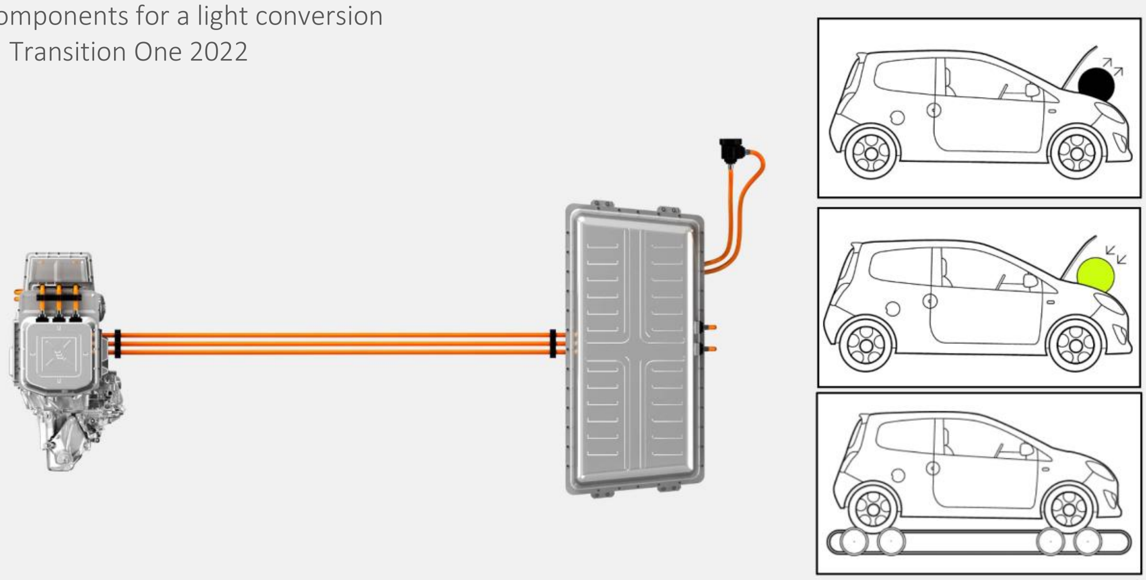
For each new vehicle retrofitted, assuming prior approval of the model, the process involves sourcing a "donor vehicle", installing the unit a.k.a. "kit" following the specifications of the manufacturer, and re-registration of the car with public authorities. In series light retrofit, the installation is performed by a network local repair shops trained and certified by the manufacturer. The investment required is minimal, the processes being very similar to repairing a car.

For heavier retrofits, the process is different: the same company sources the donor vehicles, manufacture and install the kit. The operation tends to be centralized in a factory.

Simplified process for vehicle regulatory approval in France. Source: Algoé (2020)

Light retrofit. In regulated markets, the installation of the kit involves a replacement of the parts and electric wiring that correspond to the above-described 'light conversion'. For small cars the battery replaces the fuel tank. For larger cars, the engine bay is also used to put a second battery. This 'light' conversion usually takes a week of work, but some e-retrofit companies anticipate to make it as quick as a few hours (e.g. Transition-One) by standardizing the kit and the process for specific vehicles. Basic comfort features such as heating, AC, and power steering are usually preserved. Some e-retrofit manufacturers offer optional features, such as the integration of a tablet and a larger battery. The only constraint being to keep a similar weight. More complex mechatronics features such as ESP (Electronic Stability Program) or ADAS (Advanced Driver Assistance Systems) could be challenging to keep, since they involved both hardware and software components (see discussion page 88). However, series retrofitters plan to overcome this obstacle.

Components for a light conversion
© Transition One 2022



Repairs and refit. E-retrofit can be combined with a "refit" (a.k.a. refurbishment) of the used vehicle. The necessity of such an add-on depends on the age of the donor car and the expected look and feel of the retrofitted car. It can quickly add to the bill[32]: basic fixing includes changing the tires (200-600€) and suspensions (200-300€), interior deep cleaning and basic refit (200-500€), and paint refinishing (200-400€). Further upgrades could include changing the upholstery (1,500€ for leather), full paint job (2,000-4,000€), adding airbags (1,000-2,000€). A complete restoration for a classic car also involves disassembling the vehicle, metal repairs, sand blasting old paint job, replacing parts, and reassembling. It takes hundreds of hours and adds at least another 10,000€ to the bill.

ADAS retrofit. Advanced Driver Assistance Systems (ADAS), a.k.a. autopilot or self-driving features, may also become a key add-on to e-retrofitting. After-market systems compatible with 200+ cars from 20+ brands are already commercially available in the US for $2,000 plus a monthly subscription. The current systems deliver 'level 2' automation, performing adaptive cruise control, automated lane centering, lane change assist and driver monitoring (camera). However, several US startups plan to introduce more advanced systems[33], reaching level 3 or even level 4 automation, similar to what Tesla is offering today for 10 000 €.

Heavy retrofit. In deregulated markets or if the manufacturer is willing to seek the homologation of a "new vehicle", an "heavy retrofit" can be performed. It can then go as far as a complete redesign of the vehicle: disassembly, replacement of most key parts and accessories, and reassembly (see below). In particular, the original drivetrain is disposed and replaced by a 'skateboard' chassis (e.g. eClassics, Zero Labs), hosting batteries, like the one used in new EVs. In this case, each conversion takes at least a month (e.g. Zero Labs) and can significantly increases the performance of the original vehicle, with batteries up to 100 kWh. Besides bespoke heavy retrofit, some companies are introducing series (small series for popular vintage cars such as Ford Mustang and Bronco so far). The cost structure, business model and potential of this approach is not studied in this report, which focuses on light retrofit.

2.5. SAFETY, RELIABILITY, PERFORMANCE, AND COMFORT

Given the limited track record of the industry, any conclusion on safety, reliability and performance is based on the analysis of the processes and the characteristics of the prototypes rather than any empirical evidence.

Safety. Safety is the main concern of regulators: in regulated markets, stress tests are performed on batteries and electrical systems to align with the safety requirements standards with new EVs. For other parts, the retrofitted vehicle is as safe as the donor vehicle. In regulated markets, changes in weight, weight distribution and power are caped and tested to minimize divergence with the donor's test performance. For heavier conversions, these limitations do not apply: retrofitted vehicles are usually heavier and more powerful than the donor, which requires a complete redesign of the safety features. The conversion is usually used as an opportunity to modernize all safety features (breaks, lower center of gravity, seat belts, etc.), but it obviously comes with the increased risks associated with any new model, with no large-scale safety track record[34].

Reliability. To a certain extent, the same logic applies to reliability: for heavy conversions, since almost every system is replaced, it can – at least in theory – be as good as new. For 'light' conversions, the retrofitted vehicle is as reliable as the donor vehicle, with a couple of caveats:

- For older ICE vehicles, many maintenance problems are associated with parts that happen to be removed with e-retrofiting (e.g. battery, water and fuel pump, exhaust system, engine, etc.), and other critical systems (e.g. suspension, electric wiring, tires) that are at least inspected and fixed. In theory, retrofitted cars will end-up being more reliable than the donor cars.
- On the other hand, the introduction of new electronic systems, with limited track record introduce reliability risks, similar to the ones faced by first generation of BEVs[35]. This issue is the second focal points of regulators: in regulated markets, the e-retrofit company should provide a manufacturer guarantee for the systems associated with the alteration.

Range and performance. For this report, the "performance" of a vehicle is defined in terms of top speed, acceleration, and range, with a strong emphasis on the latest. We discuss below the equation for passenger cars. The case of other vehicles in discussed in chapter 2.

- **The kWh/weight/price equation**. Within a given weight category, range and top speed are highly correlated with the capacity of the battery (kWh). Batteries that replace the ICE engines range from 115 kg (15 kWh) to 500+ kg (70 kWh). Every kWh added increases the range but also the total weight and price of the vehicle, so e-retrofit companies need to find the "sweet spot" to optimize this equation.

- **Technical constraints**. While new EVs are usually designed with a 'skateboard' chassis that hosts the battery on the floor, light e-retrofit is constrained by the space freed up by fuel tank disposal and in the engine bay (unless habitable/usable spaced is used). Based on the current density of batteries, it limits the size to 15-20 kWh for small cars, 30-40 kWh for mid-size and sport cars, and 60 kWh for SUVs. This constraint, combined with the cost of batteries leads to much shorter range the one associated with new and used EVs, usually below 200 km for city use during mild weather. Similarly, e-retrofitted vans, trucks and buses are usually associated with a shorter range than equivalent new EVs.

- **Regulatory constraints**. The regulation on series e-retrofit in France also limits the electric power delivered to 100% of the donor's vehicle past performance, while new EVs usually deliver much more power than their ICE siblings.

The situation is different in deregulated markets, especially for vintage and collectible vehicles, for which the price of conversion is not the most critical criteria, and skateboard chassis could be added. In these cases, retrofitted vehicles represent luxury upgrades of the original car, in terms of top speed and acceleration and could even deliver performance comparable to new EVs. However, the price tag of the conversion put them is a class of itself of high luxury vehicles with average performance: the range per euro is much shorter than for light conversions and any new EV on the market (see discussion page 84).

Comfort. The same conclusion largely applies to comfort: light retrofitting prioritizing cost, it does not involve many improvements in terms of comfort. It is usually limited to the optional integration of a tablet (e.g. Retrofuture). For heavy retrofits, the picture is much different: the conversion can include significant upgrades in terms of noise isolation, on-board electronics, suspensions, interior, regenerative breaking, airbags, upholstery, on-board entrainment, etc. The cost/benefit of such upgrades, which could be justify for the conversion of classic cars, is likely to significantly decrease for modern vehicles, which are already equipped with modern electronics and sound-proofing, and are harder to retrofit.

3. ENVIRONMENTAL AND SOCIAL BENEFITS

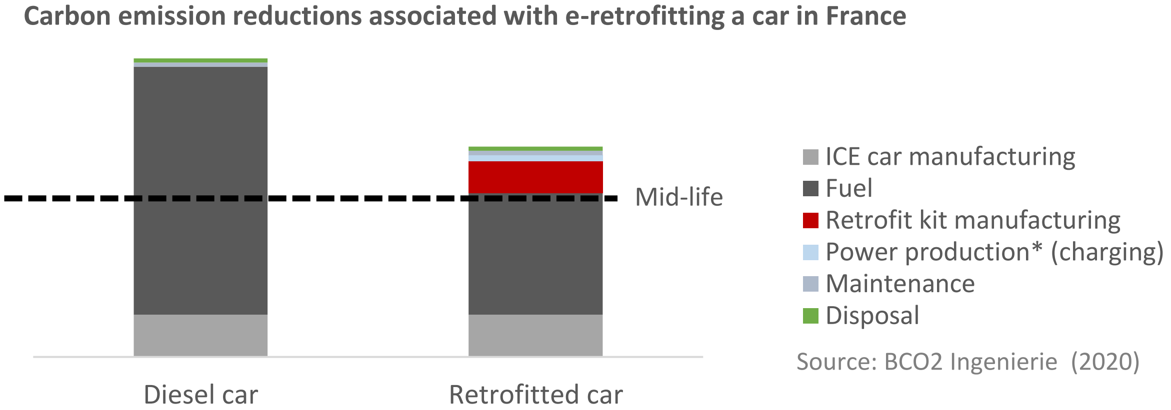
3.1. REDUCED ENVIRONMENTAL IMPACT

Review of literature. Only a few Life Cycle (LCA) or carbon footprint analysis have been conducted on retrofitted vehicles to date. The most directly relevant are a 2017 LCA for a Smart in Germany (Helmers et al.)[36] and a carbon footprint analysis (Bilan Carbone®) conducted by "BCO_2 Ingénierie" for the French environmental agency (ADEME) based on a use phase in France (60 g CO_2e/kWh). They are summarized in the Annex. Other studies have been conducted in the UK (2021) and Australia (2013)[37]. Overall, the studies conclude that e-retrofit reduces the carbon emissions significantly compared to purchasing a new BEV, keeping the ICE car, or purchasing a new one.

Study for France. The starting point is a 10-year old ICE vehicle in France in 2020.
Three scenarios have been compared:

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

The findings suggest that the environmental case for retrofitting is strong, whether it is compared against the use of an ICE car, or the purchase of an EV:



The analysis focused on the 10 years of use following the decision. LCA methodologies assume an average lifetime ranging from 14 to 18 years (or 200 000 to 300 000 km)[38] depending on the author. The "cumulated survival probability" of a car on European roads is estimated by researchers[39] at 19.5 years on average, ranging from 8.0 years in Luxemburg to 35.1 years in Poland. If the retrofit is associated with a refit and repairs and exported to eastern Europe, retrofitted vehicles will likely be used more than 10 years after the conversion, delivering additional environmental benefits.

The analysis also covered larger cars with the same results. The same conclusion also applies to other categories of road vehicles:

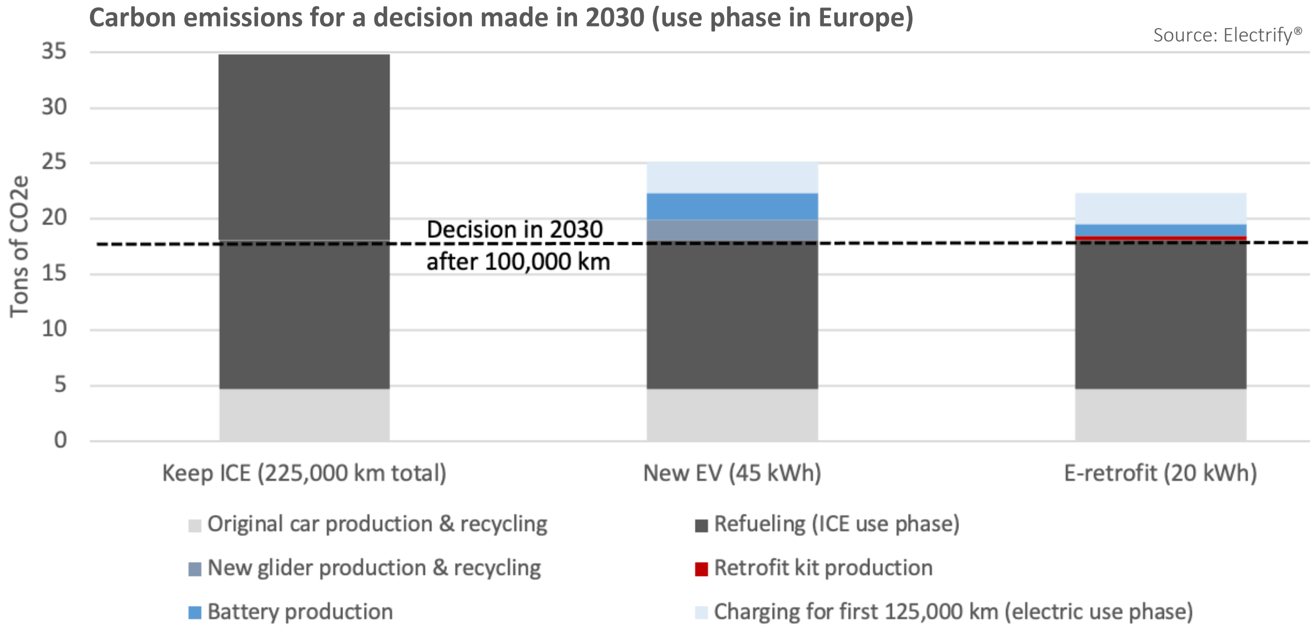
Vehicle	Keep ICE vehicle	Purchase new EV	E-retrofit
Small city car (10 000 km/year)	Diesel	50 kWh	30 kWh
Utility van with custom equipment (5000 km/year)	Diesel	40 KWh	30 kWh
16-19t heavy duty truck (40 000 km/hr)	Diesel	300 kWh	300 kWh
12 m shuttle bus (40 000 km/hr)	Diesel	300 kWh	300 kWh

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

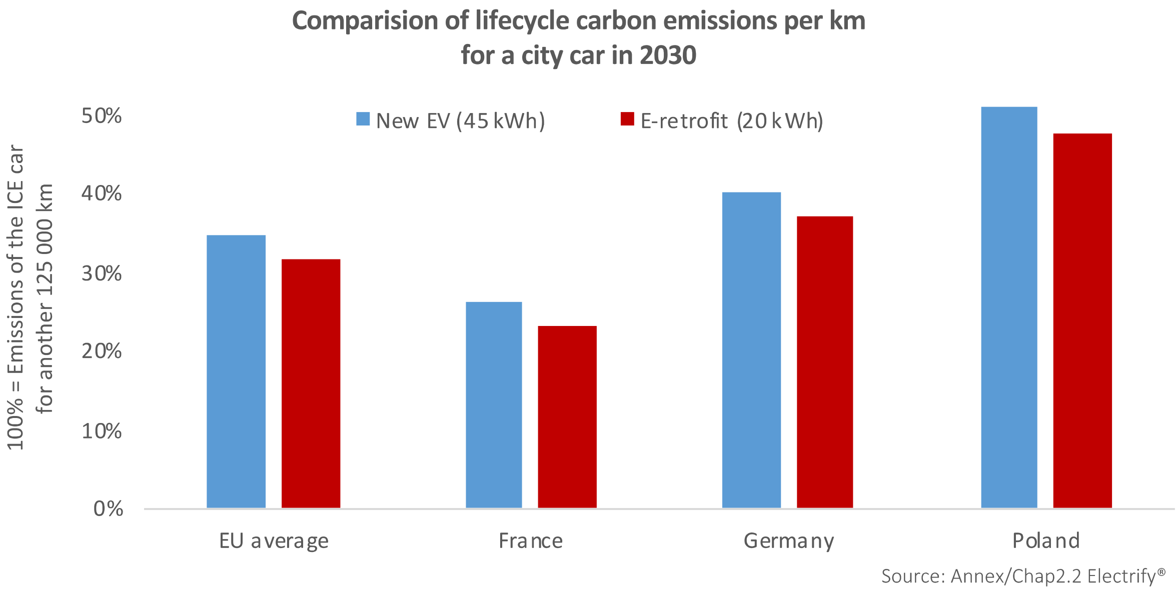
Source: ADEME/Algoé study 2020 for France. Carbon footprint BCO_2 Ingenierie.

2022 estimates for European countries. Using more specific data on each component of an e-retrofit kit, Bilan Carbone® emission factors for production, and Transport & Environment LCA results for batteries and cars production in 2022 and 2030[40], we performed a new estimate of the carbon footprint of e-retrofitted cars in Europe. The starting point being year 2030 for a small ICE car produced in 2022 that has been already used for 100,000 km. We compared three scenarios: keeping the ICE car, scrapping it, and purchasing a new EV or retrofitting the ICE car. The new results confirm the previous studies :

- Compared to keeping the ICE car, the remaining lifetime emissions are cut by **80%.**
- Compared to purchasing an EV and scrapping the used ICE car, the emissions are cut by **45%**.
  The main benefits of e-retrofit are to avoid producing a new glider and amortize the old glider on more kilometers. Current e-retrofitted cars also appear to have smaller batteries than their sister new EV in most cases observed, which further reduce the production-related emissions.



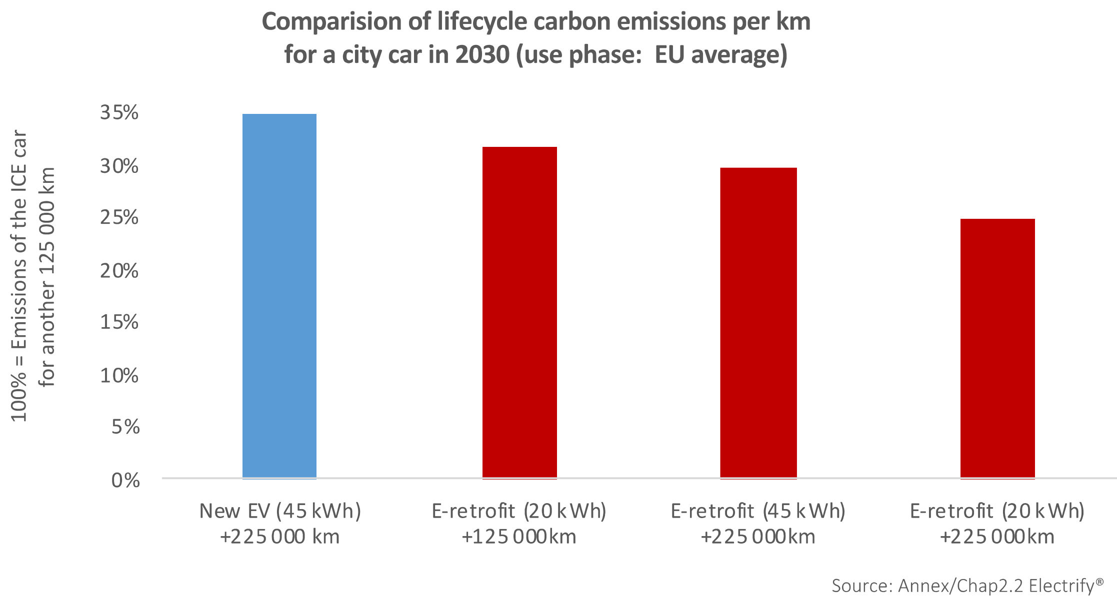
The chart below provides the results for a use phase in different countries with different carbon intensity of their electric mix (low for France, high for Poland). In all cases, the e-retrofit deliver significant emission reductions compared to the ICE car (at least 50%) and is also more efficient than purchasing a new EV.



In the chart below, we analyze the consequence of a “premium retrofit”:

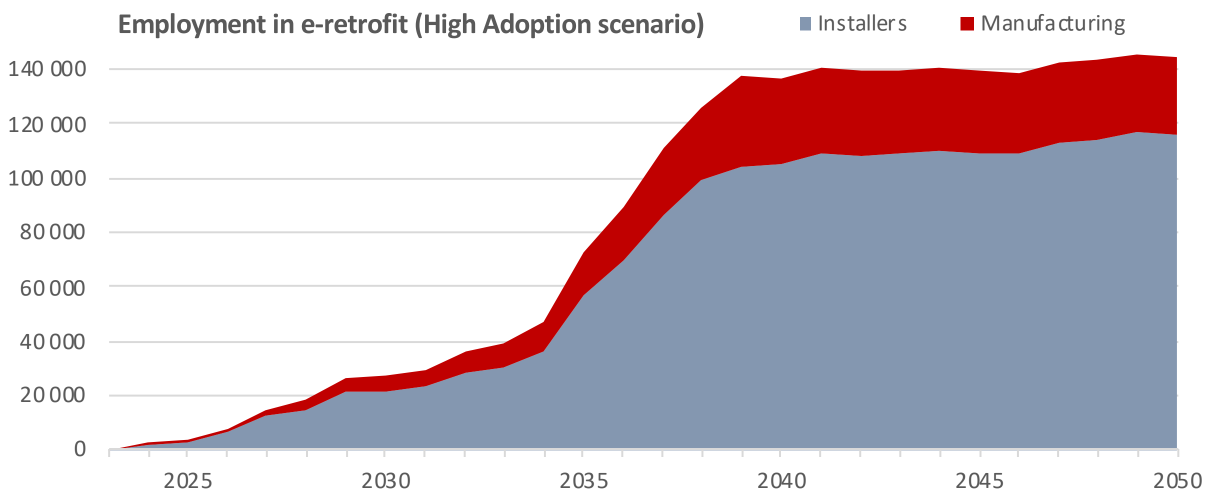
- Capacity of the battery increased to 45 kWh (like the new EV),
- Second life extended to 225,000 km, if the key components the most subject to wear and tear (suspensions, tires, etc.) have been changed during the retrofit operation.

In these two scenarios, the carbon footprint of the e-retrofitted car is significantly improved.



3.2. JOB CREATION POTENTIAL

This section discusses the potential job creation by the e-retrofit industry in the High Adoption and 1.5°C deployment scenarios presented in Chapter 8 of the report. The details of our calculations are presented in the Annex, Chapter 2.5. The job creation potential in the Low Adoption Scenario being limited, it is not discussed below.

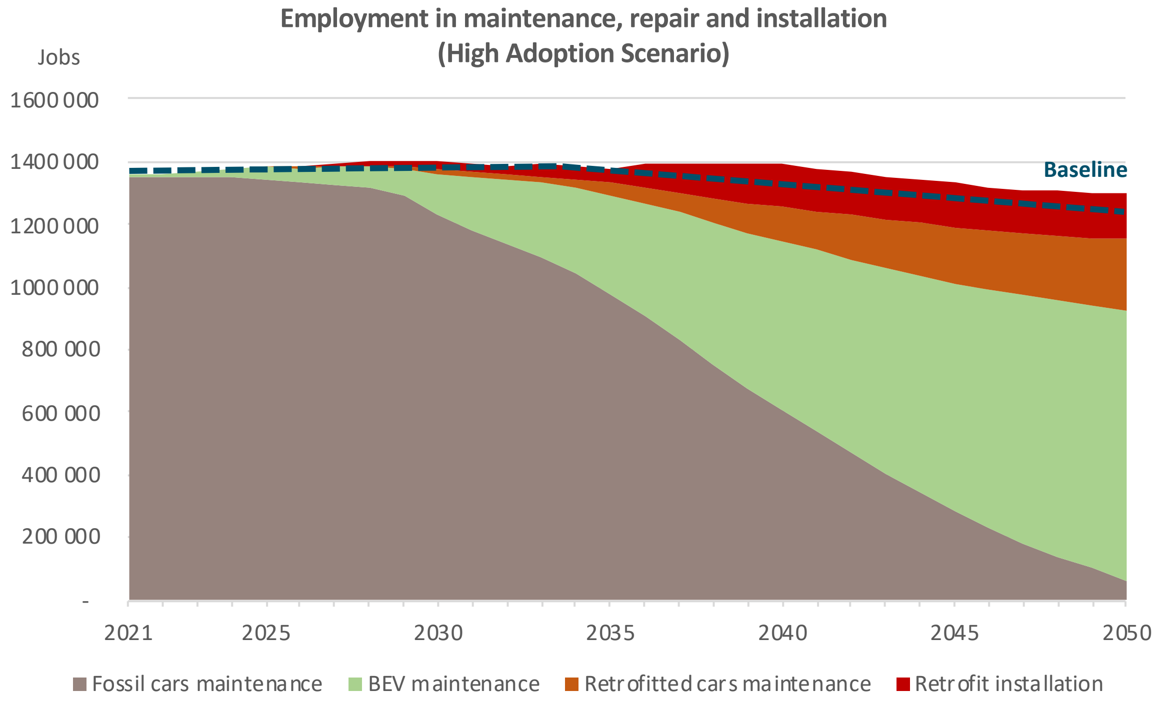


Jobs in manufacturing. We have assessed the direct jobs created in manufacturing and marketing of the e-retrofit kits, based on the ratio estimated by Algoé (2021) and French manufacturers. We assume 6 jobs per 1,000 cars retrofitted at the beginning of the period and 4 at the end. Manufacturing represents 10% to 20% of the total job creation potential, the main jobs being in installation. Our estimate does not consider jobs created in battery manufacturing and other component suppliers, which are likely to be significant in the last two scenarios.

Jobs in installation. The shift towards EVs involves simpler production, fewer parts, less maintenance, and a potentially longer vehicle lifetime. Based on various sources (see Annex/Chap 2.5), we estimate that the transition might reduce the demand for maintenance and related employment by 30%. It also represents a challenge in terms of new skill acquisition to maintain batteries and related software. As a result, repair shops will likely look for new revenue streams to face this evolution and will require training.

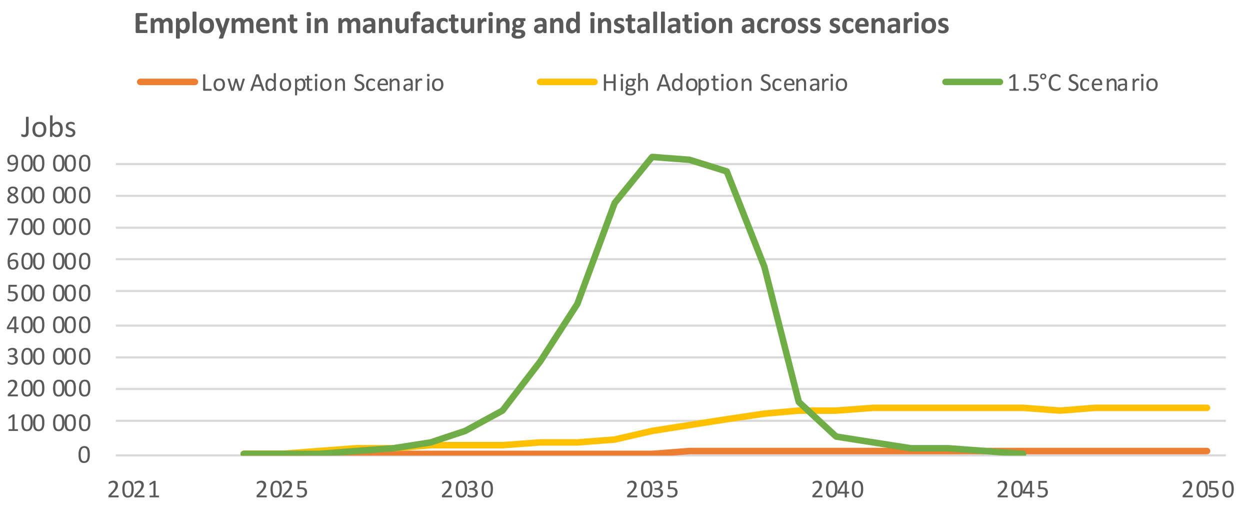
For series e-retrofit, most manufacturers plan to train and certify auto repair shops to install the kits. Repair shops enjoy a local presence in every city, the basic infrastructure required, and the customer relationship necessary to support fast scale-up. The skills necessary are the same and the repair shops are also in an excellent position to market the offer to their customers.

To estimate potential direct job creation, we have calculated the number of hours necessary to retrofit a car. In a 2020 study for France, Algoé estimated that the installation of a kit for a small car would take between 25 and 50 hours. However, based on the business plans of e-retrofit manufacturers, we fine-tuned the estimate to 37 to 42 hours[41]. The assumptions on productivity gains and the cost of labor are discussed in chapter 7.4.



Our analysis suggests that e-retrofit can create a significant number of jobs:

- **120,000 jobs** to install the kits in the High Adoption Scenario (red layer on the chart above), representing about 9% of current jobs in repair[42]. The job creation is slightly above the baseline (no retrofit, maintenance of remaining fossil car vehicles). All these jobs are local. In the scenario, they are created in Western Europe at the beginning of the period and in Eastern Europe at the end.
- **700,000 jobs** in the 1.5°C scenario (210 million cars retrofitted) over a much shorter period, representing at its peak 50% of the current employment of the sector. In such a case, the peak of activity would represent a human resources management challenge for the sector: the total employment jumping from 1.4 million jobs in 2030 to 1.9 million jobs in 2035, to drop again around 2040.



4. PRODUCTS, DONOR FLEET, AND USE CASES PER CATEGORY

4.1. E-RETROFIT COMPANIES

The e-retrofit market is at its infancy. For most vehicles, conversions are performed by small conversion shops using kits produced by specialized small-size manufacturers. There are no significant economies of scale delivered today. Series production of limited in size (e.g., 50 to 500 units), based on pre-orders and public tenders. In France where series retrofit regulation has been introduced, most e-retrofitters are waiting for their first approval, and only a few models are available for pre-order.

Selection of European players

Country	Companies	Series retrofit	Categories
Croatia	EV Evolution		Vintage, Cars, Buses, Vocational
Czechia	EV4U Custom Conversions		Vintage
Belgium	Decarbone		Vintage
	DRM e-classics		Vintage
	Monceau Automobiles		Vintage
France	Car Watt	✓	Vintage, Vocational
	Greenmot	✓	Buses
	Lormauto	✓	Cars
	Mona (Retrofleet)	✓	LCVs/vans, Cars, Trucks, Buses, Vocational
	REV Mobilités (partnership with Pepper Motion)	✓	Vintage, LCVs/vans, Cars, Trucks, Buses
	R-Fit	✓	Vintage
	TOLV (partnership with Renault)	✓	LCVs/vans
Germany	Clean Logistics	✓	Trucks, Buses
	Ecap Mobility (acquired by Clean Logistics)		LCVs/vans, Trucks, Buses, Vocational
	E-classics		Vintage
	Pepper Motion/etrofit	✓	Trucks, Buses
	Quatron	✓	Trucks, Buses
Italy	Totem Automobili		Vintage
	Officine Gentile		Vintage
Netherlands	Voiture Extravert		Vintage
	Electricmini.nl		Vintage
	EV Europe		Vintage, Cars, LCVs/vans
UK	Charge Cars (Arrival group)	✓	Vintage
	Electrogenic		Vintage
	Lunaz Applied Technologies	✓	Vintage, Vocational
	Mini Recharged (partnership with BMW group)	✓	Vintage
	London Electric Cars	✓	Vintage

Vintage Cars LCVs/vans, Trucks, Buses, Vocational

See Technical Annex/Chap 2.3. for more examples, and the website for updates.

STARTUPS

We estimate that there are about 30 to 40 players in Europe and about 150 globally. Only a few companies can be considered ‘startups’ - raising venture capital money with the objective to scale up and deliver economies of scale.

The most developed segments are heavy trucks, buses, and vocational vehicles. In this segment, market leaders are German, thanks to the massive subsidies of the German government for the electrification of buses and trucks fleets. They are early-stage (Series A/B) startups that have delivered their first beta products, have recently started to commercialize their series products, have raised funds, and are building a conversion capacity of 1000-2000 vehicles per year:

- Founded in 2019, Pepper Motion (Germany) has 100 employees in four locations and closed a Series A round of €32 million in April 2022.
- Its German competitor, Clean Logistics, founded in 2018, has about 50 employees (2021 average). It has a shareholder equity of €28 million, has raised €4.1 million of equity in 2021 on the Frankfort Stock exchange, took out an €11 million euro loan in 2022, and has a market capitalization of €38M million.
- In the UK, Lunaz, which just revealed its garbage truck after getting known for luxury classic cars conversions, has closed a $35 million funding round in early 2022, valuating the company at $200 million.

On the commercial vans markets, the players with startup ambitions are at an earlier stage of their development: they have demonstrated a first prototype or retrofitted a few vehicles and are taking pre-orders. The amounts raised correspond to seed rounds:

- TOLV had its first van approved and 30 employees in 2022. They have raised €2 million of equity and €1M of debt in 2022 and are raising another round of €7 million in early 2023.
- REV mobilities is expecting its first vehicle to be approved in 2023. They raised about €9 million in 2022. The company plans to launch passenger cars in 2024 and aims to produce 420 vehicles per month. The company plans to launch passenger cars from 2024 onwards and generate a significant revenue stream, with the ambition to exceed a billion euros of revenues by 2030 in this segment alone.
- Other passenger car players such as Lormauto, and Mona have demonstrated unapproved prototypes but are at an earlier stage, currently (Q1 2023) raising their first round.
- One of the first companies to target the low-cost passenger car segment, Transition One, discontinued its activity on Q1 2023 after failing to raise a first round.

The analysis of the pitch decks and interviews with manufacturers suggest that they envision a market size aligned with our High Adoption Scenario in 2030.

VEHICLE MANUFACTURERS

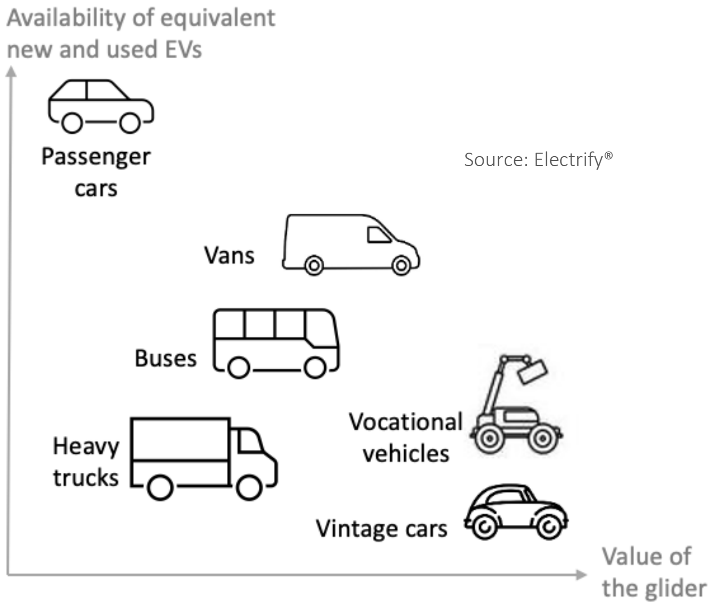
Certain e-retrofit vehicles, such as Charge Cars (Mustang) in the UK, and Q-Retrofit (heavy truck) are provided by startup electric vehicle manufacturers (Arrival, and Quatron). However, established car manufacturers are largely absent from the market.

Several luxury brands with collection models like Jaguar and Aston Martin have announced retrofit programs but have fallen short of implementing them so far[43]. However, several UK-based SMEs offer conversion of their flagship cars. On the more affordable vintage segment, BMW has launched a small-scale conversion program for its classic Mini, and VW has partnered with the German-based retrofitter E-Classic to install a conversion kit they designed for the classic Beetle[44].

On the commercial van segment, Renault announced in July 2022, a partnership with the French SME Phoenix to co-develop and demonstrate a retrofit kit for Renault's van (Renault Master) by 2024, with the objective of converting 1,000 vehicles in this pilot phase. The plan follows up on an announcement made in 2021 regarding opening a refit plant, including e-retrofit activities[45] without specifying the target volume and schedule.

Outside Europe, General Motors (Chevrolet brand) has announced in 2021 its intention to develop conversion kits for a range of vehicles (specialty equipment, boats, military vehicles, light trucks), including passenger vehicles (pick-up trucks, sports cars) starting the same year[46]. Ford followed with a much more limited ambition: an electric crate motor designed to make EV conversions easy.
In Japan, Toyota's CEO has recently announced in 2023 the intention of the group to retrofit its cars, but he felt short of specifying the timeline and scale of the project (at the time of our publication).

4.2. MODELS AND DONOR FLEET FOR PASSENGER CARS



Based on the technical limitations discussed in the first chapter, the potential clients for e-retrofit:

- Are comfortable owning an old vehicle (10-30 years old for a car).
- Have limited performance requirements in terms of range, top speed, and availability of the newest comfort and safety features.
- Are not willing/able to invest the amount required to purchase a new or used EV; or/and want to keep their existing glider[47] because it is customized (e.g. expensive equipment) or impossible to replace (e.g. cachet of a vintage car).

Such constraints significantly reduce the pool of eligible vehicles in each category. This chapter discusses the size of the 'technically eligible' fleet and the typical use cases observed in today's market for passenger cars and provides an overview for other categories of vehicles. The economic dimension of the decision-making process for cars is discussed in Chapter 7. Further limiting factors related to the complexity and cost of retrofit, such as complex mechatronics are discussed in Chapter 7 (Other roadblocks).

E-RETROFITTED CARS AVAILABLE TODAY

Today the offer of e-retrofit solutions for passenger cars is almost entirely focused on vintage cars and individual conversions. Series e-retrofit is mostly available on paper (i.e. pre-order) in France, most manufacturers waiting for regulatory approvals for their first model.

Only a couple of manufacturers offer non-vintage passenger ICE car retrofit, promising delivery for 2023 and beyond, subject to funding to kick-off the operation in both cases. A couple more retrofit light duty commercial vehicles that can be used by individuals as mini vans.

The table below provides typical examples of the offer:

Models	Battery capacity	Manufacturer	Start price	Donor car value (est.)
Passenger cars				
Peugeot 207, Renault Clio, and Citroën C3	20 kWh	REV Mobilities (France)	N/A	5,300€
Twingo 1 (1992-2007)	18 kWh	Lormauto (France)	200€/month	Included
Mini vans and light duty commercial vehicles				
Kangoo Express	34 kWh	REV Mobilities	24,000€	8,500€
Toyota Hilux	-	Mona (France)	N/A	
Vintage cars				
Citroën 2CV	10,5 kWh	R-Fit (France)	13,900€	7,500€
Mini Cooper	20 kWh	REV Mobilities (France)	16,000€	6,000€
	20 kWh	London Electric cars (UK)	£42,000	6,000€
	-	Mini - BMW group (UK)	-	6,000€
VW Beetle	25 kWh	REV Mobilities (France)	20,000€	6,000€
	-	London Electric cars (UK)	£42,000	6,000€
	36 kWh	E-Classics (Germany)	€69,000	Included
Range Rover	40 kWh	REV Mobilities (France)	€30,000	30,000€
	100 kWh	London Electric cars (UK)	£120,000	included
	-	Lunaz (UK)	€285,000	included
Ford Mustang 1967	63 kWh	Charge Cars / Arrival (UK)	$350,000	included

Regulatory approval obtained Waiting for regulatory approval Deregulated market

The offer is planned to increase significantly in the near future. For instance, REV Mobilities plans to start in 2024 with three models, and launch another three (Dacia Duster, Renault Scenic 3 and VW new Beetle) in 2025.

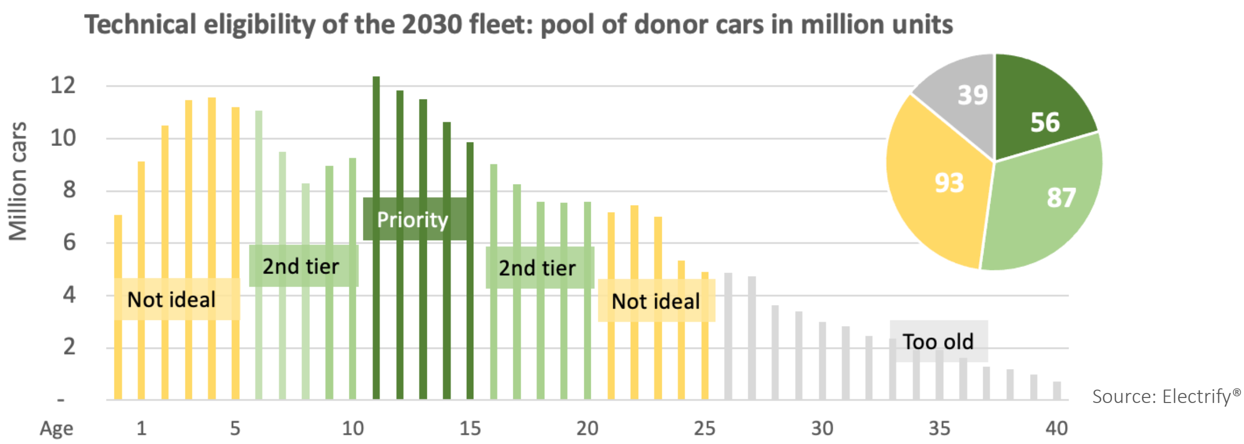
SIZE OF THE TECHNICALLY ELIGIBLE DONOR FLEET: 230 MILLION IN 2030

In 2022, there were about 293 million fossil passenger cars on European roads, including 274 million ICE cars.[48] Excluding cars older than 25 years (which might not be roadworthy for another ten years), the pool of potential donor cars that are technically eligible for immediate retrofit is reduced to 264 million. All these cars will obviously not be retrofitted, given the absence of capacity and demand today, the economics (see Chapter 7), and other roadblocks (see Chapter 8).

In all scenarios, we do not expect a significant mass e-retrofit to reach mass scale before 2030. At this time, there will still be 236 million fossil cars technically eligible, including 56 million in the priority age for e-retrofit (see chart below). The size of this pool will evolve during the "retrofit time window" (2030-45), with a triple dynamic at play:

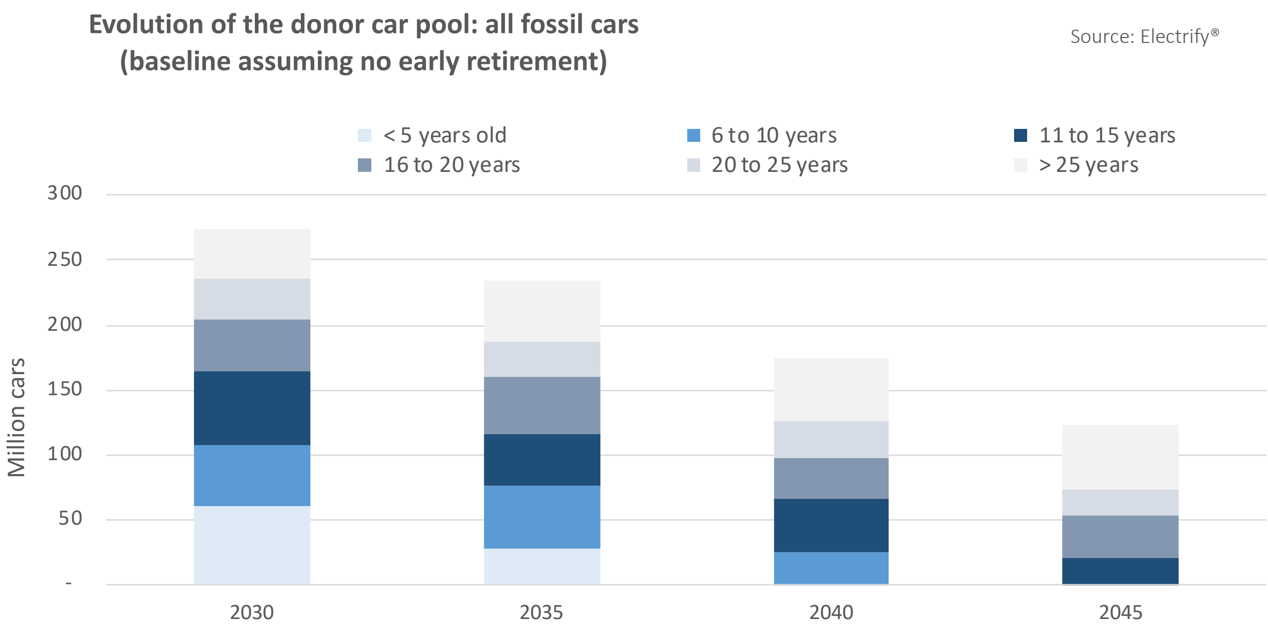
- The stock of recent cars will shrink during the time window. Assuming no early retirements, only 127 million eligible cars (<25 years old) will be left in 2040 and 74 million in 2045.
- The priorities for e-retrofit might shift due to public policies and the economics of retrofit: recent cars (< 5 years old) are not legally eligible in 2023 (in France, where regulation exists), might still not be prioritized in 2030 but could become the priority in 2040 in the context of a full phase-out of fossil cars (described in our 1.5°C scenario).

- Retrofits performed early in the period will obviously alter the age structure for the remaining pool of donor cars (the timing of a potential mass retrofit program is discussed in Chapter 1.1).



The impact of this dynamic on the pool of eligible cars in discussed in the Annex.

The chart below summarizes the evolution of the eligible fleet over the relevant time window in our baseline scenario (2030-2045) for all fossil cars and ICE only (excluding hybrids and plug-in hybrids):



4.3. CARS: MAIN USE CASES TODAY

In the near term (before 2030 in our scenario), the market seems limited to niche use cases due to its economics (see discussion in the next Chapter). We estimate the total pool of vehicles for those used cars at less than 10 million cars today (3% of the fleet).

USE CASE #1: VINTAGE CARS

Vintage cars are by far the most represented segment in retrofitted cars to date. The main reason is the emotional value and high resale price attached to the glider, which justifies investing in conversion in the absence of net economic benefits. There are about **5 million** classic collectible cars in Europe[49], 80% of which are worth below 100k€. The category could also be stretched to the less expensive vintage cars such as VW Beetle, Fiat 500, and Mini, which are the main donor cars today. Most of them are more than 20 years old, so are not accounted for in the above estimate of the eligible fleet. In the future, the total retrofittable fleet in this segment is likely to be fueled by the strong sales of sports, luxury and high luxury vehicles that owners might be reluctant to scrap: we estimate that the current fleet is about **4 million vehicles** strong, with 300,000 new cars added each year.

From an environmental and economic perspective, this segment does not represent a significant potential. However, it constitutes a 'low-hanging fruit" for e-retrofit manufacturers and is also interesting in terms of market dynamic: vintage e-retrofitted cars being rolling ads for the industry, a way to demonstrate solutions applicable to other categories of vehicles, and a way to avoid burning too much cash at the early stages of an e-retrofitting business :

- In the UK, Lunaz created a brand name for itself by retrofitting Rolls-Royce and Aston Martin classic cars and then introduced an e-retrofitted garbage truck in 2022.
- In France, REV Mobilities started with vintage cars, then launched commercial vehicles and now plans to retrofit passenger cars.

USE CASE #2: WHEELCHAIR VEHICLES

There are only scattered statistics on demand for handicap vehicles. About 5 million Europeans (1% of the population) are wheelchair users, 3% of vehicles in the UK are driven by people with disability, and 2 500 vans are adapted each year in France. We estimate that overall, **1.5 to 2.5 million** fossil vehicles of eligible age for retrofit are adapted today.

Converting a vehicle, usually a car, passenger van, or utility van, consists in modifying the commands and seats, lowering the floor, and installing a ramp. It can take up to five weeks and costs between €10,000 to €20,000, while some conversions requiring specialized equipment can cost up to €60,000. Overall, the European vehicle for the disabled market is expected to reach €2.2 Billion in 2027, growing by 13% per year on average[50]. No data exist on the relative weight of the financial burden of conversion versus other hurdles faced by people with disabilities, but a 2021 survey in the UK suggest that only 55% of citizens with disability have a driver's license compared to 83% for the general population.

Given the cost and effort required to adapt a new vehicle, e-retrofit could be a good solution for disabled drivers who have already invested in the adaptation of their ICE vehicle and want to shift to an electric drive.

4.4. CARS: TOMORROW'S POTENTIAL NEW USE CASES

The second segment targeted by series e-retrofitters today is affordable used cars. A few companies (REV mobilities, Lormauto, Mona), mostly based in France due to favorable regulation, plan to introduce series for popular models of city cars such as Renault Twingo and Clio. Expression of interest and non-binding pre-order forms are available on their websites.

They emphasized the low cost for users, with Lormauto eventually targetting a 100€/month all-inclusive rental solution (both including generous French subsidies)[51] in France. If these solutions take off (see discussion page 81), the potential markets are twofold:

USE CASE #3: SECOND AND THIRD CARS

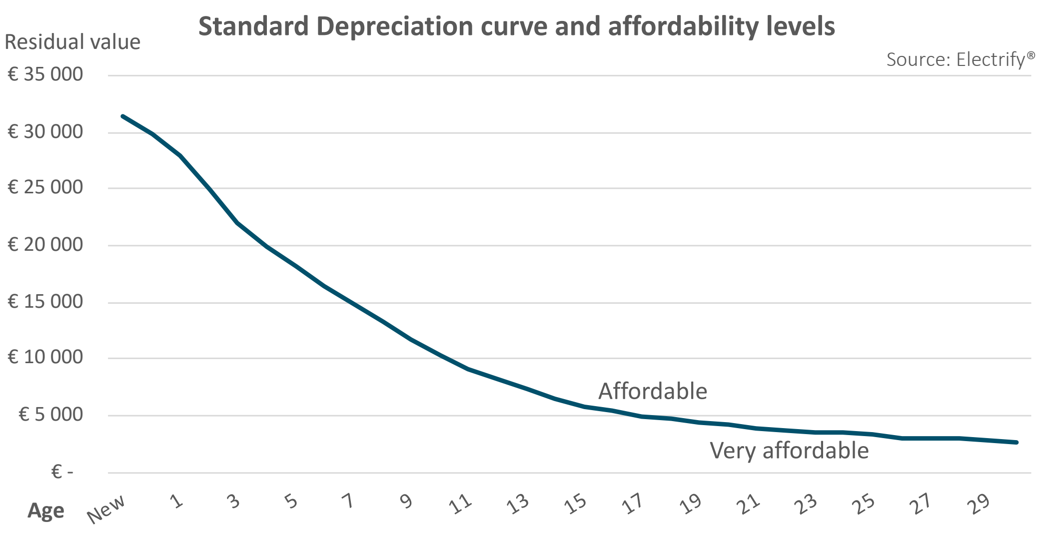
Affordable e-retrofit is a solution for the second or third car of households living in suburban areas near Zero Emission Zones, who choose to retrofit the car they already own rather than purchase a new one. As described in Chapter 3, consumers in western Europe express more appetite for e-retrofit than purchasing a new EV, at least in surveys.

The typical use cases are short local trips (e.g., picking up a kid at school, grocery shopping, etc.) or commuting to work, and the charging point being home. Statistics[52] on commuting time (<30 min), average daily distance travelled by cars (<60 km/working day), and car usage patterns (15-25% commuting, 10-15% personal errand, 30-40% social) suggest that the current minimum range of low-cost retrofitted cars (100 km) will be sufficient for this use case, assuming daily charging at home, at work or on public chargers. E-retrofit would be specifically suitable for family cars and mini vans that are slightly more expensive to retrofit but significantly more expensive to renew than small cars (see discussion in Chapter 6).

There are no comprehensive statistics on second and third cars across Europe. However, in 2020, 32% of French households have two cars, and more than 5% have three cars or more: there are respectively 9.5 million and 1.5 million second and third cars on French roads. The UK show a similar percentage, with 33% of households having two or more cars (2021). At European level, surveys suggest a similar rate[53]. Extrapolating these ratios in a conservative way[54], we estimate the eligible donor fleet will be between 40 to 50 million cars in 2030.

USE CASE #4: AFFORDABLE USED CAR MARKET

In 2020, the European used car market represented 36 million cars sold (three times the volume for new cars). The overall market is growing at 3-4% per year in value[55] even when sales of new cars plummet[56].



Based on statistics related to the age

and price of cars purchased by different income groups[57], we define “affordable” as a residual value lower than 9,400€ and “very affordable” as a residual value lower than 4,200€, which correspond to the average and mean prices of cars purchased by very low-income households (see figures in Chapter 1). Furthermore, based on the standard depreciation curve and average car price we used in the model, these value thresholds correspond to respectively, 10+ and +20 years old cars.

Using these age thresholds as proxies, we estimate the demand and offer for affordable and very affordable used cars:

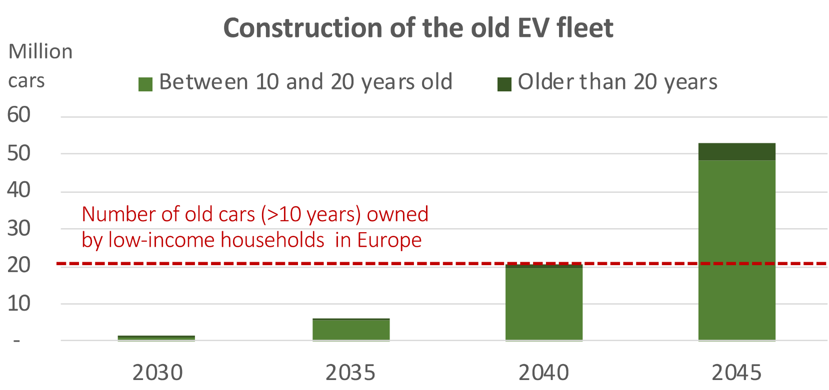
- As described in Chapter 1, there will be a shortage of old used cars in the EV fleet and used EV market, with almost no EV older than ten years in 2030 in Europe and only 53 million in 2045.
- These figures are to be compared with the “normal” fleet size of affordable cars (>10 years) owned by low and ultra-low-income households, which is respectively ≈17 and ≈3 million cars in Europe (see annex for details on the definition and methodology).
- In practical terms, if the rise in fuel prices, taxes, or regulatory constraints increases the Total Cost of Ownership of fossil cars too much, 20 million car-owning households will be priced out of car ownership and join the 12.5 million Europeans who cannot afford a car today.

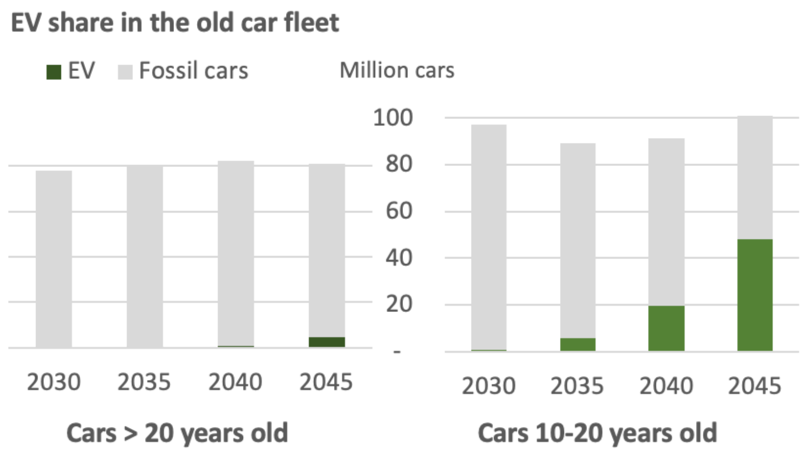
This figure is a low estimate of the problem size since lower middle-class households who own affordable cars can also experience similar difficulties.

Based on the current size of the car fleet, the estimated demand for affordable cars indicates that there will be a shortage of approximately 180 million affordable electric cars (>10 years), including roughly 80 million “very affordable” (>20 years) if fossil cars become uneconomical to use.

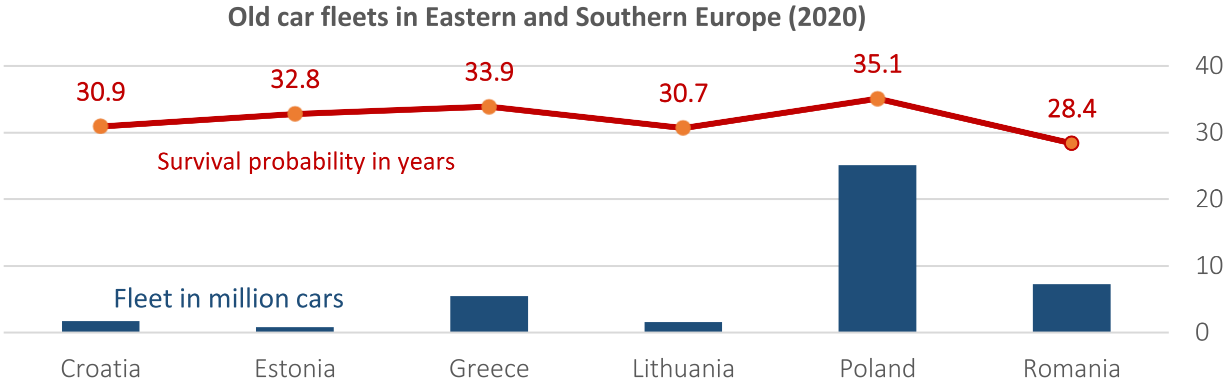
These figures relate to the total stock of cars. The gap we describe will translate into a deficit of 14 million affordable EV on the 2030 used car market (i.e., volume of annual transactions) that will gradually be reduced to 6 million in 2050 (see chart in Chapter 1).

The demand is likely to be particularly high in Eastern Europe. In many markets, the average fleet is very old, and most vehicles sold are used cars imported from Western Europe. For example, about 42% of used cars sold in Poland in 2021 were imported from Germany, and about 44% were older than 10 years.





Source: Electrify®



Source : Eurostat, Held et al (2021)

USE CASE #5: MUNICIPAL FLEETS

Corporate and municipality fleets are likely to be the main candidates for introducing the first large-scale retrofit programs, thanks to central decision-making, pre-financing capacity, reputation management, and regulatory pressure.

These fleet owners will be under growing pressure to electrify over the next decade.

In France, municipal and governmental, and corporate fleets face a mandatory requirement to integrate a share of EVs in the inflow[58]. Depending on the type of owner, the quota will evolve at different speeds, from 10-20% today to more than 70% from 2030 onwards.

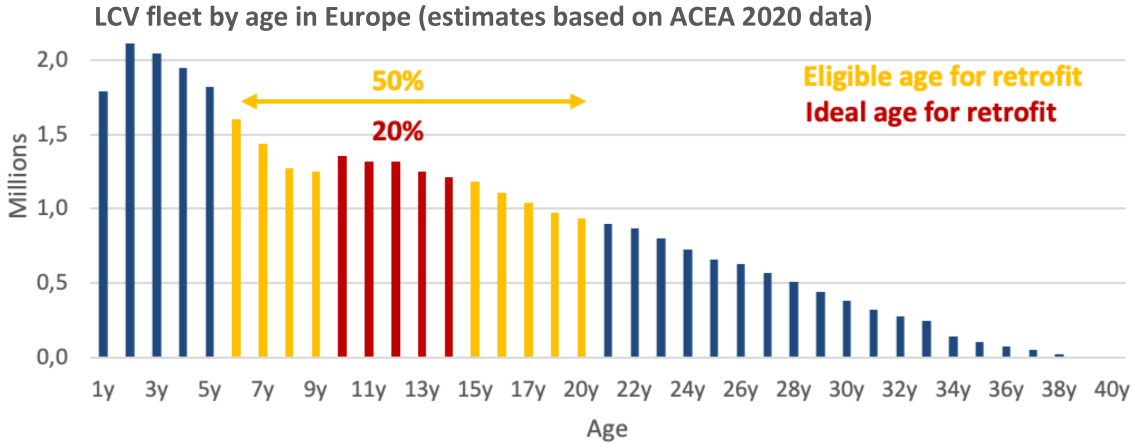
According to Deloitte[59], corporate fleets are mostly composed of new cars: about a third of new cars sold join European organizations' fleets every year. They typically own the car for 36 to 48 months. Then, the average corporate car quickly becomes privately owned via the second-hand market. However, the ownership period can be much longer for certain organizations like municipalities and SMEs.

Today the most tangible demand for e-retrofit, in the form of calls for tenders, comes from municipalities and is related to buses and utility vans. In France, REV Mobilities reports submitted five proposals in 2022. Moving forward, this type of program will likely be extended to passenger cars if the economics adds up.

4.6. OTHER CATEGORIES OF VEHICLES

UTILITY VANS

Donor fleet. There are about 34.7 million vans and other light commercial vehicles (LCVs) on European roads[60]. The fleet emits about 85 Mt of CO_2e per year, equivalent to 18% of the car fleet emissions for 11% of its size. The 2021-2030 trajectory and regulatory constraints are roughly the same as for cars, with affordability issues for independent professionals and SMEs.
As for cars, the oldest fleets concentrate in Eastern and Southern Europe, notably Greece (of 20 years old on average) and Romania (17 years old). We estimate that 17 million are of 'eligible age' for retrofit.



E-retrofit solutions. The e-retrofit offer for vans is the most dynamic after vintage cars.
Building on the regulation and incentives in France, multiple companies compete in series retrofit:

- REV Mobility offers the conversion of the most popular brands in each segment (small, mid, and large size). Only pre-orders are possible since it is waiting for the approval of its first type-version to deliver the first vehicles. The company plans to launch four models in 2023, and 8 in 2024-25.
- Noticeably, the e-retrofitter TOLV (formerly Phoenix mobility) has partnered with Renault to deploy a retrofit program in the manufacturer's "ReFactory", a new facility dedicated to used vehicles refit and circular economy projects[61]. The partnership powers TOLV with technical knowledge of Renault's vehicles and the purchasing capacity of the group for batteries.
- In 2021, a small retrofit company (Retrofleet) and a bodybuilder (GTE Automotive) partnered to launch the retrofit of a series of utility vehicles under the "Mona" brand.
- There are also players in other countries, such as E-Cap Mobility in Germany, a company specializing in truck retrofit and offering vans retrofit.

The table below provides a selection of typical models:

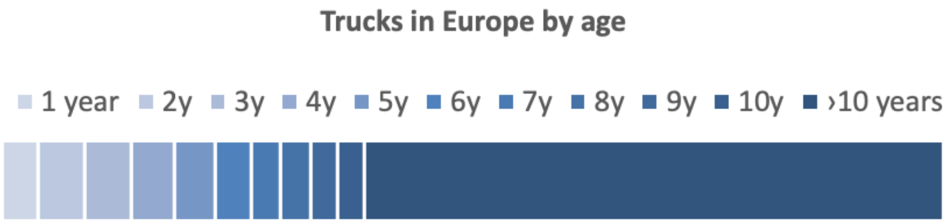
Segment	Models	Battery	Price (VAT excluded)	Delivery in…
Small	Renault Kangoo 2 (T. One)	15 kWh	10 000€	N/A
	Renault Kangoo 2 (REV) [62]	34 kWh	20 000€	Sept 2023
Mid-size	Renault Trafic (REV)[63]	40 kWh	24 000€	Sept 2023
	Renault Trafic (TOLV)	60 kWh	N/A	N/A
Large	Renault Master (REV)[64]	50 kWh	27 500€	Sept 2023
	Renault Master (TOLV)	60 kWh	N/A	N/A
	Renault Master (Mona)	N/A	N/A	N/A

USE CASE #6: UTILITY VANS CUSTOMIZED WITH COSTLY EQUIPMENT

In this category, e-retrofit competes with new and used electric vans now available for almost every model (see discussion page 89). However, like for the above-discussed case of handicap vehicles, the price of special equipment could significantly increase the cost of switching to an electric vehicle. Conversions to ambulances, firetrucks, refrigerated vans, or other special utility vehicles typically cost between €10,000 to €20,000. Advanced conversions such as into a camper can cost up to €80,000. The equipment is often not reusable from one car to the next. In these cases, e-retrofitting can make economic sense even if the e-conversion is more expensive than purchasing a new EV.

HEAVY TRUCKS

Donor fleet. According to the latest ACEA data, there are 7.1 million medium and heavy-duty trucks[65] on European roads, a disproportionally high number registered in Poland (1.2 million) and Italy (0.9 million). Trucks are, on average 13.9 years old in the European Union. With an average age of 21.4 years, Greece has the oldest truck fleet, followed by Italy (18.5).



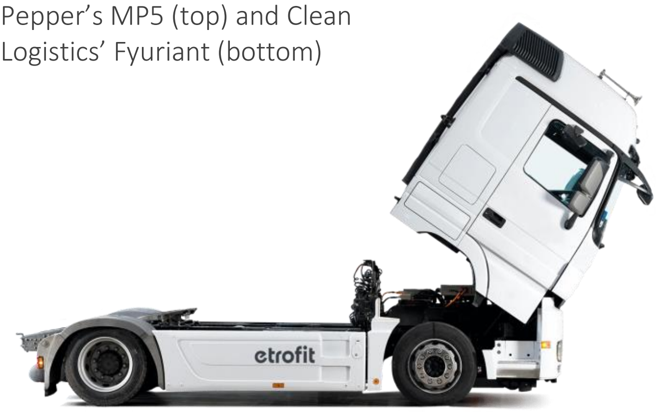
Sources:
ACEA, Eurostat (2020)

State of electrification. While they only represent 1% of the road vehicles fleet, heavy-duty trucks are responsible for more than 22% of road transport emissions, 5% of all carbon emissions across Europe, and they keep increasing[66]. The fleet is powered by ICE at 100%.

The first electric heavy trucks (>16 tons) hit the road in 2020 with 6 e-trucks registered across Europe[67] and total sales still limited to a few hundred units a year later[68]. In 2023, 42 models of e-trucks are offered in Europe in 2023, including 32 heavy-duty trucks[69]. Volvo dominates the market with 145 units sold and order book of 1,100 trucks worldwide. However, with most manufacturers still due to launch their first full-electric heavy-duty truck, the electrification of this category needs to catch up to the car market. Volvo aims for 50% of its truck deliveries to be electric by 2030.

E-retrofit solutions. E-retrofit solutions for heavy-duty trucks is an active segment in Europe, with its center of gravity in Germany, where at least three companies operate:

Pepper's MP5 (top) and Clean Logistics' Fyuriant (bottom)



- The German company Pepper Motion appears to lead the way. It started with individual conversions of the Mercedes-Benz Actros MP3 in 2021, and launched series conversion of the MP5 beginning in 2023, with plans to retrofit 2,500 units by 2030.
- In 2022 it partnered with REV Mobility to distribute its heavy trucks in France and launch smaller trucks.
- Two other German companies compete in this segment, the e-truck manufacturer Quantron, and the e-retrofit company E-Cap Mobility (boats, buses, machines, etc.) both offer individual conversions of ICE trucks to battery or fuel cell.
- E-Cap Mobility was acquired in 2021 by another German e-truck manufacturer and retrofitter called Clean Logistics. Its flagship product is the "Fyuriant" truck (prototype presented mid-2022) based on the conversion of the DAF XF 530 FT heavy truck. The company has currently a conversion capacity of 132 trucks per year. It plans to launch series production in 2023 and scale up its capacity to 1,700 trucks per year via partnerships.
- In France, CarWatt offers bespoke conversions, and Mona also plans for truck fleet retrofit.

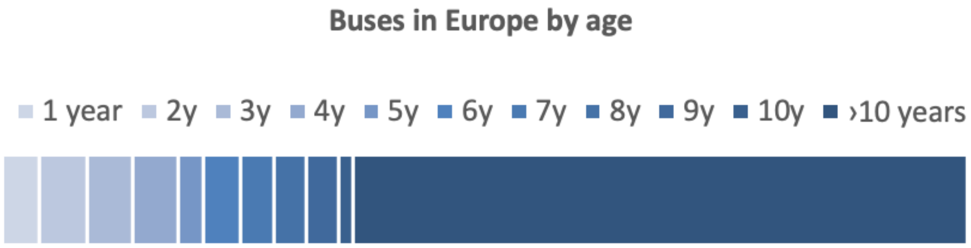
Price. For the series conversion of the Mercedes-Benz Atros MP5 truck, starting in 2023, Pepper Motion charges **270-290k€** for a 240 kWh battery delivering a 250 km range. In their 2020 study, Algoé assumed that economies of scale shortly would lead to a **190k€** conversion price for 300 kWh capacity for the average 16-19 tons retrofitted truck. In a 2022 analysis of Clean Logistics, First Berlin Equity Research estimates that the Fyuriant truck that currently costs about 520k€ to produce (series of 5) would be priced at 200-300k€ in 2027 and could be produced for 150,000€ if the production reaches 10,000 units[70].

Prospects. Retail prices for electric trucks are not public and evolve fast in the current context (inflation, changes in battery prices, semi-conductor shortage). In the US, Nikola seems to charge about $270,000 on orders for its semi-truck. A recent study[71] modelling heavy-duty truck retail prices and their evolution concluded that comparable zero carbon trucks are currently priced above 300 k€ (excluding VAT). However, the outlook for e-trucks suggests that the first-mover advantage of e-retrofit over e-trucks will fade away in the next few years, with drop in prices of up to 50% by 2030. Further analysis would be needed to analyze how e-retrofit can remain competitive in the mid-term.

Range. In terms of range, based on the current offer, e-retrofit competes with the average e-trucks available today in terms of range, but it needs to catch up with the best performers. In 2021, Mercedes-Benz started producing the e-Atros, featuring 315 to 600 kWh batteries and up to 500 km range for new models delivered in 2024. However, on the hydrogen segment, Clean Logistics' Fyuriant claims a 500km range, which is considered the minimum market requirement by analysts, the standard range of diesel trucks being about 1,000 km.

BUSES

Donor fleet. There were 780,000 buses and coaches on European roads in 2020, responsible for 4% of road transport carbon emissions. Buses are on average 12.8 years old. The Greek bus fleet is the oldest in the region, with an average age of 20 years. Only six countries in the European Union have a bus fleet that is younger than 10 years old. The fleet is 99% powered by fossil fuels, with only 8,500 e-buses delivered from 2012 to 2021[72].



Sources: ACEA, Eurostat (2020)

State of electrification. The picture for buses changes much faster than for heavy-duty trucks and cars. Zero-emissions vehicles (battery and fuel-cell) accounted for 22% of new urban buses registered in the EU in 2021, up from 15% in 2020 and 12% in 2019. The EU has set a target of at least 45 percent of newly registered city buses being equipped with alternative powertrains by the end of 2025 – and at least 65 percent by 2030. The current generation of battery-powered buses can be operated on about one-third of existing bus lines in urban areas[73].

The offer is booming with 45 models available in 2021 and more than 55 in 2022. A dozen manufacturers compete on the EV segment, and major players such as Daimler and MAN, with a target of 100% zero-emissions new urban buses by 2030. EVs are also available for coaches, but the dynamic is less pronounced and the market is way smaller. By 2025, more than 40 major European cities will only be buying zero-emission buses.

E-retrofit solutions. Expectedly, urban buses constitute one of the most dynamic categories for e-retrofit. The leader, Pepper Motion, currently plans to retrofit 8,000 buses by 2030. They compete with most truck retrofitters, including Quadron, Mona and Clean Logistics.

The economic case for buses seems much more positive than for other categories [74]. New e-buses cost between €500k and €700k, and there is almost no used vehicle for sale due to the high growth in demand for this category. In 2020, the analysis conducted by Algoé for the standard 12 m city bus in France concluded that e-retrofit was more affordable, with a cost of conversion around €225k excluding VAT. The calculation did not factor the residual value of the donor bus in the e-retrofit price tag, assuming the ability of a municipality to sell a used fleet of buses at market price is, in practice limited.

Another advantage is the delivery time: according to Pepper Motion, e-retrofit takes about 3-6 months to analyze the donor vehicle and needs, and then six weeks of conversion. It is to be compared with a delivery time of up to 18 months for new e-buses.

In terms of range, the comparison is slightly less favorable to e-retrofit, making it a low-cost low-range option: the maximum range communicated by the leading e-retrofitter (Pepper Motion) is 250 km, which corresponds to the median for new EVs but fall short of the best performances (>500 km) [75]. Clean Logistics' Pyuron bus features a range of 300km.

VOCATIONAL VEHICLES

Donor fleet. Vocational vehicles include concrete trucks (34%[76]), tankers (22%), garbage (15%) and dump trucks (13%), cranes (10%) firefighting vehicles, airport vehicles, agricultural vehicles, and a range of other applications. The cost and service life of these vehicles depend on the application: optimal lifespan are shown below, but like for other categories of vehicles, it can be stretched significantly in certain markets.

Type of vehicle	Service lifespan
Concrete truck	10 years
Waste truck	10 to 12 years
Heavy equipment (digging, loading, short distances)	8 to 10 years
Light dump truck	7 to 10 years
Agricultural equipment	7 to 22 years
Specialty equipment	6 to 15 years

State of electrification. The penetration of EVs largely varies from one segment to the next, but is generally low for high-emission segments: the first EVs for cement mixer trucks, waste trucks and construction vehicles have only been recently introduced (2019-2022), despite the clear use case for quieter trucks in urban areas.

E-retrofit solutions. The economic case for e-retrofit can be good for vehicles that are expensive due to technical equipment and adaptation (e.g. crane), and have a long expected service life. It is particularly strong when the engine is the part likely to break first. The potential for retrofit of these vehicles is, however limited by several factors:

- In several cases, the technical equipment could become obsolete or require replacement before the engine.
- The large number of subcategories necessitate engineering cost to adapt the e-retrofit kit and process to each of them, which reduces the economies of scale. On the other hand, some of these vehicles being off-road are less regulated than road vehicles.
- The electrification of these vehicles requires dedicated charging infrastructure.

Several e-retrofit companies compete in this category: CarWatt and Mona in France, E-Cap Mobility in Germany, EV Evolution in Croatia. In the UK, Lunaz Applied Technologies, known for vintage Rolls-Royce and Aston Martin conversions, plans to launch series retrofit for garbage trucks with batteries that can be swapped. The e-retrofitter did not disclose the price yet, but it claims it will be cheaper than an all-electric equivalent. They plan to produce 1,000 vehicles per year from 2023 onwards.

5. DRIVERS OF ADOPTION

5.1. ZERO AND LOW EMISSION ZONES

ZERO EMISSION ZONES

Zero Emission Zones (LEZ) are urban zones where ICE vehicles are not allowed on the roads. The area covered by a ZEZ can range from one street to an entire city or metropolitan area. To date, only Near-Zero Emissions zones (allowing plug-in-hybrids) and ZEZ for freight (vans, trucks) have been implemented[77].

Place	Type	Implementation	Vehicles affected	Area
Rotterdam (NL)	ZEZ-Freight	Jan 2015	Trucks > 3.5 tons	1.6 km street
Amsterdam (NL)	ZEZ	2025	Buses, coaches, taxis	Inner city
		2030	All	Citywide
Eindhoven (NL)	ZEZ	2025	Trucks, buses, vans	Inner city
		2030	All	
30-40 cities (NL)	ZEZ-Freight	2030	Delivery vans & trucks	City centers
Copenhagen (DK)	ZEZ (pilot)	2023	Passenger cars	Historical city center
	ZEZ-Freight	2025	Delivery vans & trucks	
City of London (UK)	Near-ZEZ	Sept 2018	All	360m street
Two London boroughs (UK)	Near-ZEZ	March 2020 to Sept 2021	All	9 streets
Paris (FR)	ZEZ	2030	All	Metro area

However, four European cities have announced the implementation of ZEZs from 2023 to 2030. The most ambitious plan, in Paris metropole, will affect a local fleet of more than 2 million vehicles and about 6 million trips each day.

In 2021, 350 cities submitted their plans to become "climate-neutral" by 2030 to the EU to receive subsidies, and 100 of them have been selected. According to the Clean Cities campaign, only 10% of these cities plan to introduce a ZEZ.

CONVERSION OF LOW EMISSION ZONES

Some cities start with pilots and aim to make them permanent, while others (e.g. in the Netherlands, France) plan to tighten the criteria of an existing LEZ (Low Emission Zone). An analysis of the existing and planned LEZs can therefore provide a proxy for the future ZEZs. LEZ ban polluting vehicles or charge a fee to enter. The criteria for entering these areas are usually based on the vehicles' age and technical specifications (generally an exclusion of old ICE vehicles (2006 for diesel, and before 2000 for gas). Like ZEZs, LEZ requirements may be applicable to heavy vehicles, light-duty vehicles, or both. The number of LEZ in Europe is expected to double from 2019 to 2025 exceeding 500. Several member states have integrated LEZs into their climate regulations and plans (France, Spain, the Netherlands, Poland). France, which has 11 LEZs today plans to extend it to all mid-size cities by 2025, covering 43 cities.

The potential for growth remains significant. There are about 800 urban areas in Europe, including 100 large cities. 3/4 of Europeans live in these urban areas and half of them in the commuting zones[78]. According to the

Clean Cities campaign research[79], 2/3 of the 100 above-mentioned 100 "climate-neutral" Europeans cities them do not yet plan an LEZ. Besides, ZEZs and LEZs tend to be implemented in countries with relatively young fleets, and are almost absent from Eastern Europe where most old ICE vehicles are.

The development of ZEZs, near-ZEZs and LEZs can become a significant driver of adoption EV in gener al and e-retrofit, especially in sub-urban areas where a vehicle might remain more convenient for commuting.

Municipalities that showed interest in supporting e-retrofit programs usually see it as a complementary measure to the implementation of an LEZ/ZEZ, to ensure continuation of access to mobility for low-income households and small delivery businesses.

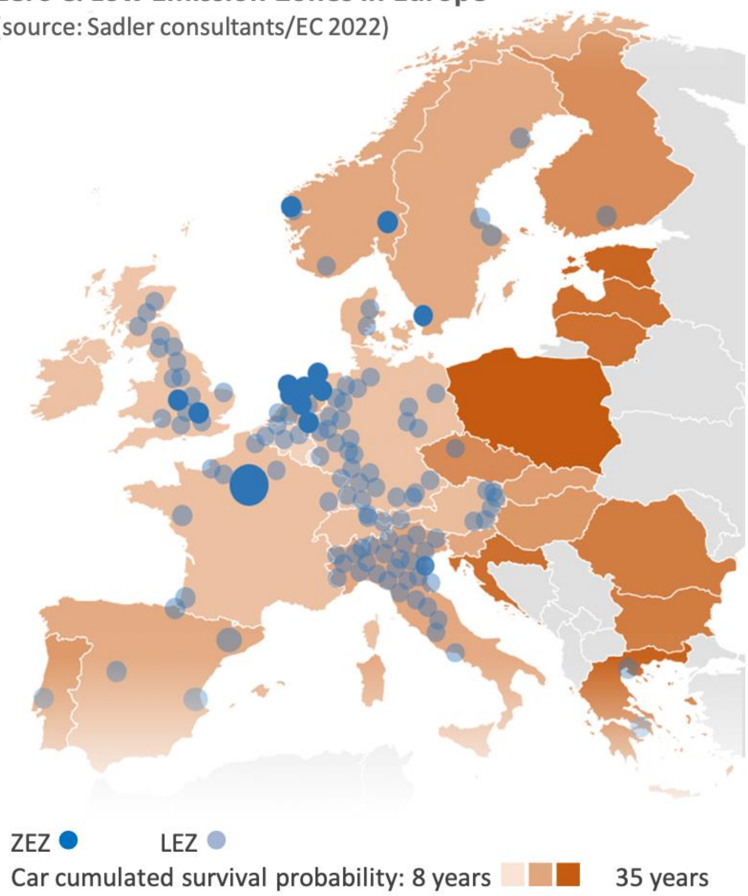
5.2. SUBSIDIES

The tax schemes applied to passenger and commercial vehicles in most European countries provide several paths to incentivize e-retrofit, that are likely to be activated if the technology is demonstrated at scale.

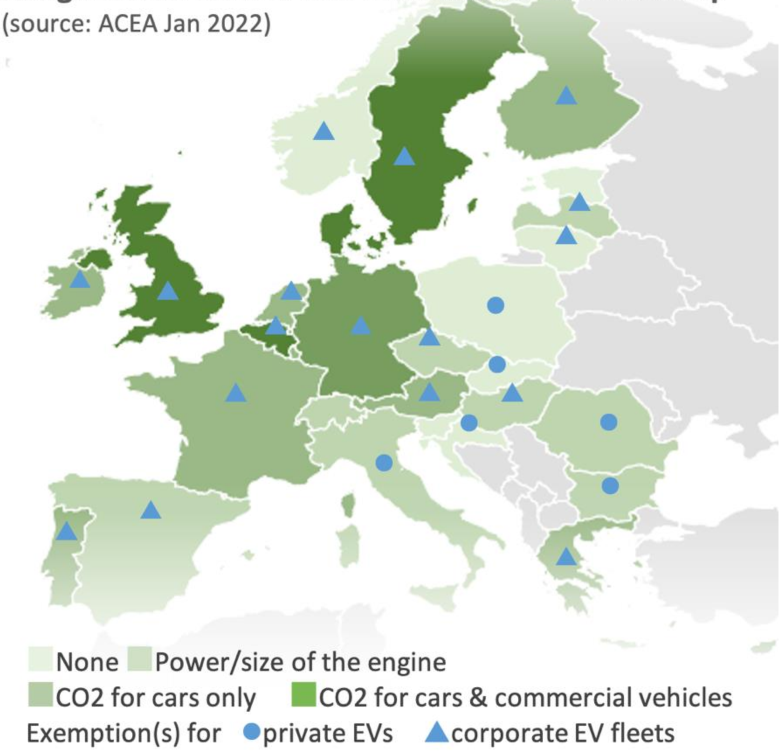
Taxes on acquisition, ownership , and fuels. Most European countries integrate the carbon emission intensity as a criterion in the calculation of the tax burden on drivers: different rates are applied to VAT and taxes on ownership (see map). Fossil fuels are also taxed. In many cases, ownership taxes are also reduced for old and low-power passenger vehicles. These schemes naturally favor e-retrofit and can be strengthen in the future, when phasing out ICE vehicles from the roads will become a policy objective.

Scrapping scheme. Scrapping schemes that incentivize the disposal of an old ICE vehicle and the purchase of new low emission vehicle instead have been introduced or expended in Europe to counter the impact of the 2008 financial crisis on vehicles sales.

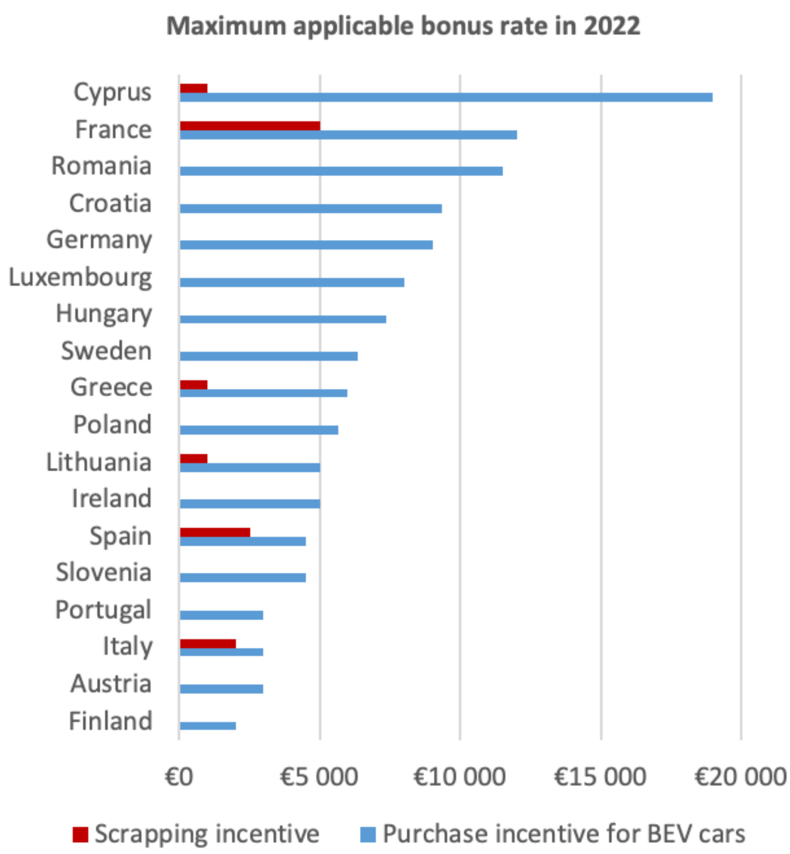
Zero & Low Emission Zones in Europe
(source: Sadler consultants/EC 2022)



Integration of carbon into tax schemes on ownership
(source: ACEA Jan 2022)



Research shows that they have proven effective[80], with a 30% impact on sales and a -3.6% impact on fuel consumption. A few European country still have these schemes in place, usually combined with the purchase of an EV for cars and vans.



Tax exemptions and subsidies for EVs. On top of the above-mentioned low carbon tax rate on acquisition and ownership that favor zero-emission vehicles, certain country provides specific tax exemptions and/or purchase incentives for electric vehicles (see map above and chart below) [81]. They usually apply to both individual and corporate owners. For individuals, the bonus rate is sometimes conditional, the best rate applies to affordable cars, and for certain countries also takes into account the household's taxable income. Certain countries also give significant subsidies for purchasing e-buses and e-trucks, up to 190,000€ in Spain.

As price parity between ICE vehicles and EVs is approaching eligibility criteria for incentives are becoming stricter (e.g. capped based on the vehicle price and household taxable incomes, exclusion of plug-in hybrids, etc.) and are reduced. In several countries, such as Germany, these incentives have a sunset date between 2022 and 2025. However, as discussed page 25, the challenges associated with access to mobility for low-income households might lead to focusing the subsidies on this group and affordable EVs, and even increasing the absolute amount for them. This is the direction of travel observed in France after the Yellow Vests crisis.

Abatement cost. Based on our carbon footprint scenario analysis for small cars (page 41), we have concluded that the French and German authorities currently pay up to **537€ per ton of CO_2** avoided through tax incentives on EVs purchase and scrapping schemes. It corresponds to the high estimate of the external cost related to climate change and air pollution avoided thanks to EVs.

It is to be noted that these tax incentives are associated with a range of other public policy goals such as supporting the domestic automotive industry, improving access to mobility for low-income households, improving road safety, reducing noise, etc. which are not factored in this calculation.

Taxes on fuels. As of January 1st, 2022, national taxes per 1,000 liters of fuel ranges from a minimum of 359€ for gasoline and 330€ for diesel (usually applied in Eastern Europe) to 824€ for gasoline (Netherlands) and 617€ for diesel (Italy). These taxes can be used to phase-out ICE from European roads after 2035.

A comparison with the social cost of carbon and the carbon price recommended to achieve the 1.5°C target suggest that much higher tax rates would be justified. Although such tax levels would be unrealistic today due to their economic impact on companies and households, they could be envisioned in an ICE phase out scenario (post 2030), including massive subsidies to transition to zero carbon mobility.

Incentives for e-retrofit. The introduction of a regulatory framework for e-retrofit at national level usually comes with the introduction of tax incentives, by adapting existing schemes. If e-retrofit prove to be a viable solution, a possible scenario would be a gradual shift of remaining subsidies from old car scrapping and EV purchase to e-retrofit.

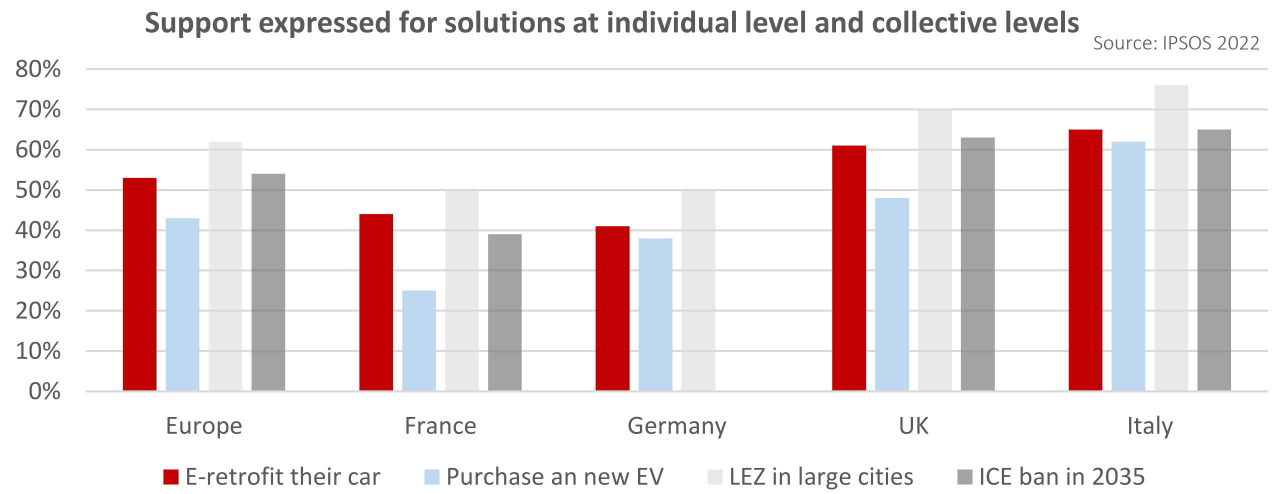
France provides a template for such a scheme: an individual who retrofits an old ICE vehicle could benefit from a specific incentive which is equivalent to the bonus for purchasing an EV plus the bonus for scrapping an old car. An additional bonus is also provided by local authorities for low-income drivers how live or work in a future ZEZ, such as Paris[82], the cumulated subsidy could reach up to 12,000€.

Factoring additional carbon savings associated with e-retrofit at the abatement cost of 537€/t of CO^2 applied today in France and Germany, our calculation suggests that e-retrofitted vehicles would be entitled to a **1,500€ premium in France and 2,700 € premium** in Germany compared to EVs.

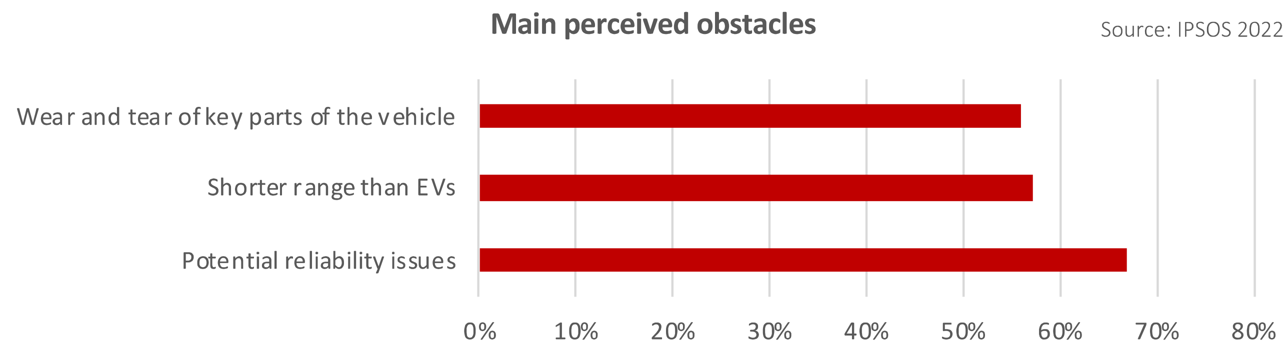
5.3. CONSUMER INTEREST

As far as passenger cars are concerned, consumer interest in e-retrofit will obviously be an important factor. The history of EV adoption shows that early adopters driven by environmental values and technology enthusiasm long before EVs reach cost parity with ICE have played a critical role in triggering a mass market.

European survey. In 2022, Ipsos conducted a survey on a panel of European consumers regarding the perception of various sustainable mobility solutions, including e-retrofit[83]. E-retrofit appear to be preferred to purchasing a new EV in every country.

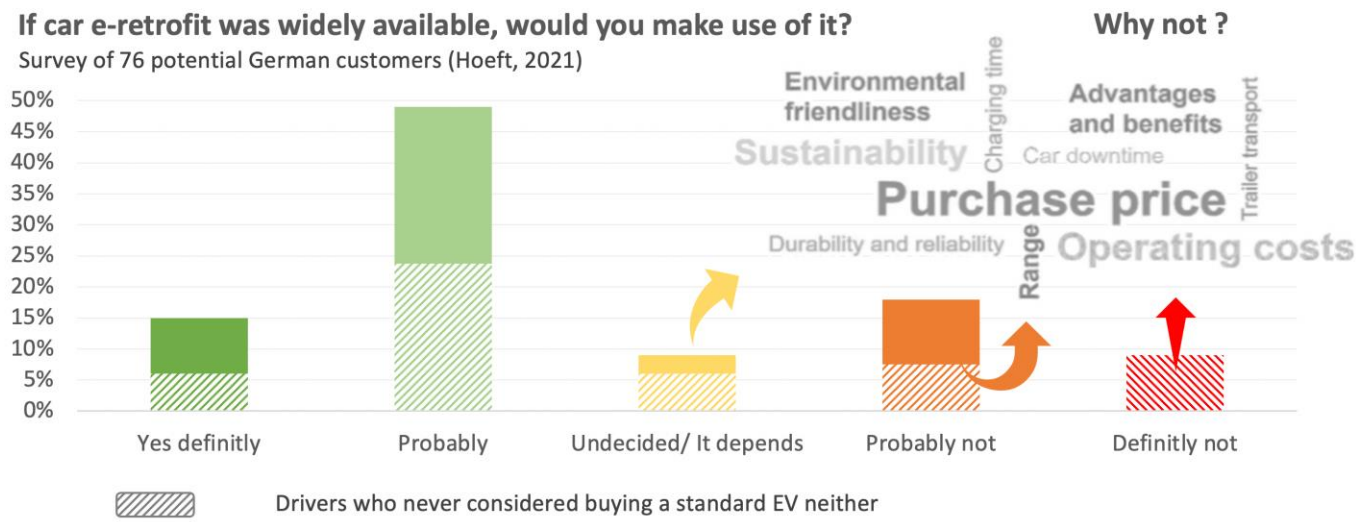


However, consumers also appear to be aware of the potential shortcomings, even though the absence of the cost of e-retrofit is suspicious.



German study. A more detailed survey on the topic, conducted in Germany on 76 potential customers reveals that 2/3 of participants would buy or would consider buying an e-retrofit solution if it was widely available[84]. Typical interested customers are suburban, mid-aged (35-44), drive 50 to 250 km per day on average, and have already considered purchasing an EV. The main motivations include the usual benefits associated with EVs (noise, environmental, acceleration, operating cost), with an emphasis on environmental benefits and regulatory perks such as the access to Zero-Emission Zones, EV parking spots and reserved lanes. Consumer also value the potential associated upgrades such as on-board electronics. Only a small minority of respondents (<10%) expressed concerns about safety or wear and tear of the donor car, but the (rightly) perceived high purchase price appears to be a major obstacle to adoption.

It is impossible to draw definitive conclusions from such a limited panel, based on a hypothetical case. However, the positive results suggest that the existence of a group of consumers willing to pay a premium to become early adopters of most eco-friendly solution cannot be discarded.



5.4. EUROPEAN CARBON REDUCTION STRATEGY

Bridging the climate target gap. As discussed, page 23, in order to meet the objectives of the Paris agreement, the EU will have to phase out its legacy ICE car fleet by 2045, which require acting from 2030 onwards.

Potential measures could include accelerating retirement/scrapping but also introducing large-scale retrofit programs, if the technology has been demonstrated by then and is competitive.

Several upcoming regulations and trends could support such an evolution :

- *Carbon disclosure requirements.* The EU is introducing new carbon disclosure requirements (CSRD regulation) from 2026 onwards for listed and private companies. The requirements are applicable to most vehicle manufacturers selling in the EU. They cover “scope 3 emissions” which include the use-phase of vehicles, and mandate the publication of transition plans and targets to reach carbon neutrality by 2050. These requirements also apply to many corporate fleet owners, as well as fleet managers. They would pave the way for potential regulatory constraints and incentives on vehicles already in use.

- ***Vehicle whereabouts tracking***. In parallel, most new cars sold today send real-time information to the manufacturer[85], enabling enhanced monitoring of real-world emissions, and tracking of the vehicle's whereabouts (see page 30). Such a trend will enable the introduction of public and corporate policies focused on vehicles-in-use impact and end-of-life.

Municipal and corporate fleets. As discussed, page 55, municipal and corporate fleets could become good candidates for e-retrofit programs. Municipalities will have a strong incentive to convert their fleet in the context of their climate-neutral strategies and the implementation of ZEZs.

Corporate fleets are also likely to face an increasing pressure to decarbonize. The analysis by the Platform for Electro-Mobility concludes that the current regulatory framework is insufficient to incentivize corporate fleet owners and recommends setting a gradual approach to reach 100% EV in new vehicle purchase in corporate fleets by 2030. The recommendation is modelled after the 2019 French LOM law that ramps up obligations from 10% in 2022 to 70% in 2030, impacting 1000 companies and 0.9 million cars purchased each year[86]. Besides the analysis of top EU fleet managers, suggest that their majority shareholders are all committed to reach net zero by 2050.

Company	Vehicles in Europe (2016)	Shareholders	Net zero target
ALD Automotive	1 250 000	Société Générale (French bank)	Yes
Lease Plan	1 120 000	Consortium of pension funds	Yes
Arval	1 000 000	BNP Paribas (French bank)	Yes
Alphabet	585 000	BMW Group	Yes
Athlon	340 000	Daimler Group	Yes

Closing the export loophole. Based on past trends and current policies, we estimate that about 45 million fossil cars will be exported by the EU over the period 2030-2050. If left addressed, a major unintended consequence of the 2035 ICE ban and the introduction of ZEZs could be to significantly increase this flow of pollutant old vehicles exported to under-regulated countries in the Balkans, Eastern Europe, Central Asia and Africa (see page 24).

The loophole can be closed at two levels:

- Some countries regulate the import of used vehicles, measures including complete ban, technology ban (usually diesel), age limit (3 to 15 years), emission standard, emission-based or age-based custom and registration tariffs, labelling, minimum safety standards. Age limits being easy to implement they are quite popular with 66 countries that enforce them. An extension of these regulations to target countries for EU exports, potentially supported by foreign aid, would address the problem.
- The restriction can also be imposed by European regulation. The recent decision of the EU to introduce a Carbon Border Adjustment Mechanism (CBAM) puts a spotlight on carbon leakage, and is likely to eventually lead to a debate on EU old ICE vehicles exports.

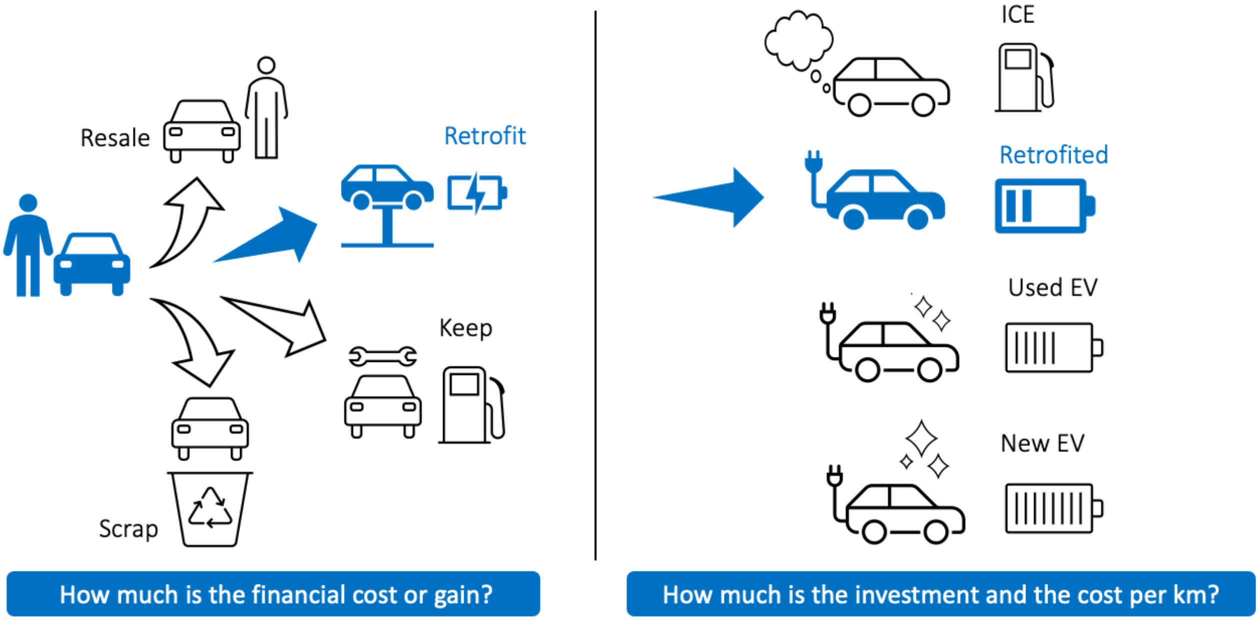
Given the usual policy-making time frame, the related policy debate would likely start between 2025 and 2030 if e-retrofit has proven to be a potential credible solution by then.

6. THE ECONOMIC EQUATION OF E-RETROFIT

6.1. DECISION-MAKING CRITERIA

The decision to retrofit a vehicle takes place at two levels:

- First an owner who consider changing their vehicle needs to prioritize e-retrofit over reselling[87], keeping or scrapping the vehicle. This decision is influenced by the tax incentives on scrapping and e-retrofitting, as well as the barriers to keeping or reselling, such as fuel taxes and vehicle inspection requirements.
- Another (or the same) owner, should then decide whether to invest in a retrofitted vehicle rather than in a used ICE, new EV or used EV. The choice of e-retrofit will be influenced by the expectations in terms of performance and comfort, as well as the availability and price of alternatives.



Source: Electrify®

In this chapter we compare the e-retrofit option to keeping the ICE car, switching to a used EV or purchasing a new EV. For certain niche categories such as collectible vehicles, the return on investment is not a core concern and the residual value of the glider can dwarf the retrofitting cost. Similarly, certain commercial and vocational vehicles are equipped with expensive owner-specific features, increasing the cost of replacing them. But for most vehicles, the owner expect savings in operating costs over the remaining life to exceed the cost of the conversion. This equation governs the decision to either convert the car or to favor other options (keep operating the donor vehicle, reselling it*, scrapping it).

E-RETROFIT ECONOMIC EQUATION

Resale value* (donor vehicle) **+** kWh of battery **+** Conversion Cost **-** Public Subsidies

=

Annual Savings **X** Expected Lifespan **+** Residual value (retrofitted vehicle)

* Whether customers retrofit their own car or purchase a car that has already been retrofitted, the residual value must be taken into account: in the first case, they give up on reselling their vehicle, and in the second case, they pay for the acquisition of the vehicle by the retrofitter.

6.2. COMPETITION WITH ICE VEHICLES

Does e-retrofit save money when compared to keep using the ICE vehicle?

In the current regulatory environment, the owner of an old ICE vehicle has the option to extend its lifetime and keep using it for a certain period, or replace it with a new or used ICE vehicle. For most use cases, the decision to retrofit the vehicle instead will ultimately depend on the total cost of ownership and how the potential savings on fuel and taxes are expected to provide a return on investment.

EXISTING TOTAL COST OF OWNERSHIP STUDIES

The 2021 ADEME/Algoé study for France suggests that e-retrofit is not a profitable investment today, for either category of vehicle. The calculation is based on 2020 prices in France for e-retrofit, fuel, batteries, electricity, taxes and subsidies, and a remaining 10-year lifespan (assumptions discussed in the annex).

Keep the ICE vehicle	E-retrofit the vehicle
Small diesel car	+75% (€/km)
Utility van	+ 67% (€/km)
16-19t heavy Duty Truck	+ 6% (€/km)
12m bus	+ 7% (€/km)

Source: Algoé 2020

An analysis conducted by the e-retrofitter Pepper Motion suggests that their repowered bus saves €144,000 compared to purchasing a new diesel bus, but it does not make this claim for repowered trucks and does not compare e-retrofit with keeping the old ICE bus.

A 2022 note from First Berlin Equity Research[88] comparing the TOC of a heavy truck retrofitted with a fuel-cell with a diesel truck concluded that the owner would save on maintenance and carbon taxes, but that the cost of hydrogen remains too expensive to reach parity with a diesel truck. They expect this situation to eventually change though.

Based on these conclusions, there seem to be a limited economic case for e-retrofit today: the decision to retrofit a standard vehicle must be driven by other factors such as constraints related to Zero Emission Zones and upcoming tailpipe emissions regulations, social status for individuals, or environmental targets for corporate and municipal owners.

OUTLOOK

This conclusion is however likely to evolve overtime: thanks to decreasing battery prices and economies of scale, EVs are expected to become cost competitive with ICE vehicles (Total Cost of Ownership) between 2025 and 2030 for cars, 2030 for medium-duty trucks and 2035 for heavy-duty trucks.

For the purpose of this study, we assume that biofuels and synthetic fuels will not emerge as a cost effective and/or environmentally effective solution for passenger cars by 2050. This question is discussed in the siter report from T&E (Clean solutions for all - How to clean up the entire car fleet in Europe, June 2023).

Moving foreward, the challenge for e-retrofit will therefore be to reach price parity with used EVs to become the affordable electric car solution.

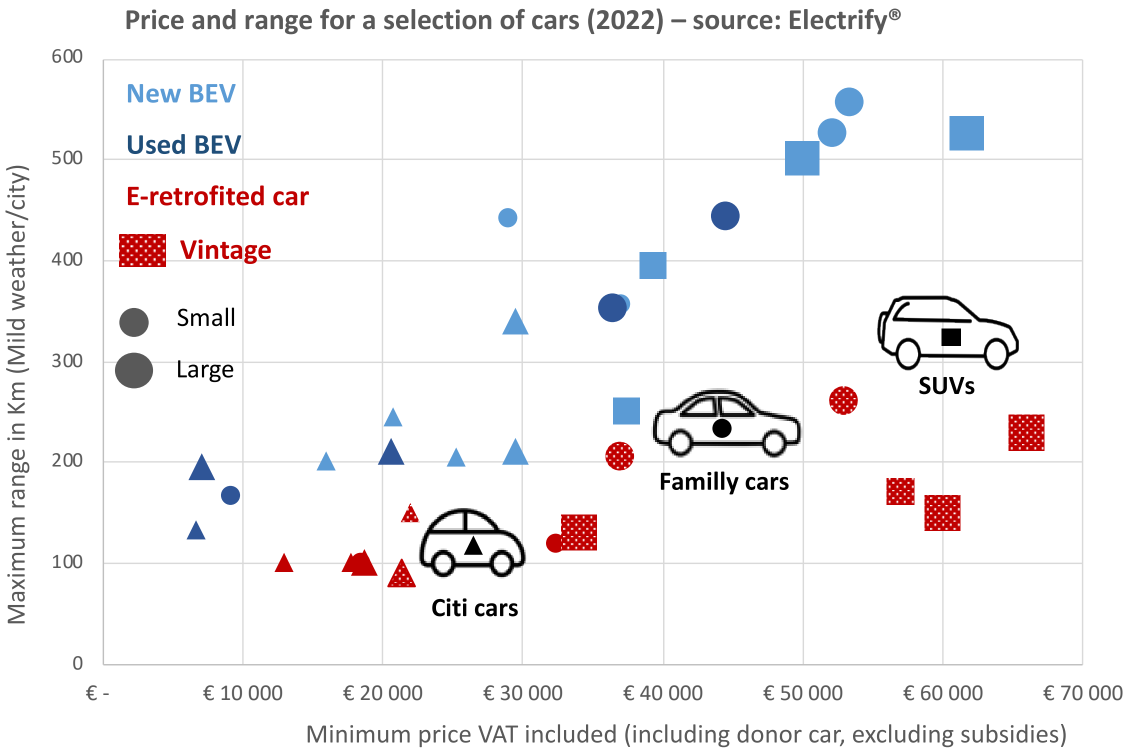
6.3. COMPETITION WITH ELECTRIC VEHICLES TODAY

The competition from ICE vehicles will eventually be reduced by regulatory pressure and cheaper batteries. However, the competition with new and used EVs is likely to rise, driven by the availability of new electric models across categories and segments, and the growth of the used EV market. Given their inherent limitations, e-retrofitted vehicles will have to be cheaper than EVs to create mass market appeal.

The analysis conducted in 2020 by Algoé for a selection of vehicles across categories concluded that e-retrofit was a competitive solution for buses, uncertain for heavy trucks, and was unable to compete with new and used EVs for passenger cars and vans. We updated the calculations in 2022 for passenger cars and vans, while factoring new affordable EVs and more used EVs, which led to similar conclusions.

PASSENGER CARS

Overall, as illustrated in the chart below, e-retrofit face an uphill battle to reach owners who value range-for-money: purchasing a new or a used EV is likely to deliver a better return on investment and a longer range per euro, in each segment. Even in absolute terms, used or new EV are cheaper than retrofitted cars today[89]. For the e-retrofit to take-off beyond vintage cars, wheelchair vans, and the enthousiast eco-friendly adopters circle, the economic equation will therefore need to improve significantly (see discussion page 70).

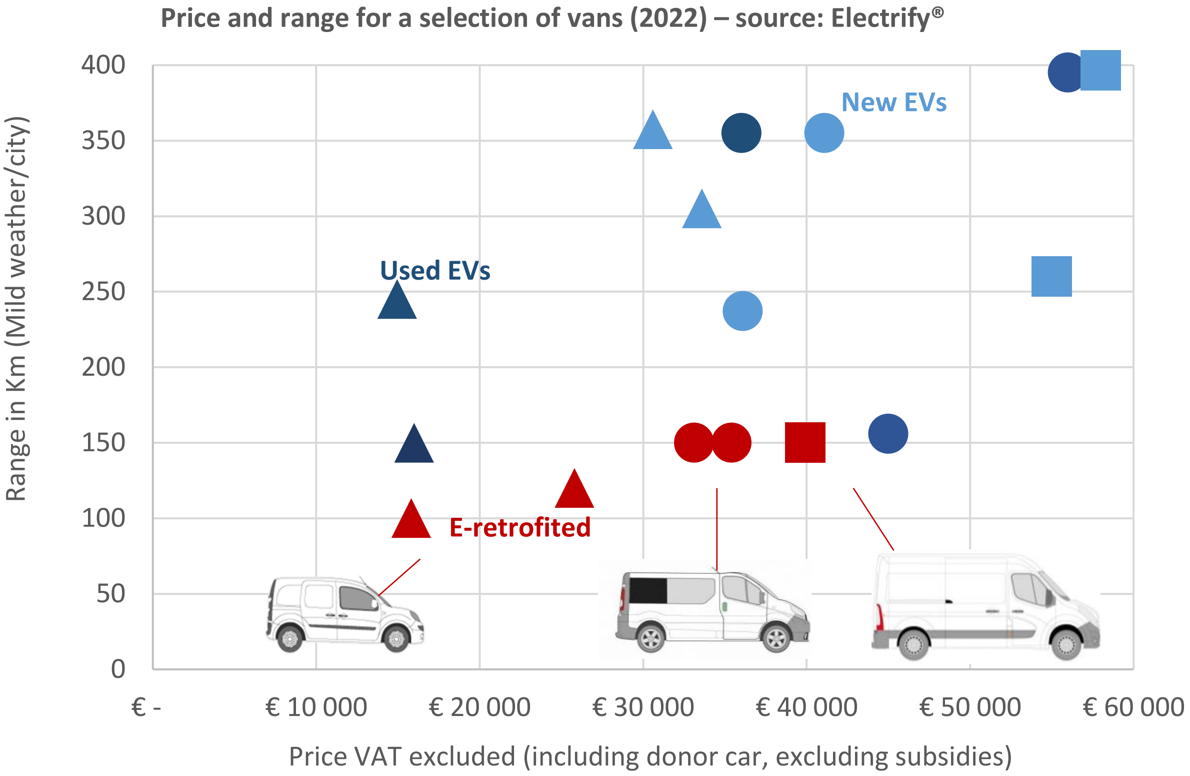


UTILITY VANS

Price comparison. As illustrated below, the situation is slightly better for utility vans but not completely favorable either:

- Competition from new electric vans has sharply increased in 2022, since the number of new EV models commercialized increased by more than 50%.
- The average range is increasing, and e-retrofitted vans are lagging, currently in the lower band or below.

- For the segment of large vans (Renault Master), e-retrofit remains the cheapest option for drivers who are willing to accept a trade-off on the range, but it is not the case anymore for other segments based on market prices. This conclusion comes with a caveat though: in practice, few used electric vans are available for sale, so depending on the exact needs of the driver, e-retrofitted vans might still be the cheapest option in other segments as well.



The case of customized vans. On the bright side, for many use cases, the economics of the decision is not captured in the chart above: many utility vans are customized with expensive (€5,000 to 20,000 or more) technical equipment that cannot easily be transferred to a new vehicle (see discussion of the related use case above). Besides, municipal, and corporate clients might be interested in retrofitting a part of their ICE fleet to achieve their environmental goals or improve their reputation, even if the economic case is not favorable. As a result, this segment appears to be one of the most dynamic after vintage cars.

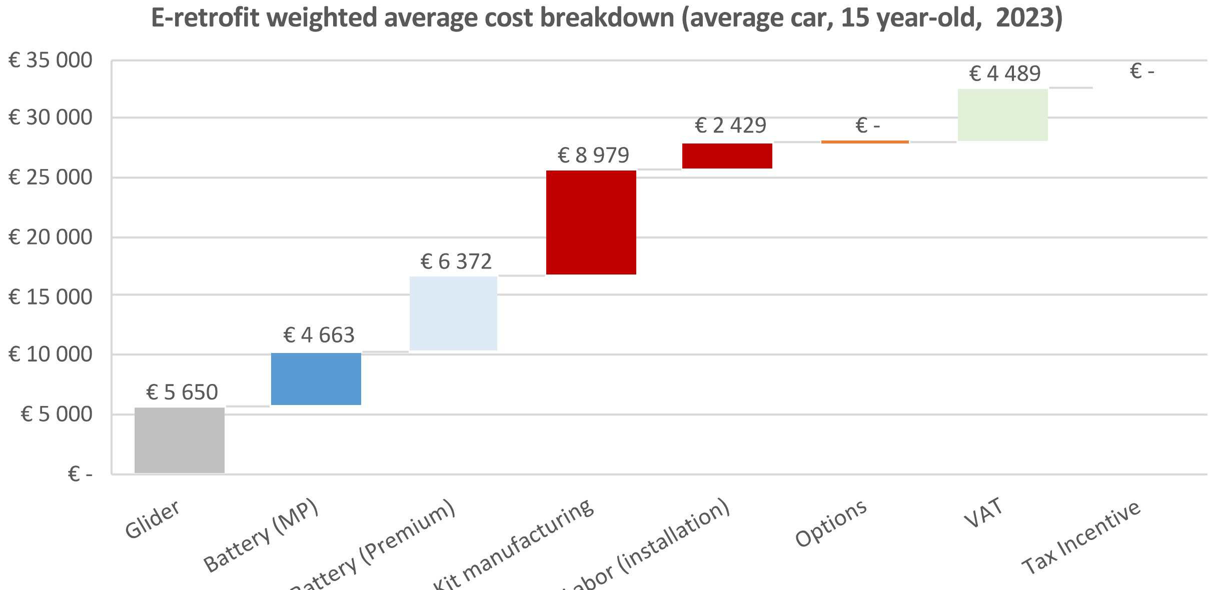
NB : the price and range analysis for other categories of vehicles is discussed in Chapter 4.6.

6.4. COST STRUCTURE AND OUTLOOK FOR CARS

This section discusses the current cost structure of e-retrofit and the outlook for 2023-2050. We outline different cost reduction scenarios that are then used as a basis to outline possible deployment scenarios (Chapter 8). Overall, the current e-retrofit market suffers from a lack of economies of scale. Potential volume growth can drive the cost down, all other things being equal.

TYPICAL COST STRUCTURE FOR A SMALL CAR

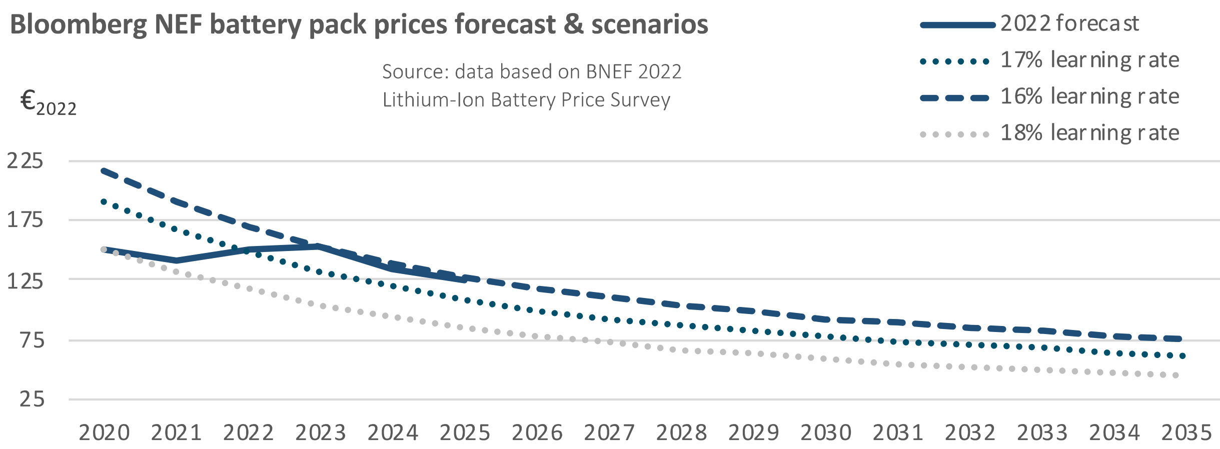
The typical cost structure of retrofitting includes the amortization of fixed costs related to R&D and regulatory approval, the retrofit kit and battery pack production, conversion labor, and marketing expenditures. The total cost should also factor in the resale value of the donor car and potential tax incentives for scrapping and EV purchase. The chart below presents a standardized version of the cost structure of low-cost e-retrofit for a small car equipped with a 20-kWh battery. We assume a retail price of 20,000€ (VAT included) for the e-retrofit operation (Kit and installation), in addition to the resale value of the donor car. Based on the levels of subsidies in France, an individual can expect up to €7,000 deducted.



Source: Annex/Chap3.2. Electrify®

BATTERY PACK

Market prices. Donor vehicle excluded, the battery pack is by far the biggest cost item in an e-conversion, representing between 30% and 50% of the total cost, depending on the capacity. The market price of batteries is expected to drop sharply in the next decade, increasing the competitiveness of e-retrofit relative to ICE vehicles. However, this trend is also expected to increase the gap between retrofitted vehicles and recent EVs in terms of range, the later also benefiting from lower market prices.

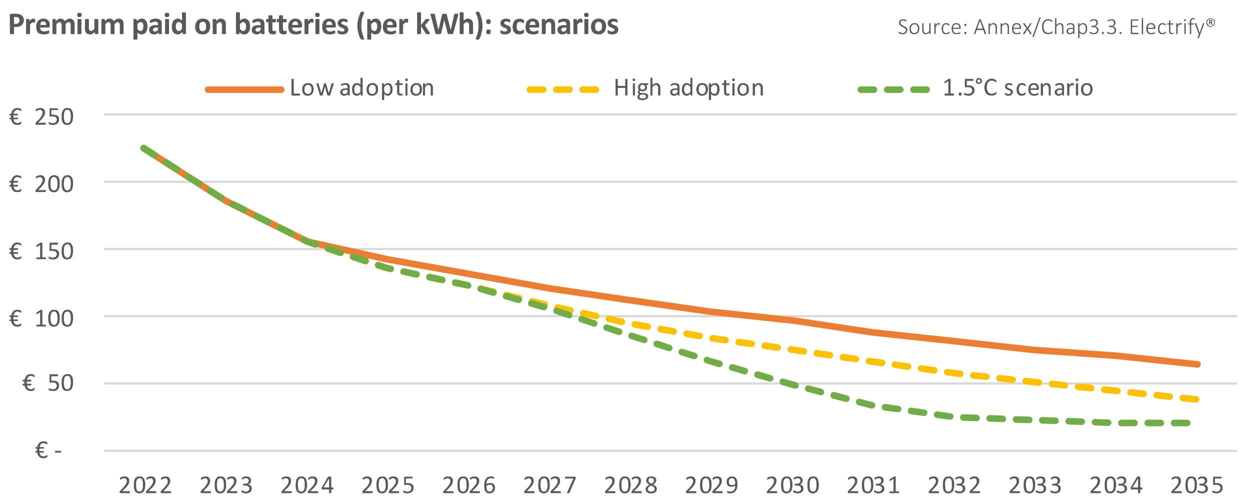


Additional cost. Today, most e-retrofitters have developed custom battery packs for each model and pay a significant premium per kWh compared to wholesale market prices. Based on interviews with e-retrofitters, we estimate that they are currently charged retail prices or above, which is more than twice the average market price for OEMs. Letting the donor car price aside, this premium is the single biggest hurdle to reaching price parity with affordable new EVs.

Moving forward, the premium is expected to shrink but remain significant due to three factors:

- **Economies of scale**. Higher volumes are expected to drive the premium down significantly. Before reaching high volumes, retrofitters can adapt standard battery packs already produced in large volumes for new EVs and partner with OEMs to benefit from their purchasing power or battery manufacturers directly. In such a scenario, e-retrofit companies are meant to depend on OEMs or new EV manufacturing companies. Examples of such partnerships include TOLV with Renault and Charge Cars with Arrival.
- **Used batteries**. Research shows that Lithium-Ion batteries keep 95% of their capacity after a few years. Therefore, another avenue to cut battery costs (by 20% or more) is to reuse battery cells from accidented EVs with low mileage. This is common practice in unregulated markets for both e-retrofitters and conversion kit dealers. Based on French regulation, this practice is not authorized in series retrofit, since each vehicle's specificities need to be identical.
- **Safety "case"**. Even if the premium is reduced, batteries for e-retrofit will remain more expensive than the same batteries for new EVs: for safety reason (in France, where a dedicated regulation on series retrofit apply), they must be protected from fire and impact with a dedicated case, while the body of a new EV fulfils this protection role.

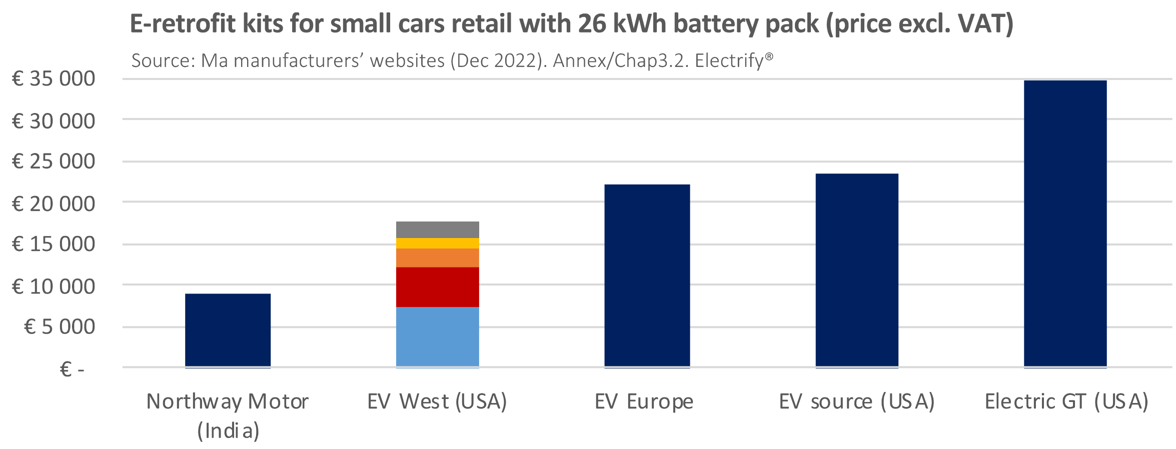
Based on the volumes envisioned in each deployment scenario (see Chapter 8), we have estimated three potential trajectories for this premium, assuming no technological breakthrough:



RETROFIT UNIT MANUFACTURING

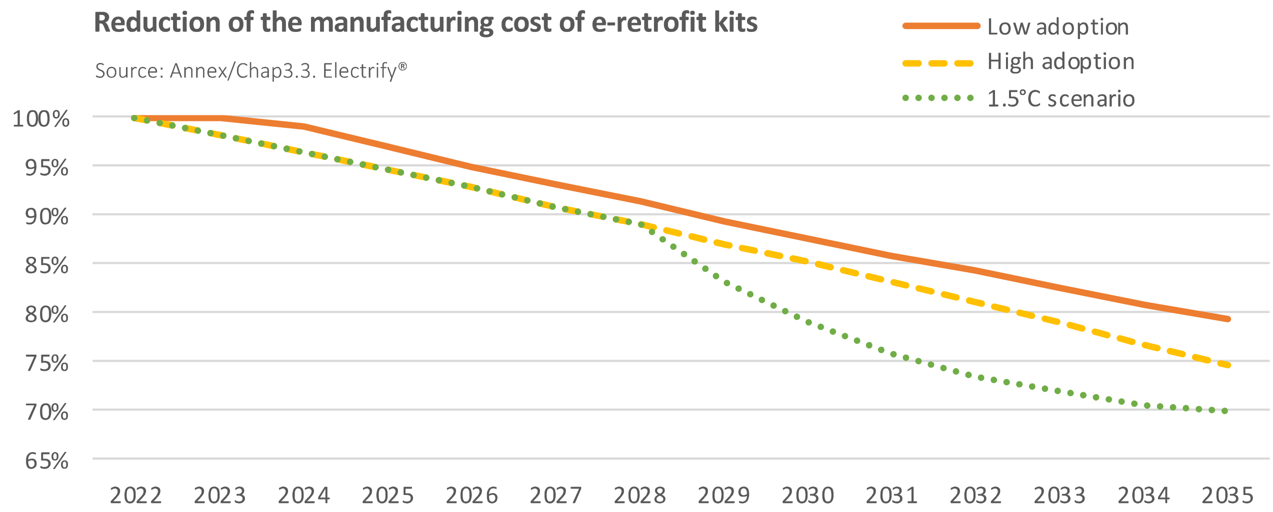
Current cost for e-retrofitters. The second biggest lever of cost optimization for e-retrofit companies is the cost of manufacturing the unit or "kit". In its 2021 study of French companies, Algoé estimated the average manufacturing cost of a kit for a small car at €6,000-€10,000 (excluding batteries), depending on the volume produced. The new analysis led to similar conclusions and is also consistent with the retail prices observed.

Retail prices. The chart below shows examples of retail prices (excluding VAT) in different markets for full e-retrofit kits, including the battery pack. These kits are 'generic' and can be used for different models of cars. Without the battery pack, retail prices for small cars kits start from €2,600 in China, €4,000 in India, and €8,200 in the US, and can reach more than €25,000 for more fancy kits.



Industrial scale manufacturing. We expect leading e-retrofit companies to reach industrial scale manufacturing directly or through partnerships with established industrial players. A potential driver of cost reduction is the mass production of "e-axles": the equivalent of a e-retrofit kit to produce a new EV based on an old platform designed for ICE vehicles. Half a dozen of manufacturers (including Bosch, Continental, GKN, Nidec) have started Industrial scale production between 2017 and 2019[90] and sell e-axles to OEMs. In India, Bosch as developed prototypes of retrofitted cars using their system.

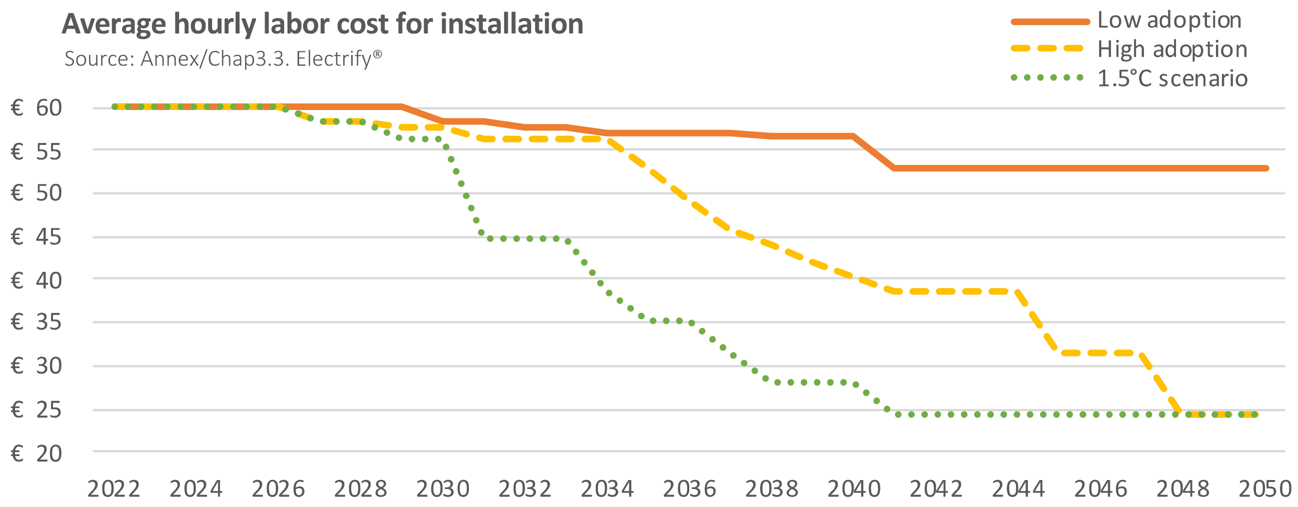
Outlook. The ability of e-retrofit companies to reduce the cost of the kit will largely determine their capacity to compete with new and used EVs. Based on retail prices observed and industry trends, we assume in our model that the manufacturing cost can be reduced by at least 25% and up to 30% if very high volumes are produced. The assumed speed of reduction depends on the volumes produced in each scenario.



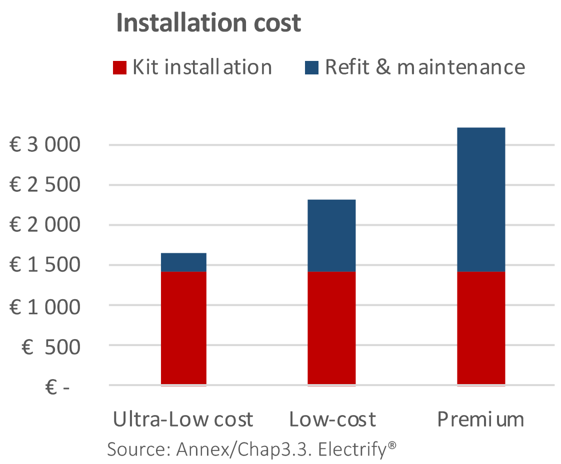
INSTALLATION

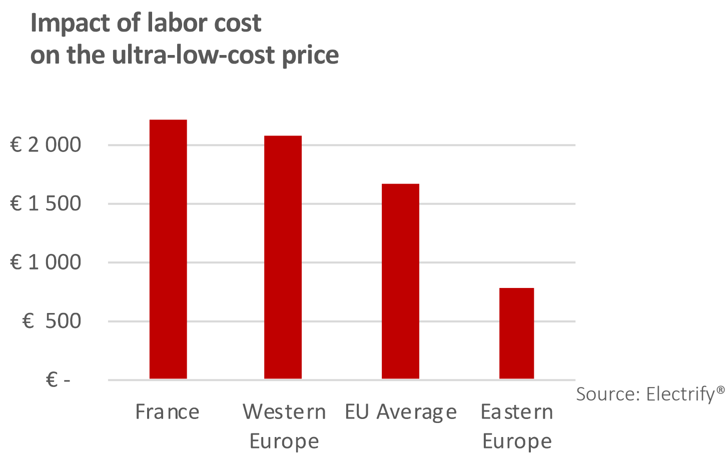
Time. The time required for series e-retrofit is mostly based on assumptions since no company has reached a significant volume of production to date. In their 2021 study for France, Algoé estimated that the installation of a kit for a small car will take between 25 and 50 hours, while some e-retrofit claim that the operation will eventually only take 5 hours when the process will be fully standardized. For the model, we used as a baseline 37 hours for a small car and 42 hours for a large one.

Labor cost. For series retrofit, most players plan to delegate the installation to a network of installers, primarily existing repair shops that will be trained and equipped to perform the operation. The labor cost is therefore likely to be equivalent to the hourly fees for car repairs. In the model, we assume that the market takes off in France, where the cost of labor is among the highest in Europe and then the activity expends in Europe. The labor cost is therefore reduced, notably when cars are retrofitted in Eastern Europe to serve the domestic affordable used car market. When high volumes are reached, we also assume that a significant share of cars will be bought on the use car market, transported, and then retrofitted in factories rather than repair shops, thus further reducing the time and cost of labor. Our labor cost scenarios assume no technological breakthrough.



Maintenance and refit. As discussed on page 37, e-retrofitting a car will create an opportunity for basic repairs and refit. For many conversions, notably for car fleets, basic maintenance (changing tires and suspensions) and a basic refurbishment of the interior might be necessary. Some e-retrofitters, such as Lormauto plan to include it in their basic offer. In our model, we include a 300€ package for ultra-low cost retrofit, and plan 40% to 95% additional labor cost for refit and maintenance in low-cost and premium conversions.





OTHER COSTS

Marketing and sales. Marketing and sales typically represent 8% of the retail price for cars. The cost for e-retrofit is likely to be much higher at the early stages of the industry since e-retrofit companies not only need to compete with each other but also sell the basic concept to consumers. In our model, we estimate the marketing cost at 10% of the production cost or €1,467 per unit for small low-cost cars. We expect this cost item to drop in absolute value with the price of the conversion but remain around 8-10% all scenarios.

R&D expenditures. Today, the cost of R&D expenditures, including approval procedures is the first hurdle for e-retrofit companies in regulated markets. Based on interviews with companies, we estimate the cost of getting the approval of a first model between €1.5M and €2M, with a potential to drop to €300k-€400k after a few series. The main cost items include:

- The engineering of the kit and battery pack (€400-500k),
- The car conversion engineering such as wiring, software, integration, etc. (€400k). This cost is likely to increase significantly if e-retrofitters start converting modern vehicles with complex mechatronics.
- Outsourced pre-tests (€200k),
- Mandatory test and approval (€600k).

The cost of R&D and approvals is huge at the very early stages (50% of the unit price for a 100 cars series), but becomes negligible when conversion programs get larger (less than 5% for a 1,000 cars series, less than 1% above 10 000).

TAXES & SUBSIDIES

VAT. In our model, we assume a standard rate of 20% to calculate the retail price*. In is to be noted that over the scenario period, the VAT collected offsets the subsidies distributed partly in the High Adoption Scenario and fully in the 1.5°C scenario (which has a positive impact on public expenditure – see Chapter 8).

Tax incentives. The regulation of e-retrofit usually comes with subsidies. In France, e-retrofitted cars benefit from both the tax incentives for EV purchase and for scrapping (up to €12,000). As discussed in section 5.3, the current maximum subsidy for switching to BEVs ranges from 1,000€ to close to 18,000€ across Europe. Subsidies are being introduced for purchasing used EVs (see discussion in Chapter 1), but they are usually smaller than for new EVs (1,000 to 2,000€).

To make the retrofitted cars more competitive against used EVs, a subsidy should only be available for e-retrofit, but currently, that is not the case. In our scenario model, we have considered four potential levels:

1. In the default scenario, there is zero additional subsidy.
2. A level of subsidy aligned with the additional environmental benefits provided by e-retrofit over the purchase of a new EV, based on the results of the carbon footprint analysis (see Chapter 3). The environmental benefit has been translated into a social cost, using the EC guidance on the matter (see Annex/chap1.5). We came up with two levels: €1,500 euros for the low estimate, and €2,700 euros for the high estimate.
3. A third level of €5,000 aims at factoring in the social benefits of bridging the affordability gap (discussed page 25). This level is aligned with the average level of subsidy observed today across Europe, assuming that most of these tax incentives will be phased out after 2030 for new EVs and would likely be rechanneled to address the affordability gap challenge.

Deployment scenarios	Subsidies specific to e-retrofit
Low Adoption Scenario (8 million cars retrofitted)	No additional subsidy for e-retrofit. Standard subsidies for purchasing new EVs and scrapping fossil cars, which also benefit to e-retrofit.
High Adoption Scenario (100 million cars retrofitted)	No specific subsidy until 2028. 2,700€ from 2028 to 2030. 5,000€ from 2030 to 2050.
1.5°C Scenario (210 million cars retrofitted)	No specific subsidy until 2028. 2,700€ from 2028 to 2030. 5,000€ from 2030 to 2033. €2,700 from 2034 to 2035, then €1,500 to 2040.

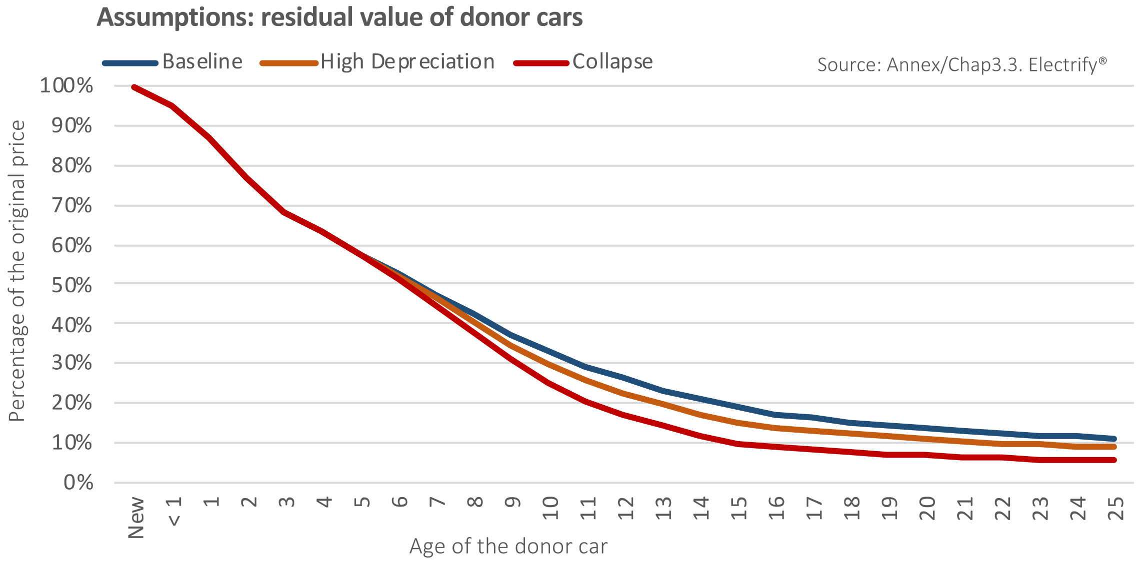
* Calculated on the basis of the retrofit cost, battery included and donor car excluded.

RESALE VALUE OF DONOR CARS

The resale value of the donor car (glider) could represent the biggest cost item for e-retrofit. Although it does not necessarily constitute a direct expense made by the customers, if they bring their own car, it is factored into the total cost. Indeed, the e-retrofit prevents customers from reselling the fossil car as they would normally do when purchasing a used or new EV.

To the cost analysis, we have considered three depreciation scenarios:

- Our **baseline** is a depreciation of fossil cars aligns with historical trends. The regulatory pressure on fossil car ownership is not strong enough to significantly affect their resale value, even after 2035.
- In the **high depreciation scenario**, the TCO of fossil cars increases significantly due to higher fuel prices, environmental regulations, and ZEZs. It makes the less eco-efficient cars increasingly uneconomical to operate. The situation leads to higher depreciation of old fossil cars from 2028, up to 20%*, the TOC being factored in the resale price and the demand for this type of used cars reducing significantly. This situation improves the competitiveness of e-retrofit.
- Finally, we have simulated an additional step: **a collapse of the resale value** of old fossil cars triggered by mandatory early retirement (retrofit or scrapping). In this case, the old cars cannot be sold on the secondary market and are uneconomical to operate (relative to purchasing a used EV or retrofitting the car). In the model, we assume that from 2030, old fossil cars depreciate faster, up to 80%*faster than the baseline for cars 15 of years and older. Such a scenario obviously requires significant policy action to materialize, the event is introduced after 2030 in our 1.5°C scenario (see chapter 9).

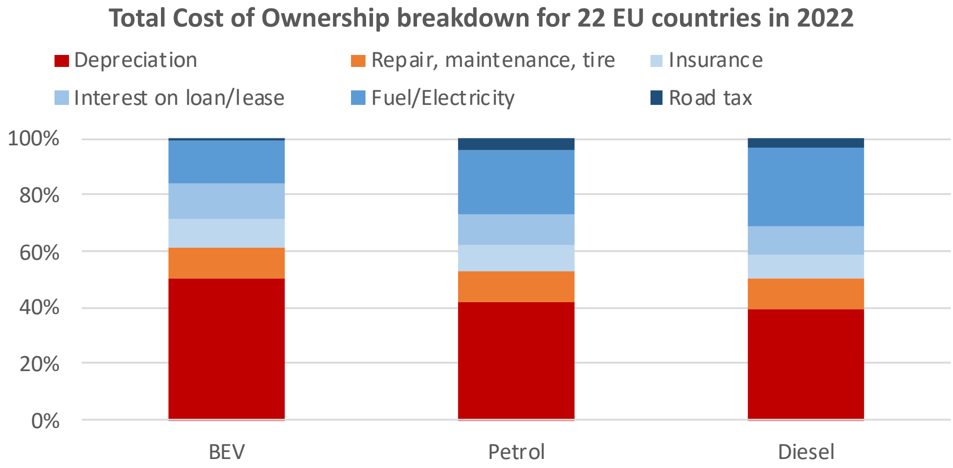


TOTAL COST OF OWNERSHIP

The 2020 analysis of the TOC of BEV cars shows that they are cheaper than ICE cars in terms of taxes (-88%), fuel (-54%) and maintenance (-23%) and more expensive in tires (+2%) and insurance (+6%). They are however more expensive in terms of depreciation (+17%), but this aspect seems to reverse recently (see discussion in the Annex/Chap.1.3). The TOC greatly varies per country, and the cost parity with ICE cars is

* These rates are the maximum difference between the baseline depreciation curve and high depreciation curves, which only materializes for old cars, all the curves being aligned for younger cars.

achieved in certain countries (-7% in France) and still far in others (+16 in Germany, +31 in Poland) – see annex for details per country.
There is no historical data on the Total Cost of Ownership (TOC) of e-retrofitted cars and the analysis does not rely on this indicator for comparison purposes, but based on the data for EVs we can assume the following:



Source: Lease Plan Car Cost Index 2022.
First four years of ownership, assuming an annual mileage of 30,000km.

Maintenance. The maintenance costs are likely to be in between the cost for BEVs and ICEs: not in favor of e-retrofit, but not a major factor. E-retrofitted cars benefit from the reduced maintenance cost of BEVs related to the absence of engine and exhaust system, and for some of them will have their suspension and tires changed. However, they still have some moving parts (transmission) and are overall based on used cars. In our model for job creation (Chapter 3), we assume that EVs are 30% cheaper than fossil cars to maintain and 15% cheaper for e-retrofitted cars.

- **Residual value**. Depreciation is by far the main cost item for BEVs. It is likely to be the same for e-retrofitted cars and obviously depends on the original price. Therefore, our analysis focuses on the price, rather than the overall TOC. Regarding the depreciation rate, there is no historical data to analyze and too many moving pieces to perform a comparison with used EVs, which have a limited history (see discussion in Chapter 8). We can assume that e-retrofitted cars will depreciate faster at the current price. In addition, the novelty of the approach and concerns about reliability and wear and tear (see page 67) are also likely to generate the accelerated depreciation that has been observed in the first generation of EVs.

- On the other hand, for e-retrofitted cars, the battery's lifetime is likely to exceed the lifetime of the glider. In such a case, the retirement of e-retrofitted cars will generate used batteries with 70% to 90% of their original capacity that can be used for stationary energy storage. For households, e-retrofit has the potential to become a two-step process involving the electrification of their car as a first step, and then switching to solar panels and energy storage for their home by reusing the battery. Such a scenario would boost the residual value of retrofitted cars and offset the factors of higher depreciation.

- **Financing.** The car being used as collateral, its residual value influences the interest rate. Besides, the e-retrofitted cars can present a specificity for the market as a whole: to streamline the conversion process for large series, e-retrofitters will likely buy used donor cars, retrofit them, and then sell them and seek pre-financing for the operation. Debt financing is likely to play a big role in the dynamic of the industry, but in a different way than for new cars.

Overall, given the uncertainty on depreciation and its strong relationship with the original retail price, we focus our analysis on the latest.

6.5. COMPETITION WITH ELECTRIC VEHICLES: 2023-2040 OUTLOOK

COST SCENARIO ANALYSIS

Research question. The analysis aims to understand to what extent and when e-retrofit could become more affordable than purchasing a low-cost new EV or a comparable used EV. The underlying research question is to understand under which conditions e-retrofit could become an economically viable solution to the challenges highlighted in the first Chapter: decarbonizing the legacy fossil fleet while bridging the old used EV gap. Could e-retrofit become the low-cost low-range solution to the used EV affordability problem?

Approach. To address this question, we have developed scenarios based on historical data and forecasts for the following elements:

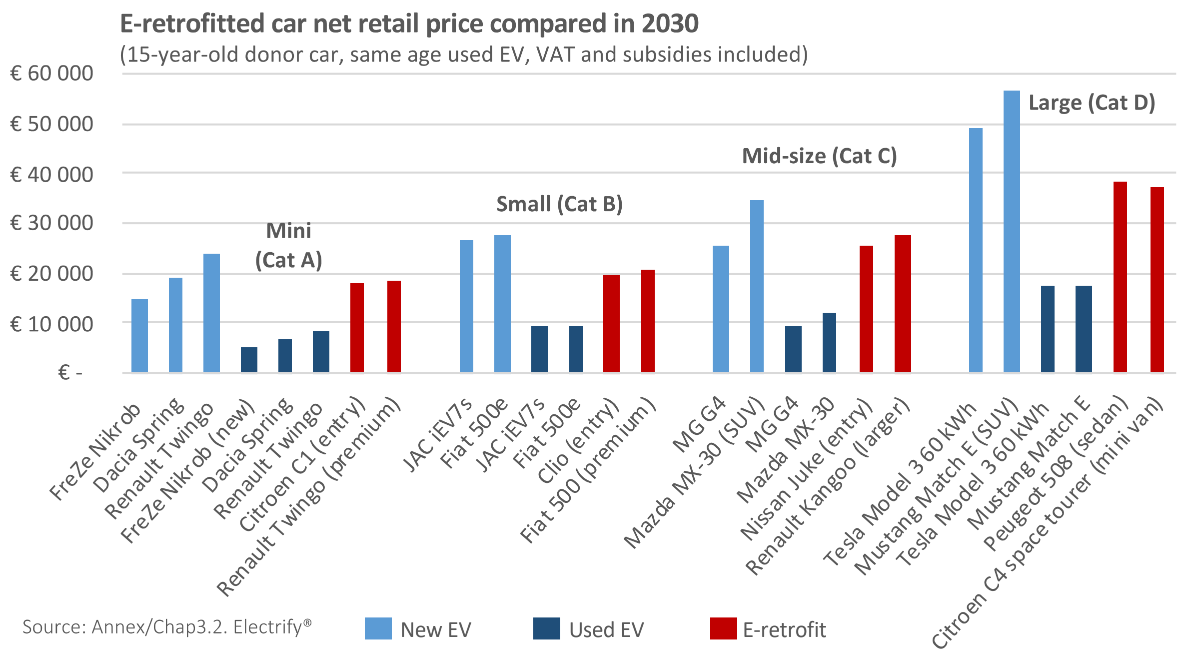
- The main cost items of e-retrofit described above, notably the market price of batteries, the premium paid by e-retrofitters, the cost of kit manufacturing and installation and the average level of add-on (onboard tablet, refit, ADAS, etc.),
- The level of additional tax incentives (i.e., on top of those provided to new and used EVs).
- The residual value of the fossil donor car (glider) for different ages,
- The residual value of used EVs, for different ages.

The outlook period is 2023-2050, which corresponds to the time window for action.

We then compared the estimated retail price (VAT included) of:

1) A retrofitted EV based on a 2022 fossil car,
2) A new EV (same or equivalent model, produced in 2030),
3) A used EV (same model as the new EV).

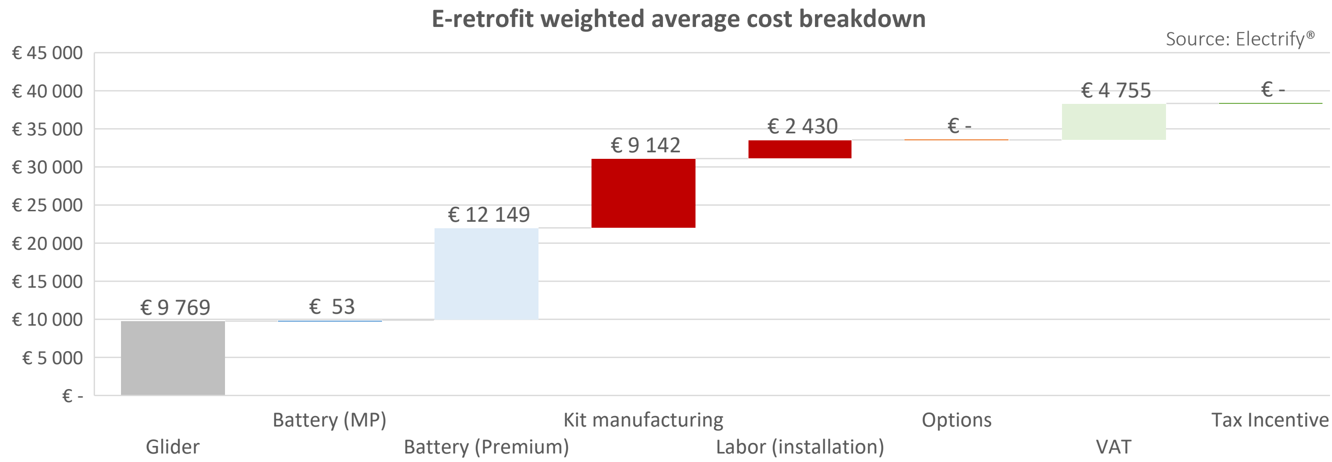
We tested different scenarios regarding the age of the cars (donor, used EV) and the size of the battery pack (see details in Annex/Chapter 3.2).



Assumptions. To study the prices and range, we took a sample of 26 cars and their retail price in France, as of December 2022. We compared the range communicated by the e-retrofitters (usually based on the prototype or even computer simulations) for similar cars (weight, category), with the maximum range provided by EV-database.org for new EVs:

- Most e-retrofitters communicate on their car's range in vague terms, we have assumed that they communicate the maximum range. The range has been corrected when it was not the case, using the formula we discussed above in Chapter 6.2.
- For EVs, we used the maximum range (city, mild weather) and applied a 5% loss for used EVs after older than 5 years.

Sample. For each powertrain, two cars are selected in each segment: mini (A), small (B), mid-size (C), and large (D), including mid-size and large SUVs. The goal was to get a sample representative of the use cases while selecting the most affordable EVs in the lower segments (A, B, C). To determine the average price, we weighted the results for each category based on the market share of the segment. The output for each existing powertrain (ICE, new EV, used EV) might therefore be different from the actual market average.



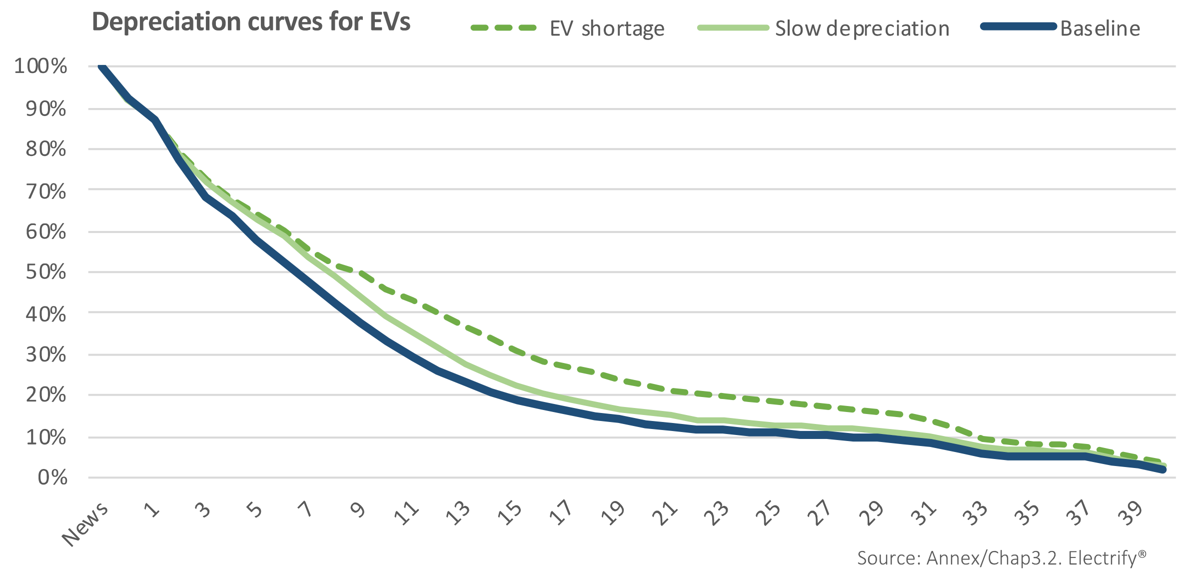
The cost items discussed in chapter 7.4 have been aggregated in broader categories: the cost of kit manufacturing includes R&D, overheads, marketing. The cost of labor includes basic refit and maintenance. The model and results are further described in the annex.

ASSUMPTIONS REGARDING USED EV DEPRECIATION

In all scenarios and for all categories, e-retrofitted cars produced in large series are or quickly become cheaper than new EVs. However, reaching price parity with used EVs is a major challenge for the industry. How the resale value of EVs evolves will therefore be critical for the competitiveness of e-retrofit.

For the analysis, we have considered three scenarios:

- The application of historical trends for all cars (baseline).
- A slow depreciation (-20% relative to ICEs) in line with the recent trends observed on certain markets for long-range EVs.
- A used "EV shortage scenario" where the residual value is inflated (up to +70% relative to the baseline for old cars) due to a shortage of used EVs and high demand. The inflation level in this scenario is comparable to what has been observed in the used car market during the COVID crisis (Annex/Chap1.3)



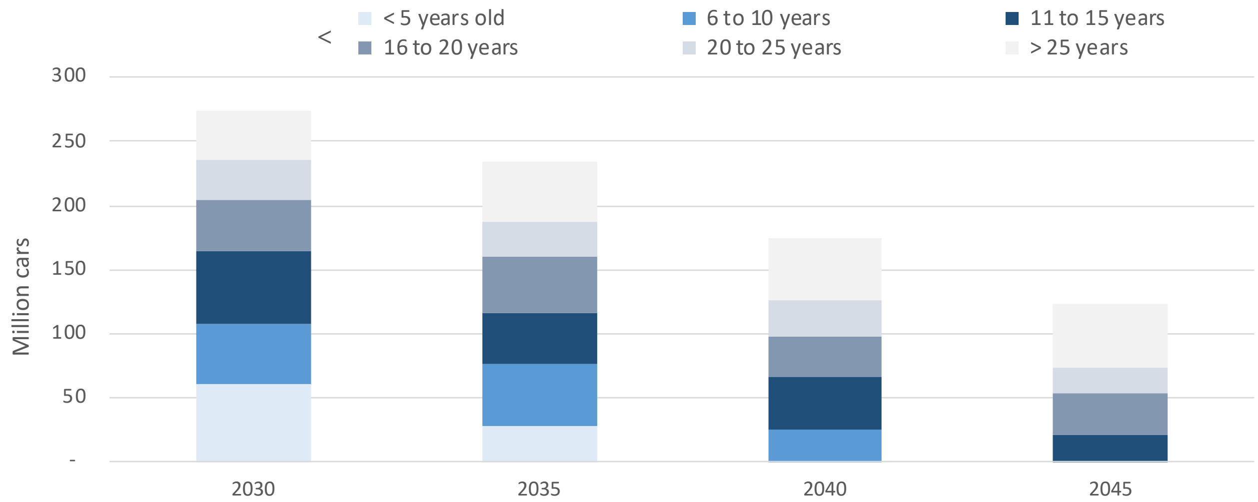
Source: Annex/Chap3.2. Electrify®

7. TECHNICAL ROADBLOCKS

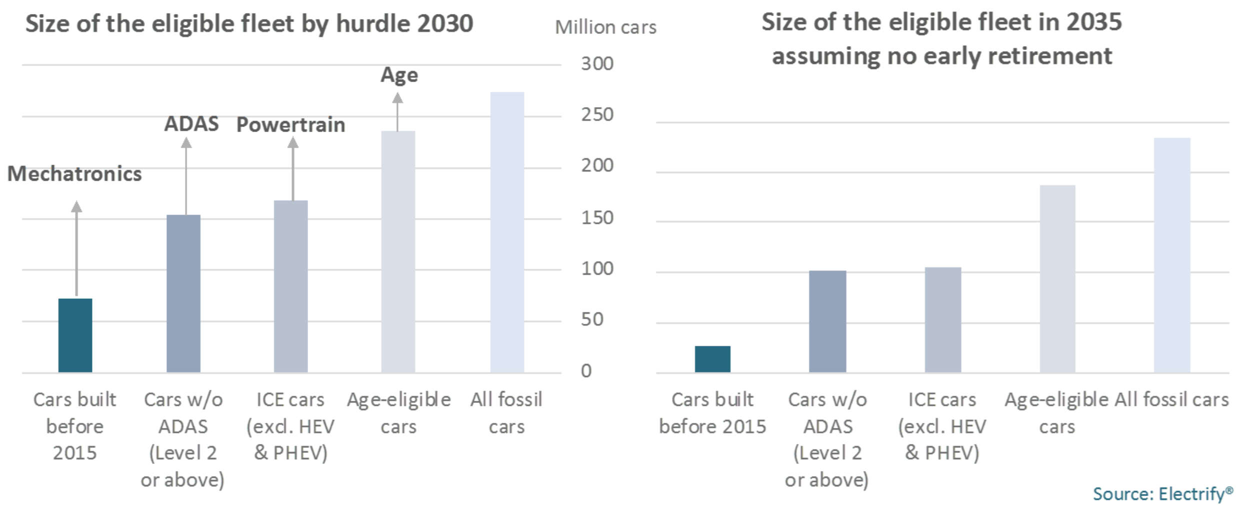
This chapter assumes that the economic equation of e-retrofit will eventually become favorable and that no new obstacle will materialize, such as the development of synthetic fuels. It therefore focuses on the other roadblocks that e-retrofitters will have to address in such scenarios to reach the full potential in terms of number of vehicles retrofitted and carbon emission reductions. Our approach for this chapter consists in evaluating how the pool of 236 million cars technically eligible for retrofit in 2030 (see chart below) would shrink if e-retrofit companies do not address the different roadblocks.

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

Source: Annex/Chap3.1. Electrify®

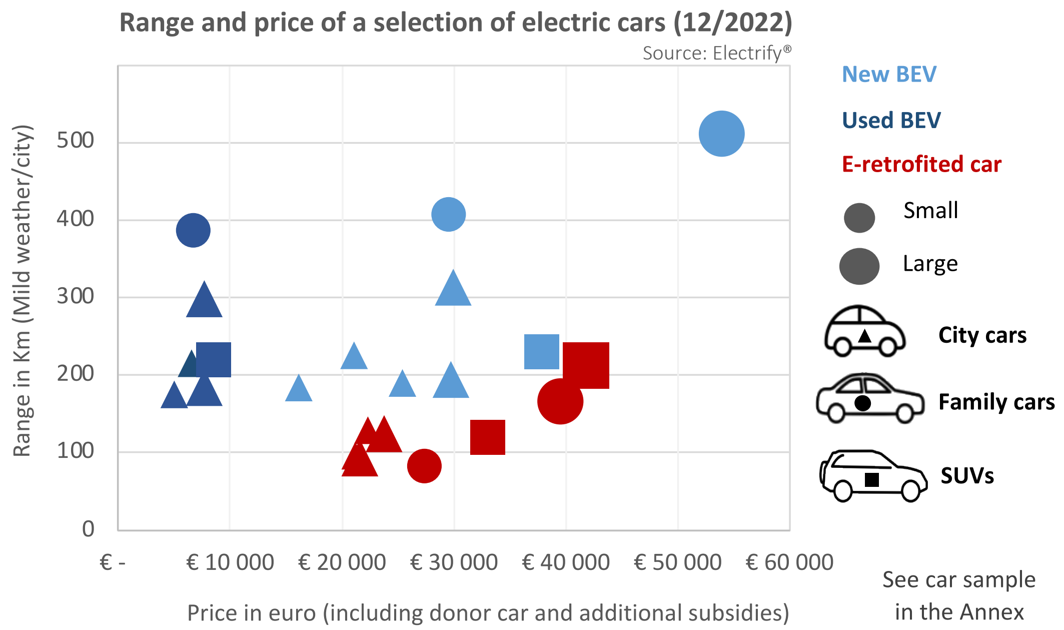


The short range of e-retrofitted cars is the first obstacle and potentially affects the entire donor fleet. Besides the table below outlines the roadblocks and the associated number of vehicles that could become ineligible if the roadblocks are not addressed in time. It shows that e-retrofitters will have to address the complexity related to mechatronics on recent and future cars to retrofit 110 million cars. If they fail, only 70 million cars will be eligible in 2030. If this challenge is addressed, they will then have to solve the difficulties related to ADAS and hybridization to reach 230 million cars. 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.

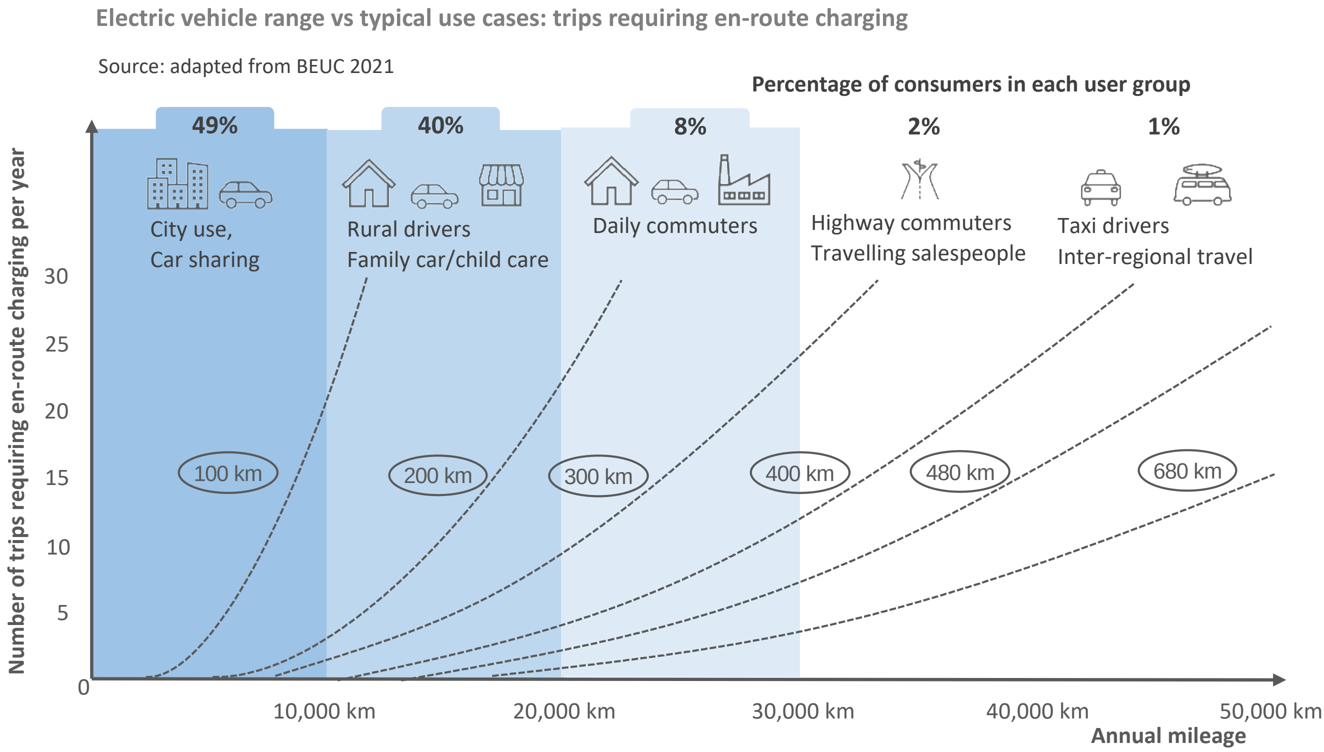


7.1. RANGE

Situation today. As discussed in Chapters 2 and 7 and illustrated below, the range of series e-retrofitted cars is currently limited to 100-150 km, due to the limited space available to fit the battery and the cost of additional kWh. Given their current price, they compete with new EVs that have a range of 200 to 500+ km, which is obviously a major roadblock.



Range vs needs. Letting the price aside, it appears that most Europeans use their car in a way that would be compatible with such a short range for daily use, requiring en-route recharging for less than 30 trips per year.



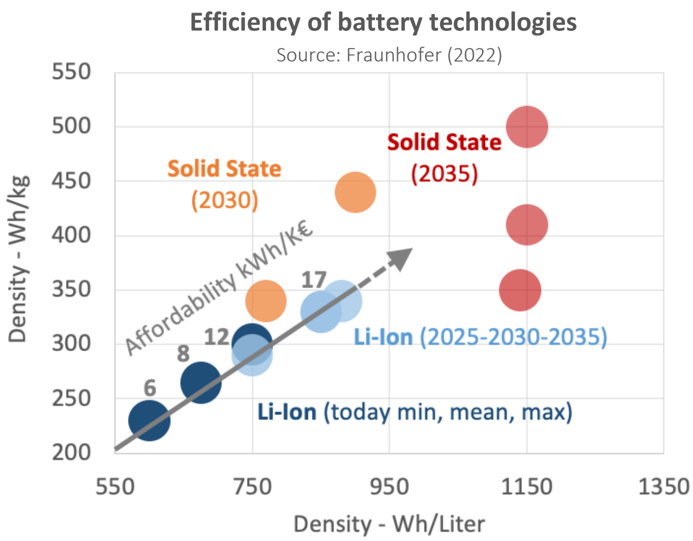
Outlook. Some high-hand e-retrofitted SUVs (e.g., Electric GT) available today incorporate batteries of up to 95 kWh with range above 300 km. The price of batteries is expected to be dived by two by 2030, and three by 2035. It will enable e-retrofitters to increase the range of cars that can host large batteries.

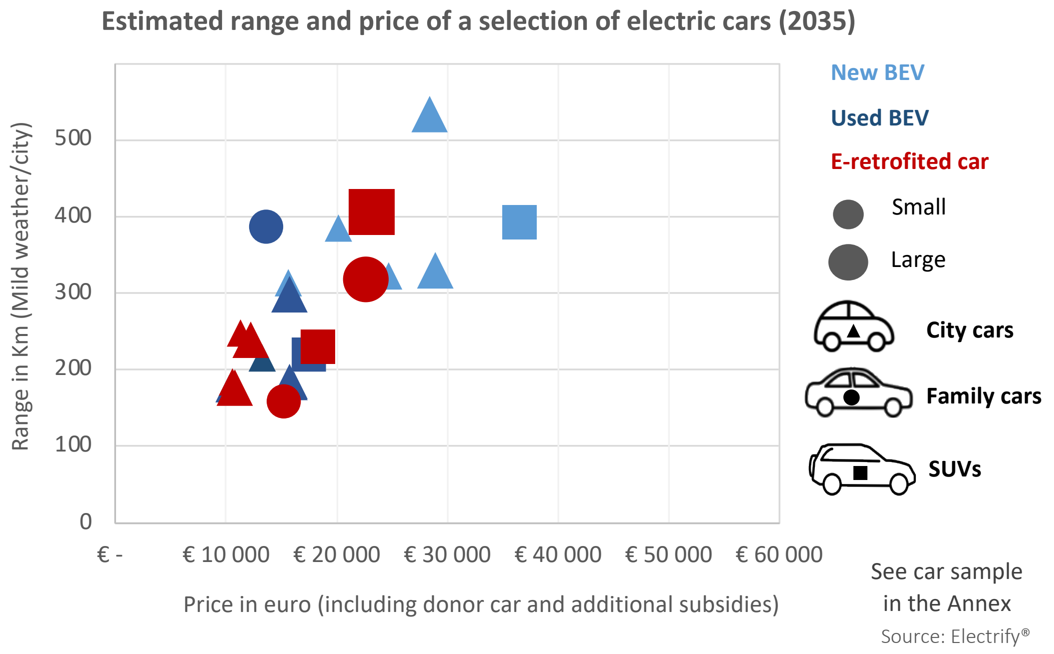
However, for small cars (segments A and B), the obstacle is bigger since technical limitations (further discussed below) currently cap the battery size to 18-20 kWh. Fortunately, the energy density of the current technology (Li-Ion) is expected to increase significantly. Beyond, Solid-State Batteries[91] could deliver a breakthrough. In 2030-35 their price will be high, and their market share limited share (about 1%), but the technology could drive changes at the end of the scenario period.

Thanks to these improvements e-retrofit could be able to address the current technical limitations in terms of maximum range after 2030 (see details in Annex/Chap2.3). Such a development could eventually become a game changer for e-retrofit competitiveness with used EVs.

The above-mentioned reduction of battery prices will enable retrofitters to increase the range of large cars with larger batteries, while reducing their price relative to today's levels.

However, such improvement is unlikely to take place before 2035 and new EVs will equally benefit from gains in energy density.





7.2. VEHICLE WEIGHT

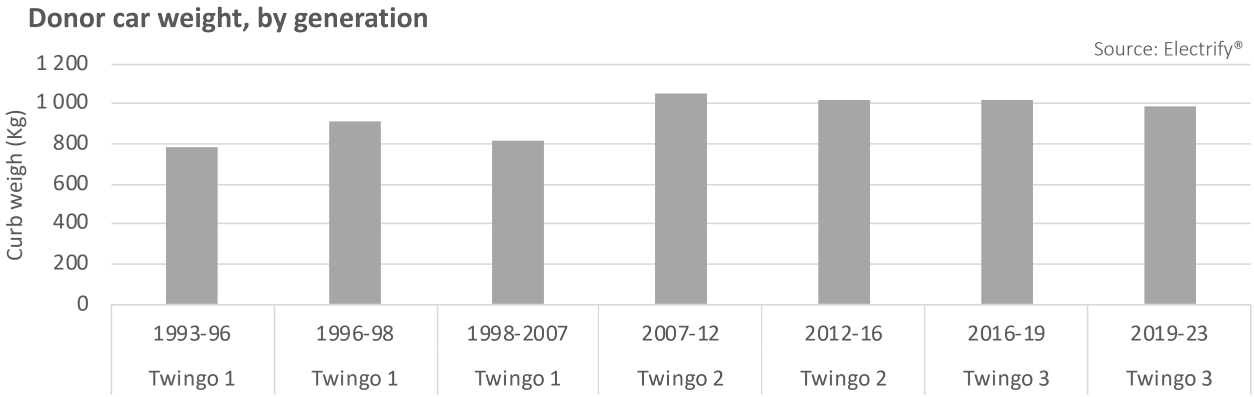
Challenge. As discussed in the first section, there are limitations to the size of the battery that can be integrated in a retrofitted car without reducing the interior space: the battery should fit in the space left after fuel tank and engine have been removed.

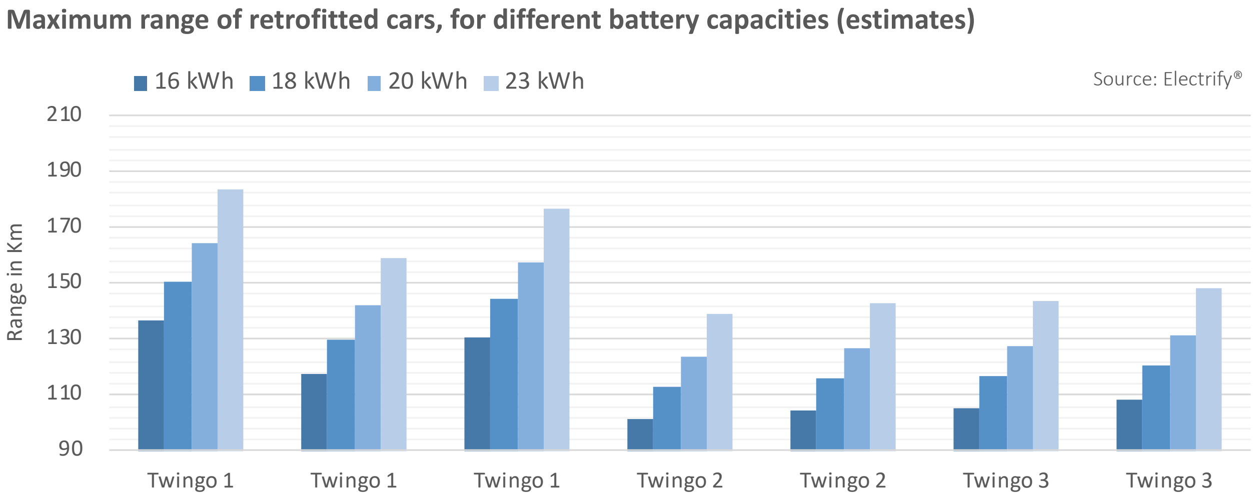
Certain cars with too heavy gliders compared to the size of their fuel tank and engine bay are therefore not suitable for e-retrofit. Besides any additional weight involves either a lower range or a bigger, more expensive battery. It also further adds to the total weight: an average 6 to 8 kg per kWh. Finally, limited space obliges the e-retrofitters to design new battery packs specifically for each model, rather than adapting an existing one, thus limiting economies of scale.

Weight inflation. Typical recent passenger ICE vehicles weight between 1.1 ton (city car) and 2.4 tons (SUV), including ICE engine weighting 130 to 200 kg. Weight tends to increase overtime: the vintage Fiat 500 weights 500 kg, while the new version starts at 1.3 tons. The same goes for Mini and VW Beetle models. On a shorter timescale, Renault Twingo gained 200 kg between the 1993 and 2023 version. However, the size of the fuel tank did shrink from 40 liters before 2014 to 35 liters after.

So far, most e-retrofit prototypes for small cars are based on relative light cars: the vintage Fiat 500 or Mini, or the earlier/lighter versions of Twingo. E-retrofit has not been proof-tested on more recent cars.
The equation is a bit different for larger cars and SUVs, which might have enough space left to fit a larger battery but are way heavier: in this case, the weight problem becomes a cost problem.

Example. Overall, a 'back-of-the-envelop' calculation on a typical case[92] suggests that this problem is significant, but manageable. The charts below illustrate the situation for the conversion of a Twingo, which is a model offered by Lormauto (Twingo 1)[93] and will compete against the used version of Renault's e-Twingo that has an estimated range of 150-205 km with a 23-kWh battery. For the battery capacity currently planned by e-retrofitters (16 kWh), a 35 km difference is observed between the worst (100 km) and best case (135 km), which matters for such a short range.





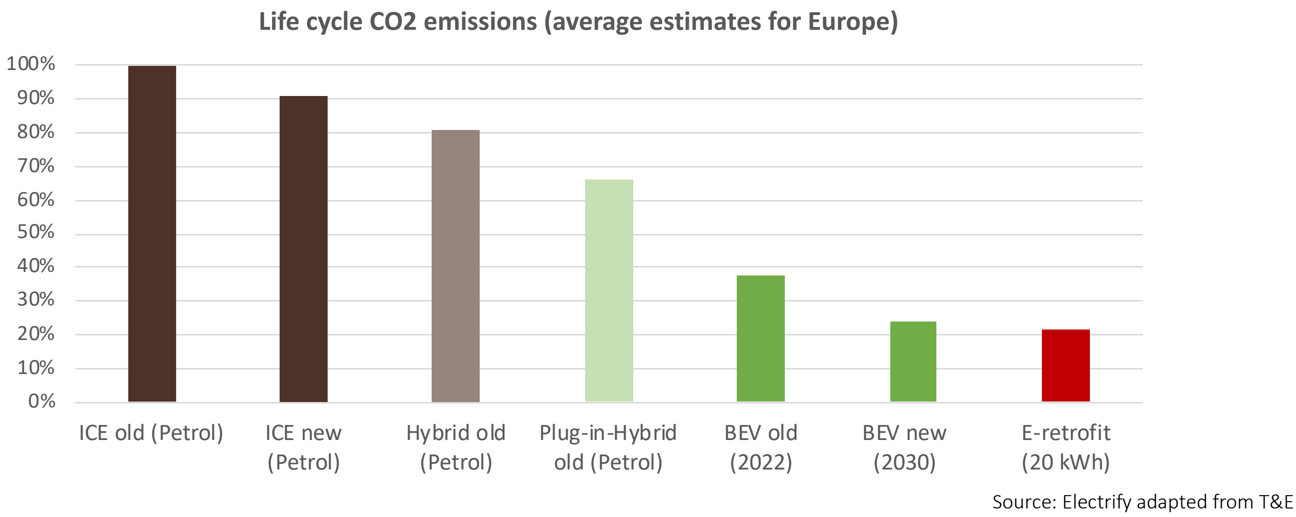
Nevertheless, the problem seems manageable: historical data (Bloomberg/BNEF) shows that battery cells energy density has almost triple since 2010 and forward-looking analysis suggest that this trend is likely to keep stay for the next 10-15 years (see discussion above). Based on the expected gains in weight and size, our calculation shows that the e-retrofitters will be able to fit a battery between 20 kWh and 23 kWh from 2030 onwards, which offsets the impact of the weight gain between the worst and best case.

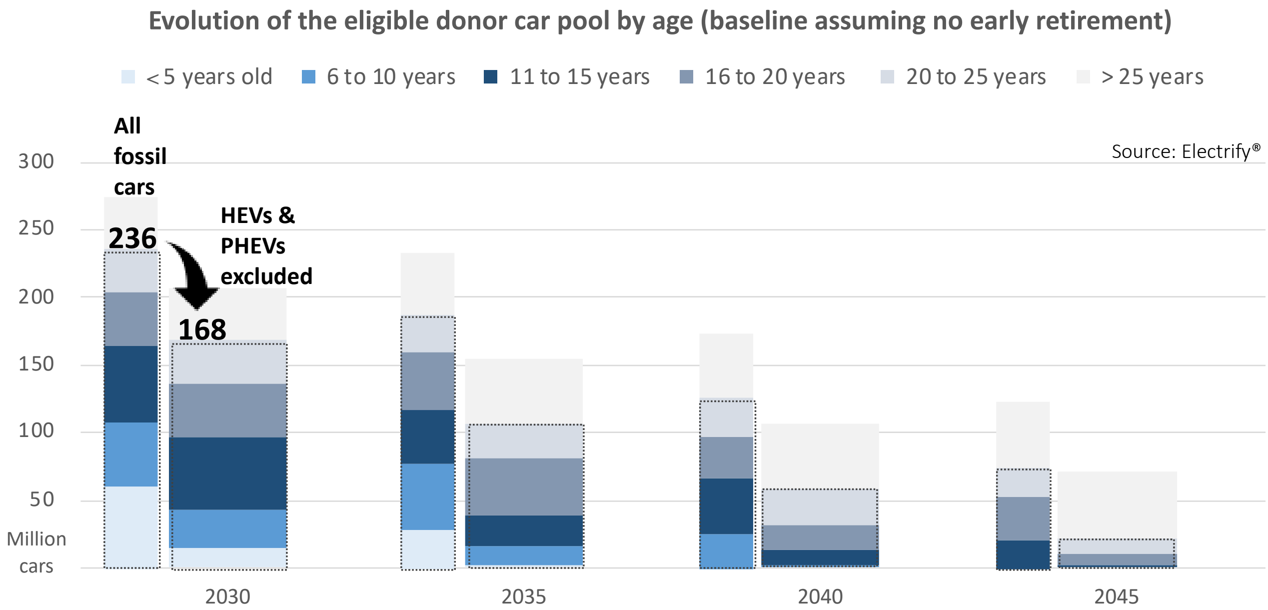
Further research would be necessary to determine the consequence on the size of the eligible fleet, but a first look at the problem suggests that it might not significantly impact the long-term outlook (2030 and beyond).

7.3. HYBRID AND PLUG-IN-HYBRID

Retrofittability. Currently, e-retrofit solutions are not designed for hybrid vehicles and the series regulation (in France) is not even explicit on whether these vehicles are concerned or not. Interviews with some e-retrofitters suggest that these vehicles would be technically retrofittable, although the operation will come with additional steps and therefore costs, with notable differences between the types of hybridizations. Some interviewees suggested that modern plug-in-hybrids could even be easier and cheaper to retrofit, given the design of the car body and the ability to reuse the electric engines and batteries. Further research would be needed for assessing the cost implications for different types of hybridizations, the overall conclusion being that it is a matter of cost rather than a fundamental hurdle.

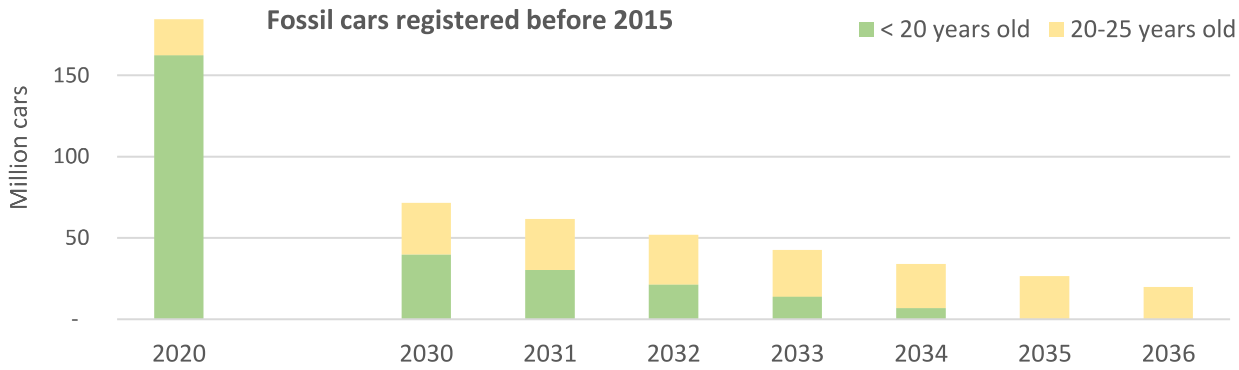
Policy priority. Another hurdle is the fact that the environmental benefits of e-retrofit are slightly limited compared to the conversion from a standard ICE vehicle, given the lower fuel consumption and emission profile of hybrids and plug-in-hybrids (first chart below). Consequently, this category of vehicle is likely to be less exposed to fossil fuel phase out policies such as Low Emission Zones and fuel tax increases, and less of a policy priority for public retrofit programs and subsidies. As shown on the second chart, excluding HEV and PHEVs would reduce the size of the eligible donor fleet by a about 30% in 2030 and up to 60% in 2045.





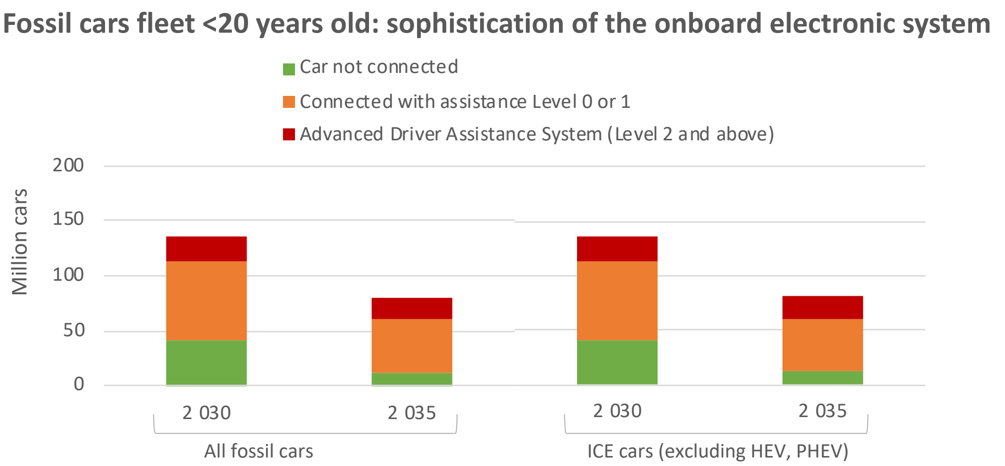
7.4. MECHATRONICS

Modern vehicles increasingly rely on a deep integration of mechanical, electrical and electronic engineering systems. These features notably include critical safety systems such as the ESP (Electronic Stability Program) that control braking systems. The conversion modifies the system and requires to "re-wire" and recalibrate the systems, which is could be complex. Most e-retrofit solutions offered today focus on cars produced before 2015 and vans (equipped with more basic mechatronics). On the contrary, these 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. As illustrated below, 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 period.



Source: Electrify®

In practical terms, it means that e-retrofitters will have to find technical solutions to overcome these difficulties or/and establish partnerships with manufacturers and parts suppliers to get access to the critical software systems. If they overcome the hurdles related to ESP and other mechatronics feature, e-retrofitter will then have to deal with the more complex sub-problem of Advanced Driver Assistance Systems (ADAS).



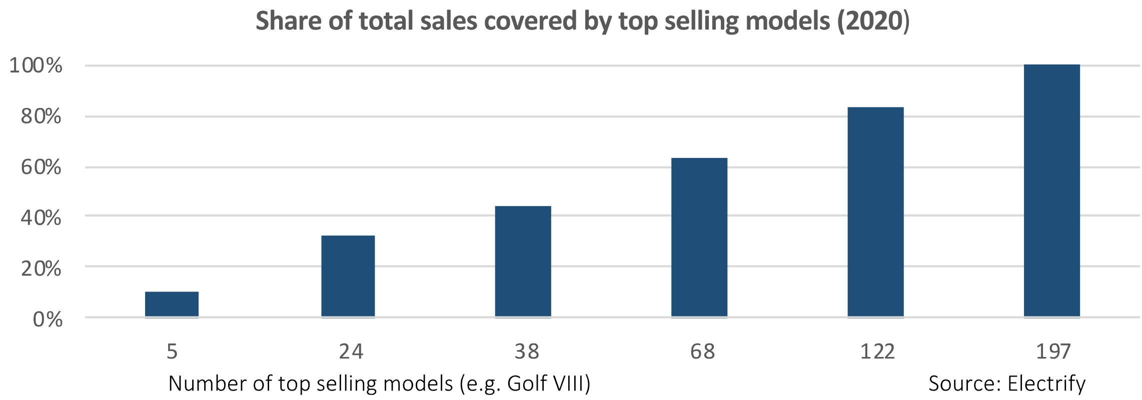
Source: Electrify®

Today, most 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. However, more advanced systems such as 'level 2' (adaptive cruise control, automated lane centering, lane change assist and driver monitoring- camera) and above are becoming a key component of the car's value. Keeping these systems in place would require retrofitters to collaborate with car manufacturers to adapt the software.

7.5. APPROVAL REGULATION AND SERIES SIZE

Given the cost and time associated with the approval process, a large enough pool of donor cars for a given type-variant-version approved is necessary to justify the manufacturer's R&D investment. E-retrofit therefore focus on top sellers.

Series size for cars. 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 below shows the share of total sales of new cars by top selling models in 2020.



Overall, the size of series is not expected to be a major obstacle in the early stages given the market share of top sellers and is not likely to be a roadblock neither if the market takes off, for three reasons:

- Interviews with retrofit companies suggest that they plan achieve significant economies of scale by getting several type-series and variants approached: -80% from the first (e.g. Clio III) to the next five series (e.g. Clio II, C3, 207), and -90% for a variant within a series (e.g. Clio IV).
- For many recent cars different models from different brands are actually build on the same platform (e.g. VW Touran and Audi TT), so the fleet is actually less diversified than it appears to be.
- With large scale conversion, the problem fades away, the share of R&D and approval expenditures in the total cost becoming negligeable (<1%).

Series size for vans Most vehicles have been produced in series large enough to justify R&D investments and approval for series retrofit. The light commercial vehicle market is much more concentrated than the car market: in 2020, the top-ten best-selling models accounted for 57% of new registrations. Accounting for models from different brands built on the same platform (e.g. Citroen and Peugeot, Nissan and Renault), the concentration is even higher. Therefore, the economies of scale when getting approval for series retrofit are much higher than for cars.

Approval time. The approval time is one of the main factors that delays the deployment of series retrofit today, most players waiting for the approval of their first model.

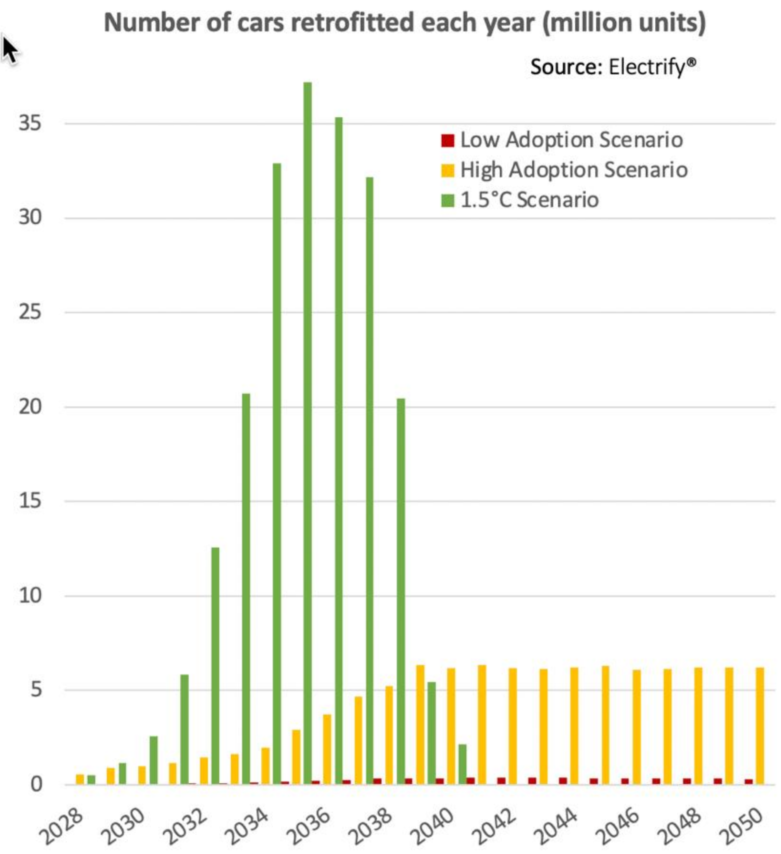
The time require to get an approval on a new model is estimated by e-retrofitters at 36 to 24 months for a first application, 18 months when the next 5 series, with the possibility to reduce it below 6 months for extension or when the process will be streamlined. On the long-term, this dimension is not likely to remain a major roadblock, assuming the EU or/and member states put in place a favorable regulatory framework in coming years.

8. E-RETROFIT OUTLOOK 2050 AND BEYOND

Building on the estimates of the "technically eligible" fleet (see page 47), the cost scenario analysis (Chapter 7) and the assessment of the technical roadblocks (Chapter 8), the chapter 8 describes three plausible scenarios in terms of market uptake:

- 8 million cars are retrofitted in the Low Adoption Scenario,
- 100 million cars are retrofitted in the High Adoption Scenario,
- 210 million cars are retrofitted in the 1.5C Scenario.

The scenario analysis focuses on the passenger car fleet; the other categories are described to give context. All fleet size and carbon emission figures relate to the European car fleet (EU-27, Norway, Switzerland, UK) for 2021-2050.



8.1. LOW ADOPTION SCENARIO

In the Low Adoption Scenario (LAS), 8 million cars are retrofitted. Most conversions occur after 2045 when the economic and regulatory pressure on fossil car use intensifies. In this scenario, e-retrofit focuses on vintage cars and niche low-range use cases. As a result, the e-retrofit economic equation still needs to be solved, and this technology never plays a significant role in addressing the demand for affordable cars.

KEY FACTORS

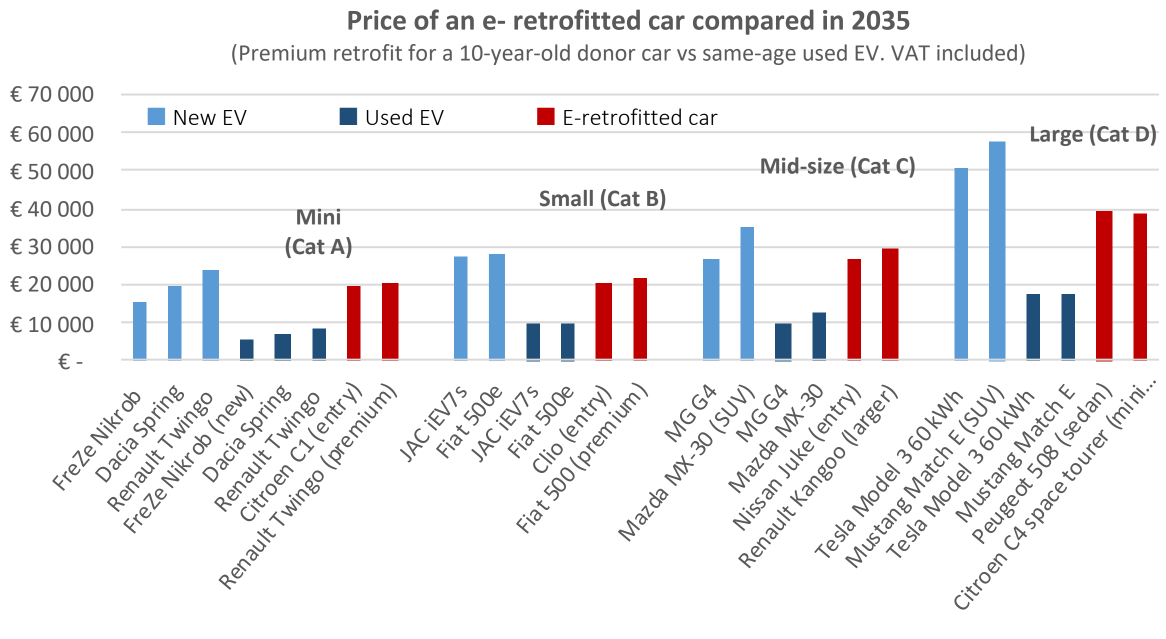
Policies. In this scenario, Zero Emissions Zones are introduced but in a limited number, public authorities favoring Low Emission Zones for social reasons. The efforts and subsidies for affordable EV ownership are focused on new cars and related social leasing programs. As far as low-income households who cannot afford a new EV are concerned, the authorities, notably in Eastern Europe, try to ease the pressure by maintaining a reasonable TCO for old fossil cars in rural and suburban areas. No significant restriction is introduced on the export or import of used fossil cars.

Competition with alternative fuels. Today so-called synthetic fuels are mainly biofuels produced from edible oils and sugar feedstocks, which limit the possibility to scale due to competition with food consumption. However, companies such as Siemens, Bosh, Audi and Porsche are investing in demonstration projects to produce synthetic fuels from carbon capture and renewable electricity, to overcome this obstacle. While certain observers like McKinsey[94] expect these synthetic (a.k.a. "e-fuels") to play a significant role in the decarbonization of road transport, others, like Ricardo[95] and T&E[96], envision a future limited to air and marine transport due to the cost and inefficiency relative to BEVs. However, if these e-fuels hit the road by 2035, even at a high price and in small quantities they might provide an alternative to e-retrofit for vintage vehicles in Zero Emission Zones. The Low Adoption Scenario assumes that it will not be the case.

Market prices. Fossil cars depreciate in line with historical trends (baseline depreciation scenario), until the end of their natural lifetime. The absence of pressure on fossil car owners limits the demand for used EVs, which also depreciate in line with the baseline curve. Battery market prices and new EVs retail prices drop in line with current forecasts.

Cost of e-retrofit. The low adoption scenario is a projection of current trends with the same market conditions. The economies of scale are significant: e-retrofitted cars benefit from the investments and economies of scale generated by the bus, truck and vans segments, the vintage car segment being used as a marketing tool for these segments. The market price of batteries drops in line with BNEF 2022 scenario (slow learning curve). The premium manufacturers pay drops regularly but remains above 100% in 2050. The cost of retrofit kit manufacturing drops by 25% over the period. In this scenario, we assumed the same level of subsidies for new EVs, used Evs, and retrofited cars, in line with what is observed in France where series e-retrofit is regulated (as of January 2023).

Competitiveness. The entry price drops from €16,000 in 2023 to €9,500 in 2050, driven by lower market prices for batteries, and economies of scale (bargaining power on batteries, cost reduction in manufacturing) which translates into respectively €18,500 and €12,000 including a 15-year-old donor car. However, the bottom line (see annex) remains the same during the entire period: e-retrofit provides a shorter range for a higher price than used EVs. Besides, price reductions are delivered too late, after 2040, when affordable used EVs are already available: e-retrofit remains more expensive than used EVs of the same age during the whole period. Therefore, the demand remains focused on "passion conversions", and a significant part corresponds to premium and heavy retrofits.



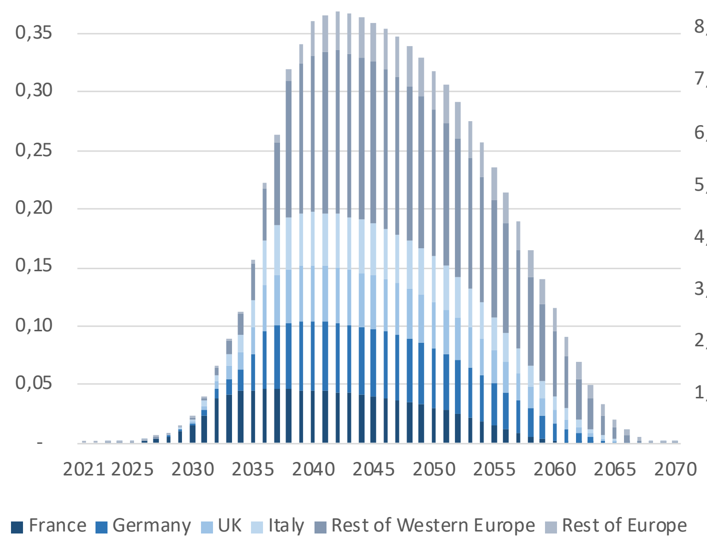
Source: Electrify®

E-RETROFIT DEPLOYMENT

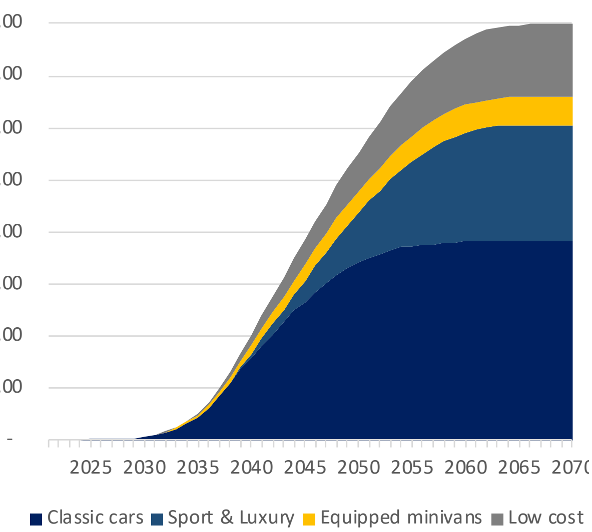
The broader e-retrofit market is driven by the strong demand of municipalities for buses and vocational trucks. In these markets, e-retrofit takes significant market share to new EVs and delivers emission reductions. The market for vans and heavy trucks takes off in the mid-2020ies but then stagnates and fades away after 2035, when the EV truck, buses and van market becomes big enough.

For passenger cars, the market first takes off in France around 2025 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 when most vintage cars owned by electrification enthusiasts have been converted. Most conversions take place after 2045 though, when the economic and regulatory pressure on fossil car use intensifies and pushes late adopters.

Annual volume retrofitted by country (million cars)



Cumulated volume retrofitted (million cars)



Source: Electrify®

For passenger cars, the deployment of e-retrofit remains largely limited to today's use cases (as described in Chapter 4):

- The market takes off for vintage cars including the stock renewed by the last luxury and sport vehicles. It is a passion market for second and collectible cars owned by affluent households. Fossil cars becoming stigmatized in certain social circles and classic retrofit trendy, two-third of the eligible fleet are eventually retrofitted, decarbonizing a total of 6 million vehicles.
- For standard passenger cars, the economic equation remains a major roadblock until the mid-30ies when batteries become more affordable. Then mechatronics takes over as fundamental roadblock. The demand grows significantly compared to today's level, but is limited to equipped vehicles (disable cars, camper vans) and ultra-low-cost retrofits for old cars reused as carts and similar downgraded used cases. These two use cases add another 2 million vehicles.

E-retrofit does not play any significant role in addressing the demand for affordable and very affordable cars that is partly addressed by a combination of used low-cost EVs, social leasing and used fossil cars.

CARBON EMISSIONS

With emission reductions delivered by the e-retrofit of the car fleet remain limited, most of the cars retrofitted enjoying low annual mileage. Overall, the direct carbon emissions of the fleet reach 8.5 Gt at the end of the forecast period in line with the baseline described in Chapter 1.1. An additional 2.5 Gt corresponds to the remaining lifetime emissions of exported fossil cars (see Chapter 1.3). These emissions align with a ≈1.8°C carbon budget of 2022 (see discussion in the annex).

ELECTRIFY
cars

8.2. HIGH ADOPTION SCENARIO

In the High Adoption Scenario, e-retrofit benefits from strong public support, including massive subsidies and a favorable regulatory framework, which triggers high demand. 50 million cars are retrofitted from 2023 to 2050, all of them older than 10 years, reducing CO_2 emissions by 0.3 Gt relative to the baseline.

KEY FACTORS

Public policies. In this scenario, the main concern of policymakers is to find solutions to create affordable electric cars. New EVs enjoy lower TCO in all countries by 2025 and reach price parity in 2028. Subsidies for new EVs are reduced in most countries and focused on addressing the affordability challenge. E-retrofit, which has gained visibility with buses, trucks and vans is identified as a potential solution in 2028: many cities and regions introduce specific subsidies and calls for tenders to retrofit private cars near ZEZs.

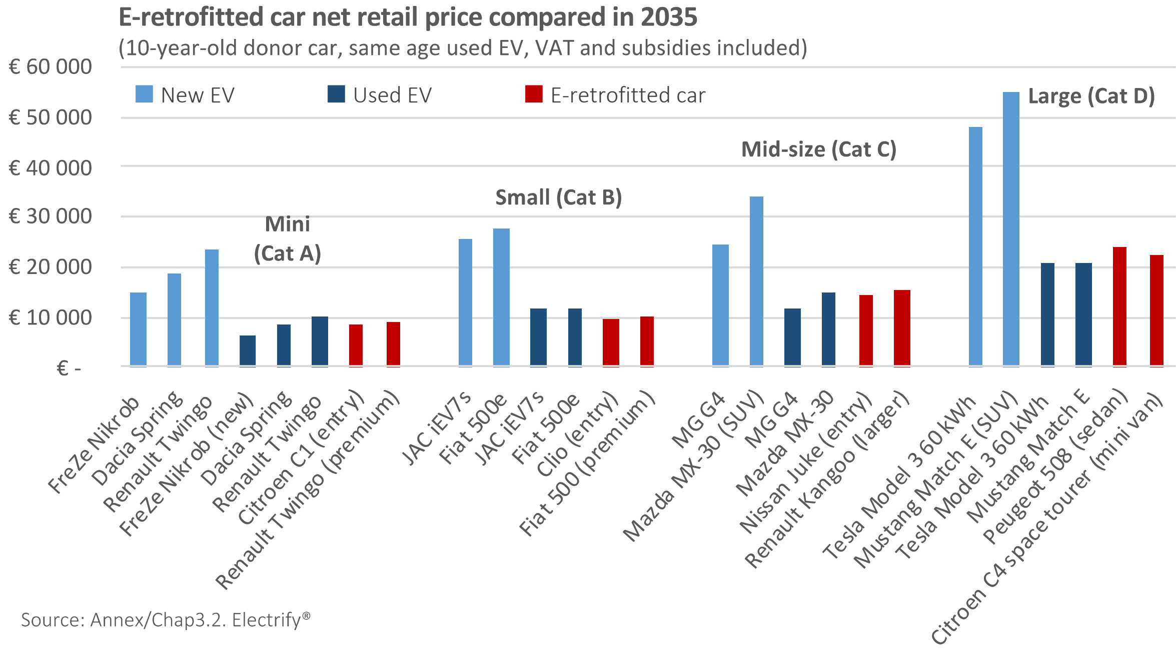
Regulation and subsidies. Zero Emissions Zones are deployed at scale across Western Europe, combined with social leasing programs and subsidies targeted at low-income households to support affordable used EVs adoption. E-retrofit benefits from these subsidies, as well as additional dedicated subsidies for conversion, which are increased in 2030. An early retirement regulation for cars older than 35 years is introduced in 2035.

Policy instruments (fictional)	Implementation	Implications
Additional subsidies specific to e-retrofit	None until 2028 2,700€ in 2028 and 2029 5,000€ from 2030 to 2050	**€245 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 €30Bn of public expenditure (which overlaps with existing scrapping schemes) and lead to the early scrapping of 63 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.

Market dynamic. At the beginning of the scenario period, both EVs and fossil cars depreciate in line with the baseline. The regulatory pressure on fossil car ownership increases significantly across Europe, accelerating the depreciation of old fossil fuel cars from 2028 onwards (up to 20% relative to the baseline). The demand for affordable used EV rises dramatically from 2028, while less than one million EVs are 10 years or older: this situation triggers inflation for used EVs (up to 20% for older models) – see calculations in Annex/Chap3.2.2.

Cost of e-retrofit. The first stage of this scenario (2023-2027) is like the low adoption scenario: e-retrofitted cars are more expensive than more recent used EVs. During this period, early adopters focus on vintage cars and passion projects aimed at keeping existing cars on the road in Low Emission Zones.

From 2028 to 2037, dedicated subsidies and changes in residual values of both donor cars and used EVs enable e-retrofit to compete with used EVs younger than the donor car (see data in Annex/Chap3.2.3). From 2030, partnerships between e-retrofitters and manufacturers are developed to cut costs on battery design and purchase. A retrofit program for cars becomes an option in many calls for tenders from municipalities focused on retrofitted buses and delivery vans. In 2035, factoring in subsidies, the starting price of retrofit drops below €4,500, which translated into a €9,500 price tag including donor car, making it affordable. From 2035, e-retrofitted cars reach price parity with used EVs of the same age in small and mid-size categories. Larger batteries are integrated and the range increases. Sales grow to reach a peak in 2040.



Source: Annex/Chap3.2. Electrify®

End of life. Being quite old, the fleet of e-retrofitted cars has a limited lifespan. Many retrofitted cars are retired after 10 years, before the end of life of their battery, with a remaining maximum capacity of up to 80-90%. From 2040, the flow of retired e-retrofitted cars generates used batteries of 16 kWh or more, which can be used to store energy produced by solar panels, helping car owners to decarbonize their houses too. This opportunity creates new job opportunities for the workers involved in the installation of e-retrofit kits.

ROADBLOCKS

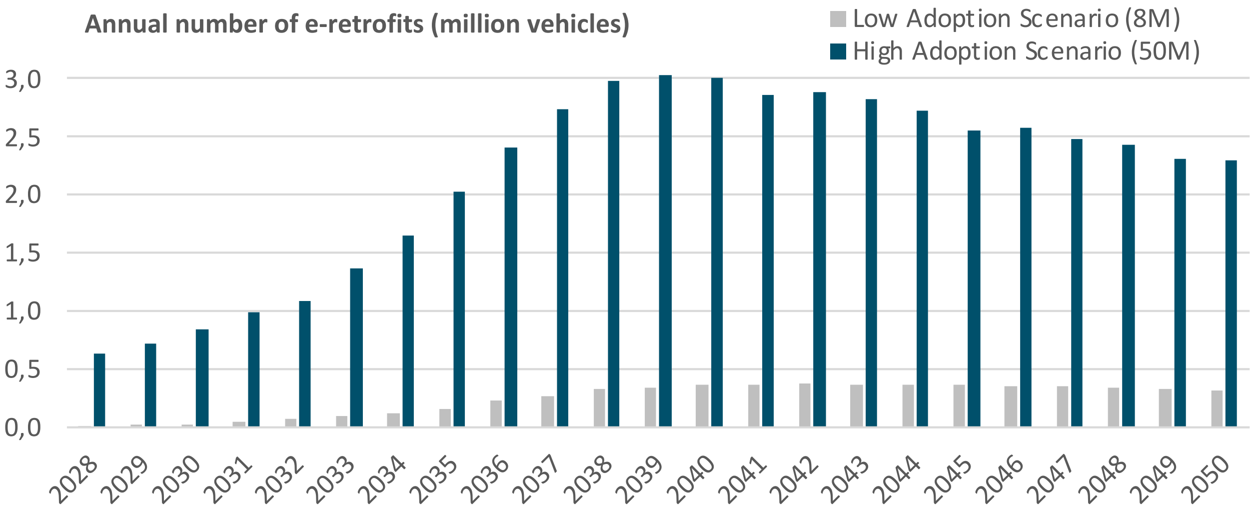
Three main factors, related to both demand and production limit the number of cars retrofitted in this scenario (as opposed to the 1.5°C scenario):

Cap on subsidies. Given the high net cost for taxpayers, the subsidies for e-retrofit are limited to low-income households impacted by Zero and Low Emission Zones. Most cars are converted in the context of municipal and regional programs led by local authorities in partnership with e-retrofit companies, which involved pre-financing and leasing, mobilizing blended finance. Due to the overall cost for public finance, the number of retrofits is de-facto capped by budget constraints.

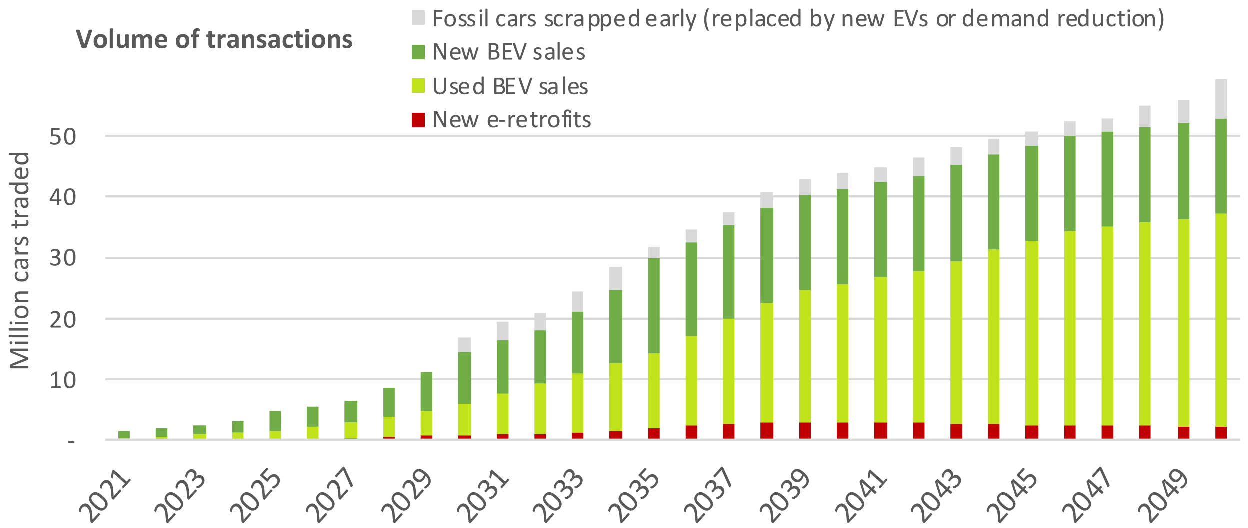
Conversion capacity. In this scenario, most retrofits take place locally, in converted maintenance shops. The investment, training and certification are also subsidized and limited in volume. Besides, the competition with new BEV manufacturing for batteries with high energy density leads to high density battery shortages for e-retrofitters. The access to affordable batteries is negotiated in the context of the above-mentioned programs, and therefore limited in number.

Competition with new BEVs. Until 2035, e-retrofitters focus on technically eligible cars with limited complexities (ADAS, hybridization, etc.), however from 2040 onwards all the remaining cars present complexities. In parallel, the competition from used BEVs increases with more old used cars on the market and longer range for recent used cars. In response, e-retrofitters are obliged to increase the range of retrofitted cars and refit most cars to remain competitive, thus offsetting some of the cost reductions and reducing the competitiveness against used EVs.

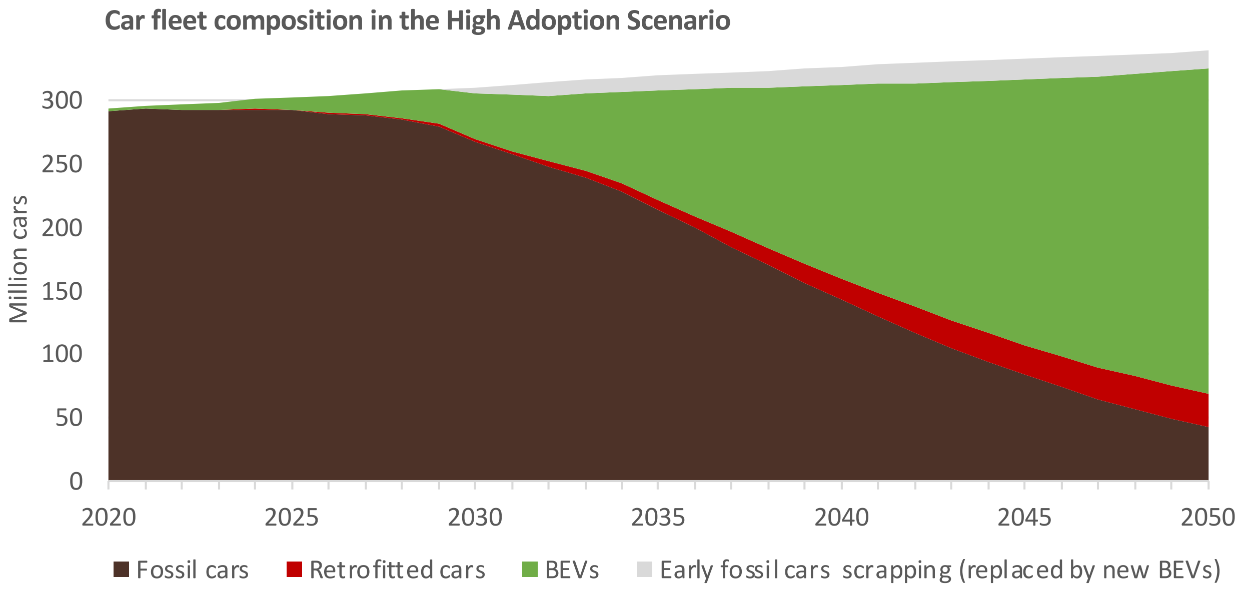
E-RETROFIT DEPLOYMENT



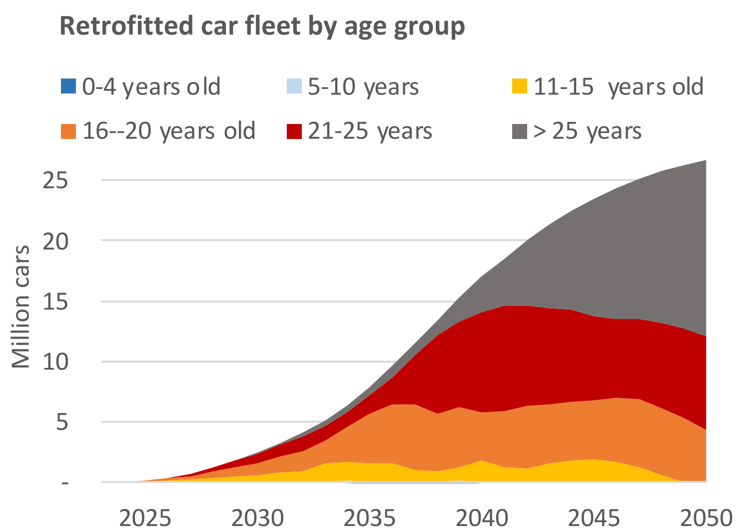
The market takes off in the late 2020ies and plateaus in the early 2040's, when older used EVs become available. In total, 50 million cars are retrofitted over the period. The annual volume of e-retrofits reaches 3 million vehicles per year, which represents about 9% of today's used car market in volume. In the 2040ies, e-retrofit represent a small share of the electric car market (used and new) focused on the affordable segment:

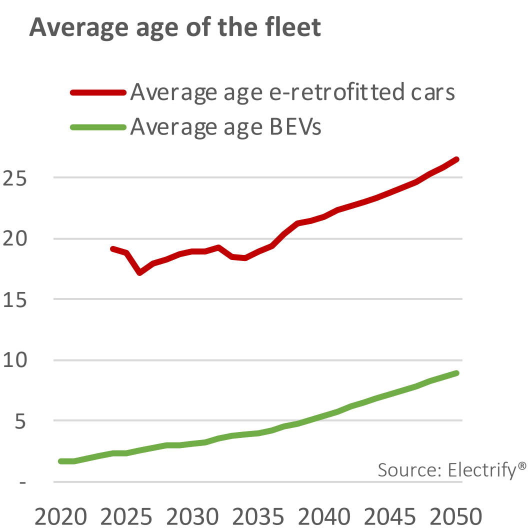


Composition of the fleet. E-retrofited cars constitute a small percentage of the fleet until 2040 and then progressively replace some old small and mid-size fossil cars. The number of retrofitted cars on the roads reaches 8% of the car fleet in 2050, with 27 million vehicles.

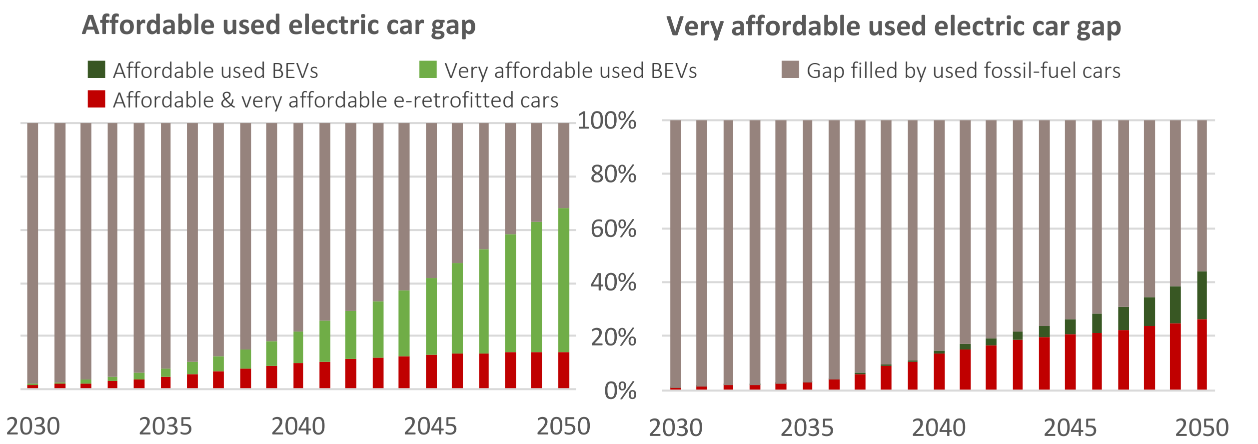


Age of the fleet. The average e-retrofitted car remains above 15 year-old during the whole period and reaches 25 years old at the end of the period. They mostly replace old cars used in cities and suburban areas for commuting and running errands. In most cases, they replace the household's second or third cars. They are also a way for households who switch to car sharing for daily use while keeping their old car for out-of-town gateways. In contrast, the average age of the BEV fleet only reaches 9 years in 2050, compared to an average age of 12 years for the European car fleet today.



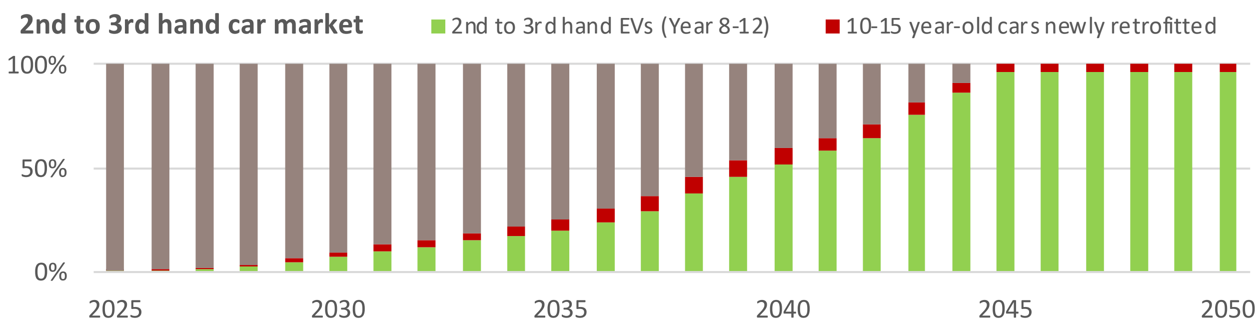


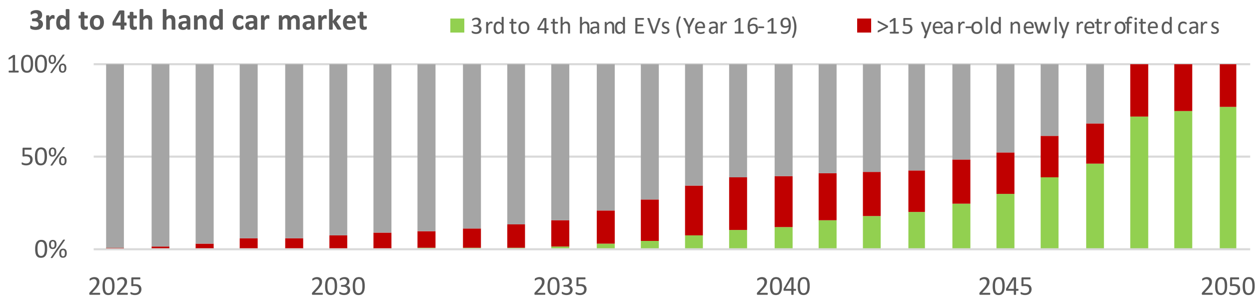
Stock of affordable electric cars. When restrictions on the use of old fossil cars begin to increase their TCO to unsustainable levels (after 2035), e-retrofitted cars help reduce the shortage of old/affordable used BEVs on the market. Most cars retrofitted from 2035 have a net purchase price below €10,000. As shown on the charts below, even if the percentage of retrofitted cars in the fleet remains limited, they play a significant role in building a stock of affordable used car[97], notably on the 20+ year-old segment.

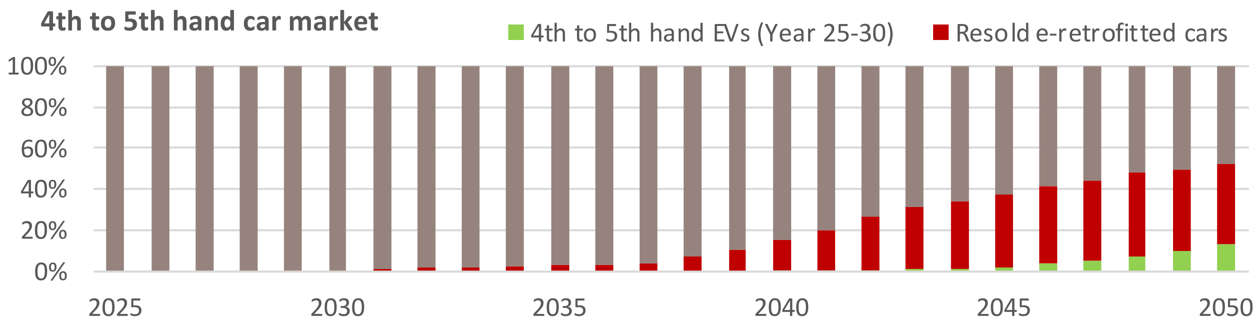


Source: Electrify® Annex/Chap4.3.2

Affordable used car market. The three charts below show how the above-described shortage of old electric cars translates into unmet demand on the used car market filled by old fossil cars (in brown). E-retrofit help reduce this gap. The contribution remains limited for secondhand cars (first chart) but is critical for third- and fourth-hand cars (following charts below). The starting price of a retrofitted car (including subsidy and donor car) drops from €10,000+ in 2029 to less than €5,000 for cars that are 15 years and older, at the end of the outlook period.

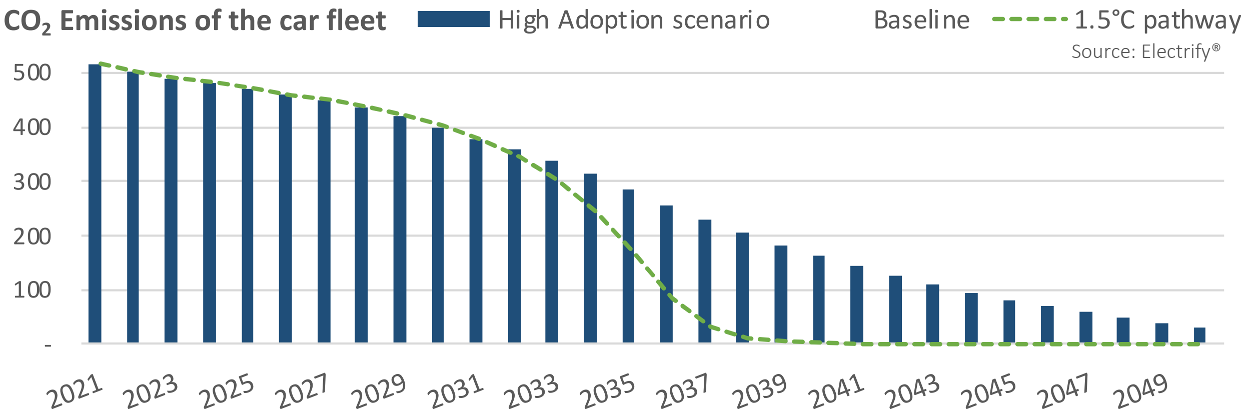






CARBON EMISSIONS

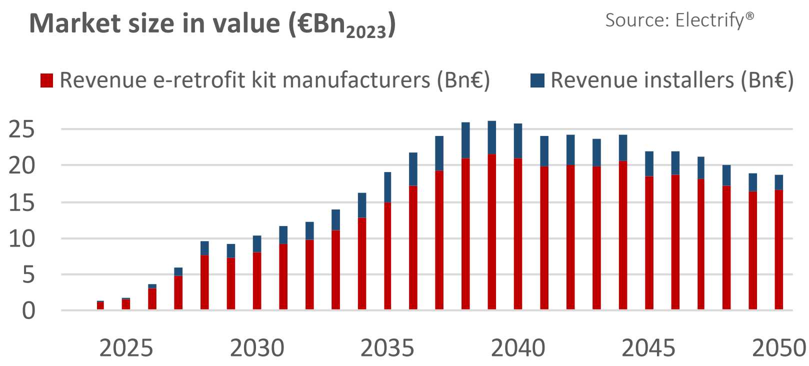
Over the period, about 330 Mt of CO_2 are avoided thanks to early retirements (scrapping and e-retrofits) relative to the baseline scenario, which represents a 4% reduction over the outlook period (2021-2050). The reduction remains limited, representing about 8 months of today's emissions. The overall trajectory remains missaligned with a 1.5°C pathway and closer to the baseline scenario: there are not enough fossil car retirements, and they occur too late, when the 1.5°C carbon budget is already exhausted. Furthermore, most cars retrofitted or scrapped being old, they enjoy a low annual mileage, the most recent fossil cars, associated, on average with higher annual mileage remain on the road.

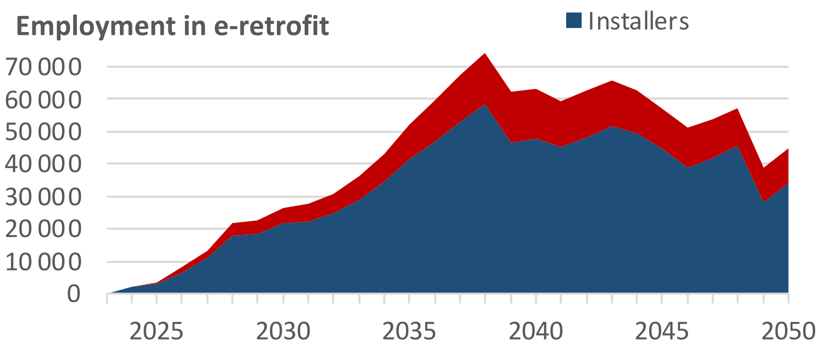


MARKET SIZE

Revenues. The e-retrofit market (kit manufacturing and installation excluding additional refit services and cost of donor cars) peaks at €25Bn in 2037-40, which represents 6% of the used car market in value. Depending on the period, installers capture between 10% and 20% of the revenues. In this scenario we assume that a large majority of retrofitted cars belong to the mini and small segments and retrofits operations, are low-cost.

Job creation. E-retrofit generates between 60,000 and 70,000 jobs at its peak. Kit manufacturing represents about 0.25% of automotive manufacturing jobs, and installation represents 5% of jobs in maintenance and repairs.

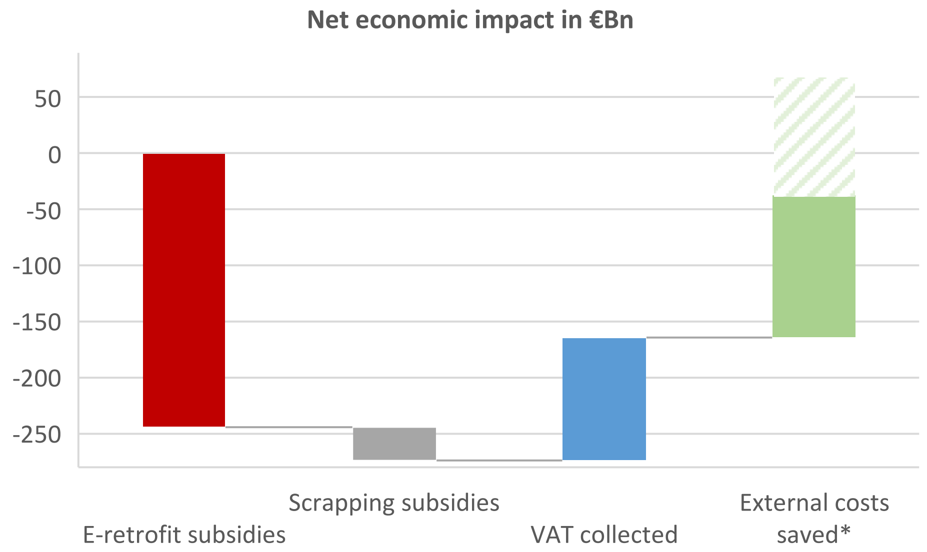




Financing needs. In this scenario, we assume that a large majority of e-retrofits will take place in the context of social financing programs. Pre-financing cover the net cost of retrofit (minus subsidies), as well as the acquisition of the donor car by the retrofit companies for most transactions. From 2030 onwards, most cars are associated with lease-to-buy or are rented. The financing needs peak between €40Bn and 50Bn per year in 2037-2044, which represents about 5% of today's annual car sales (new + used) in value.

COST FOR TAXPAYERS

The net cost of the program is likely to be neutral: the additional subsidies distributed reach €275Bn over the period, for €110Bn of VAT collected on e-retrofit operations (which is also additional). The annual level of subsidies at its peak reaches €15Bn, which is about the current level of EU subsidies for bioenergy, and 3.5% of the current fiscal income from road vehicles in Europe. When the external costs on climate change and pollution are factored in, the net economic impact is slightly negative (about -€35Bn) using the central estimate for the cost of carbon and becomes slightly positive (+€70Bn) using the high estimate (see Annex/Chap1.5).



Source: Electrify®
Annex/Chap1.5

*Cost of climate change & pollution. The central value for climate change impact is 288€/t of CO_2. The high estimate is 719€/t (source: EC guidance).

8.3. 1.5°C SCENARIO

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. 210 million cars are retrofitted in a very short period of time.

KEY FACTORS

Political factors. In this scenario global political instability leads to high fuel prices and prolonged stagflation. Combined with parking restrictions and Zero Emissions Zones (ZEZs), low- income households are gradually priced-out of car ownership in urban and suburban areas. Yellow vests-like protests emerge across Europe. In parallel, several extreme weather events and new scientific findings on climate tipping points increase the level of support of European citizens for more ambitious climate measures.

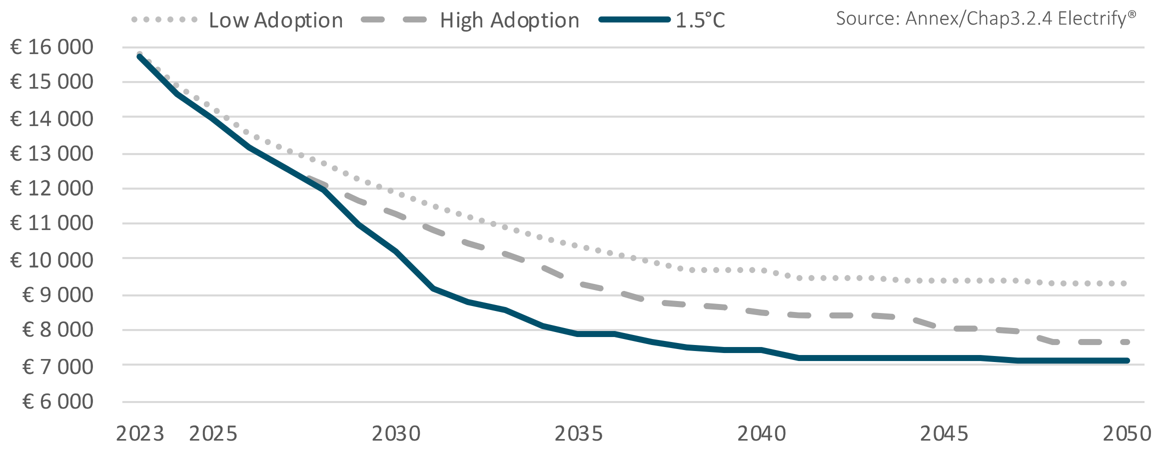
Policies. Zero Emissions Zones are deployed at scale across Europe, combined with social leasing programs and income-linked subsidies to support affordable new and used EVs adoption. Due to high fuel prices, the TCO of EVs become lower than that of fossil cars across Europe by 2028. By 2030, there is a political consensus that supporting affordable ownership of fossil cars became a dead-end.
Expiration dates on fossil cars are introduced gradually from 2030 to 2040, associated with bans on resale and export. Owners are obliged to scrap or retrofit expired cars. In parallel, a massive government-sponsored conversion program is introduced, including social financing solutions and subsidies.

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	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.
Expiration dates on fossil cars	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%).

Cost of e-retrofit. From 2028, the gross cost of e-retrofit (excluding subsidies and donor car) drops much faster than in the High Adoption Scenario thanks to much higher volumes and related economies of scale (see Chapter 6 for details of each factor). The starting price (small car with 16 kWh battery) crosses the €10,000 line in 2030 and drops below €7,500 in 2037 (see next chart below).

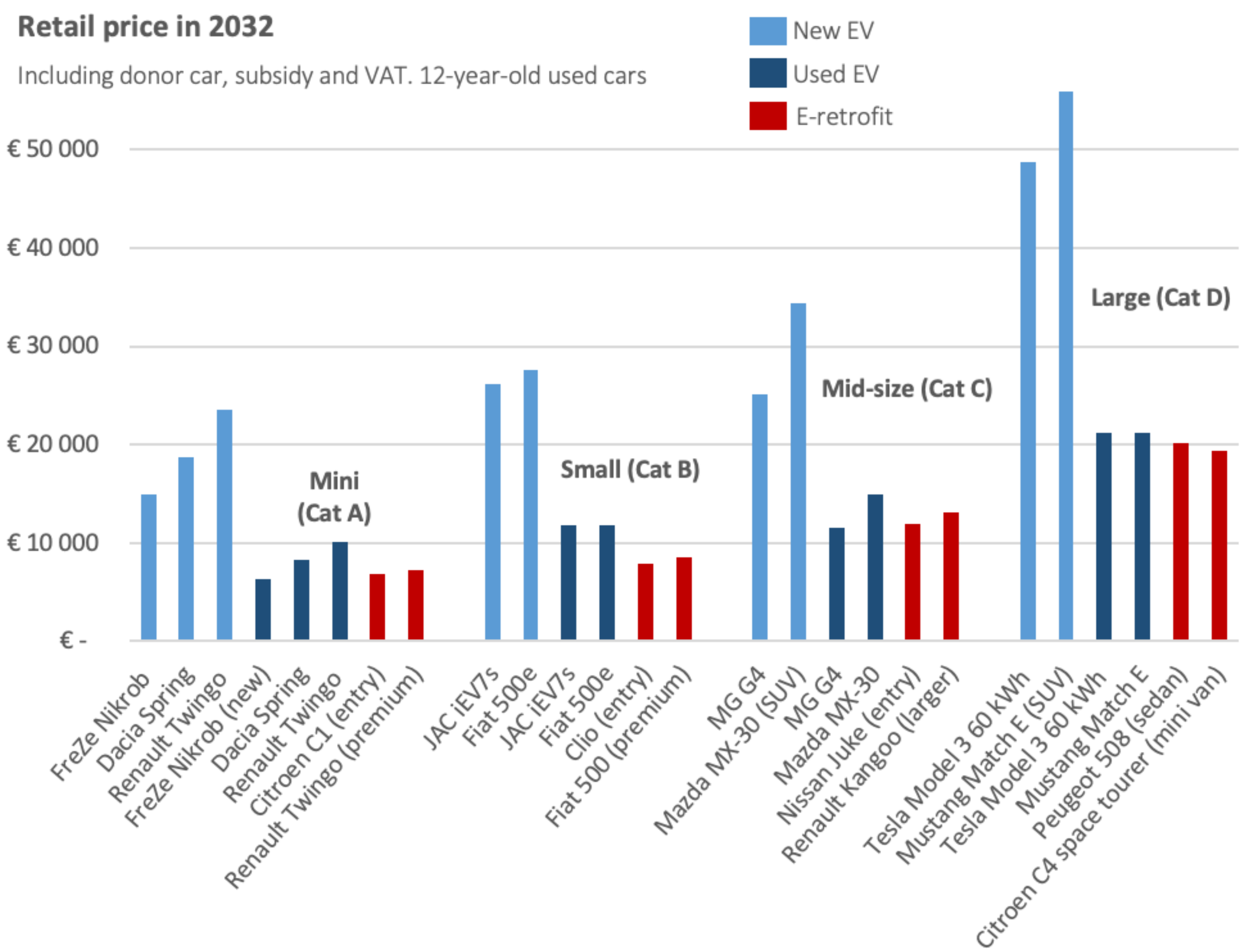
Net price of retrofitted cars. E-retrofit also enjoys a sharp drop in the residual value of donor cars and the introduction of generous subsidies, which combines to boost demand in 2030-2035 before mandatory expiration dates kick-in. Then, subsidies are reduced, but the residual value of donor cars approaching their expiration date remains low (see following chart below).

Starting price of e-retrofit (excl. donor car and subsidies)



Price parity with used EVs. The net price of e-retrofitted cars relative to used EVs drops even faster, driven by inflation for old models on the used electric car market (see discussion in Chapter 6). From 2030 onwards, e-retrofit becomes the affordable electric car solution, becoming cheaper than same-age used EVs for small cars. From 2032, e-retrofit is the cheaper option across all categories (chart below), helping consumer to save up to €2,500 on same-age small cars (see Annex/Chap3.2.4).

Source: Electrify®



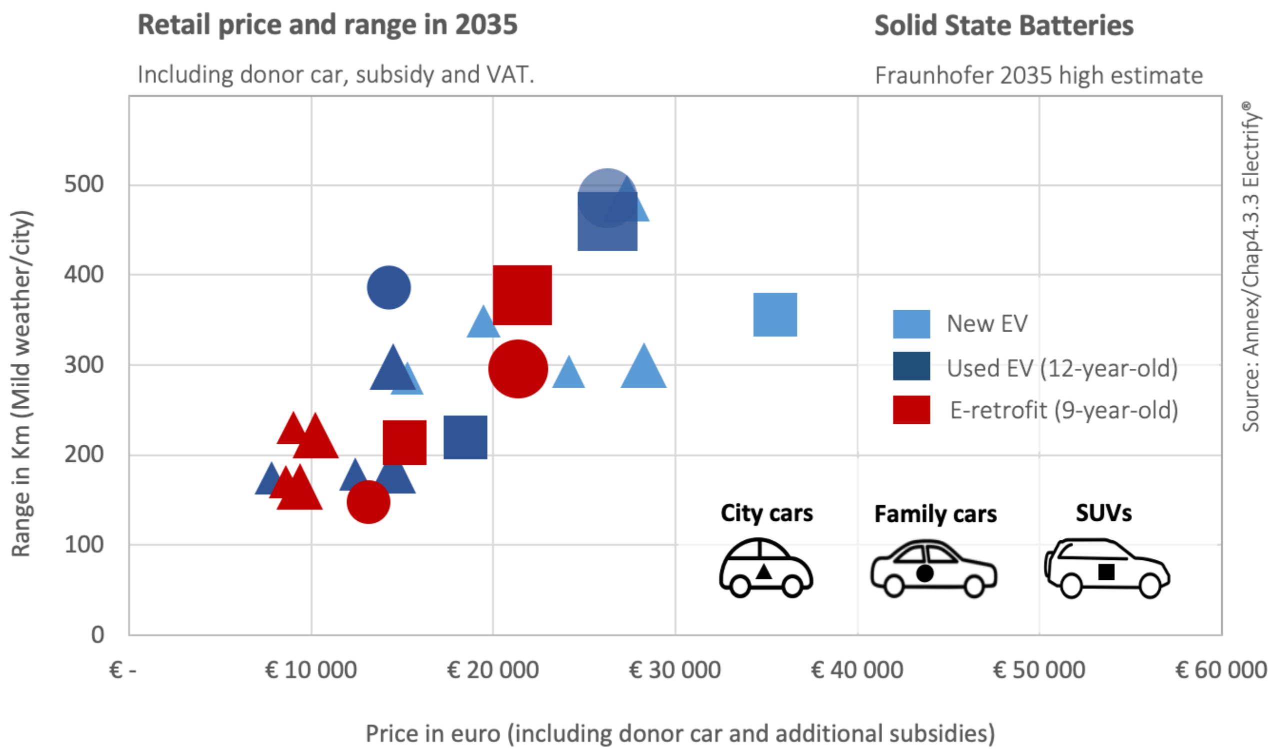
E-retrofitted cars remain the most affordable option for second-hand cars when the subsidies are reduced after 2033 (following chart below). Besides, the important volume of cars retrofitted from 2030 creates a stock of cars that fuels a "second-hand e-retrofitted car market", providing even more affordable options.

Combined with the possibility to reuse batteries for stationary storage in houses (see discussion above in the High Adoption Scenario), e-retrofit becomes a major tool in the European just transition approach.

Barriers. In this scenario, the e-retrofit industry overcomes most of the technical barriers (described in Chapter 7) by the end of the period, although most cars retrofitted by 2030 are relatively old compared to the ideal age window. In the 2030ies, progress in the energy density of batteries and the introduction of solid-state batteries enable retrofits with bigger batteries: e-retrofitted cars reach range parity with used EVs.

Progress in the battery capacity of retrofitted cars (best case, average for the category)

Category	Li-Ion baseline	Lion-Ion 2025	Lion-Ion 2030	Solid-State 2035
Mini	17 kWh	22 kWh	24 kWh	30 kWh
Small	18 kWh	23 kWh	26 kWh	32 kWh
Mid-size	27 kWh	34 kWh	38 kWh	50 kWh
Large	45 kWh	56 kWh	64 kWh	80 kWh



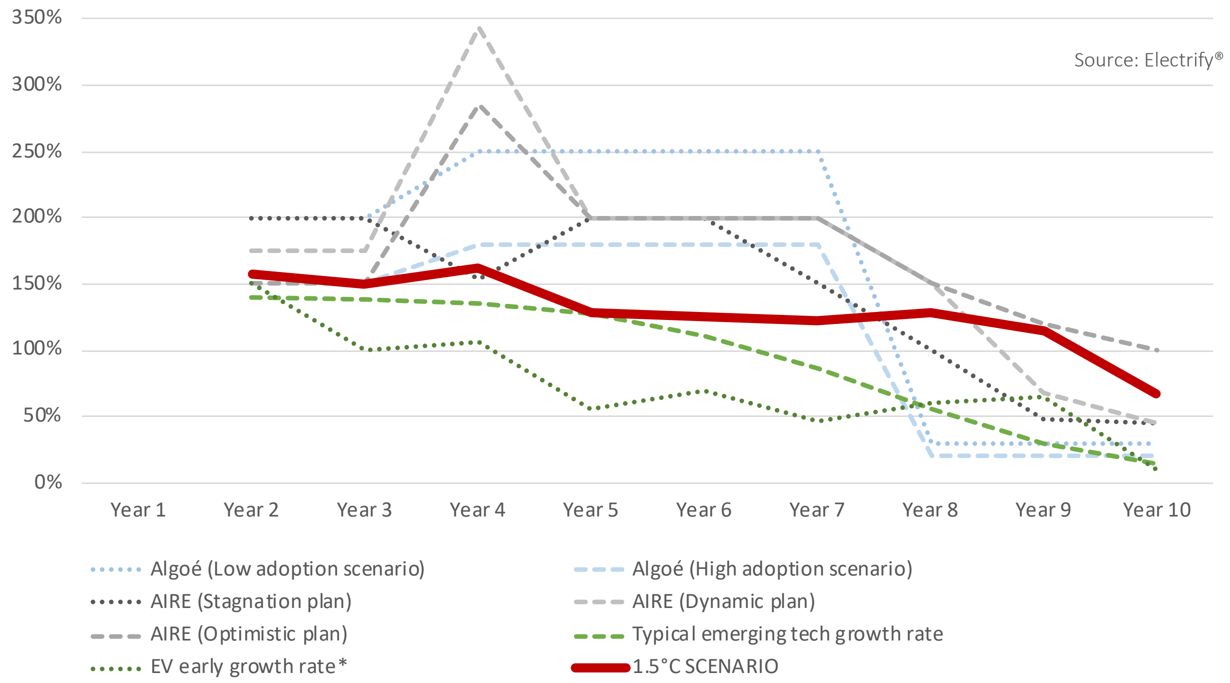
E-RETROFIT DEPLOYMENT

Overall, about 210 million cars with a cumulated residual value of €1 Tn (baseline not factoring in accelerated depreciation) are retrofitted after 2030. It is close to the total technically eligible fleet of 236 million in 2030.

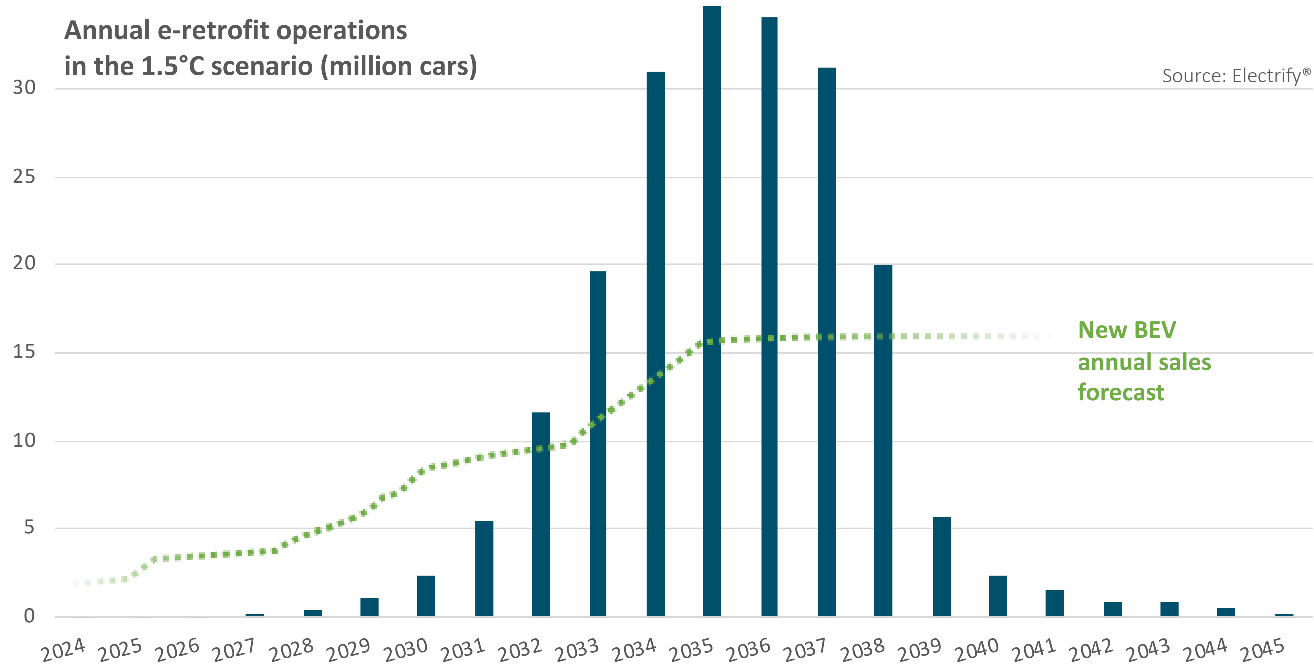
Phase	Period	Volume retrofitted	Target segment	CAGR
Vintage	2023-2027	360,000 cars	19-25 years old vintage cars	+150%
4th hand cars	2028-2031	10 million cars	16-20 years old cars, low-cost conversions	+125%
3rd hand cars	2032-2035	100 million cars	Program focused on cars > 12 years old	+63%
2nd hand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

Early growth rate. In this scenario, the number of retrofits peaks in 2034, after eleven years of growth 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 assumptions at the beginning of the period are lower than those used in previous scenario analysis (Algoé, AIRE) though, but they decline in year 10, instead of year 8 in other scenarios.

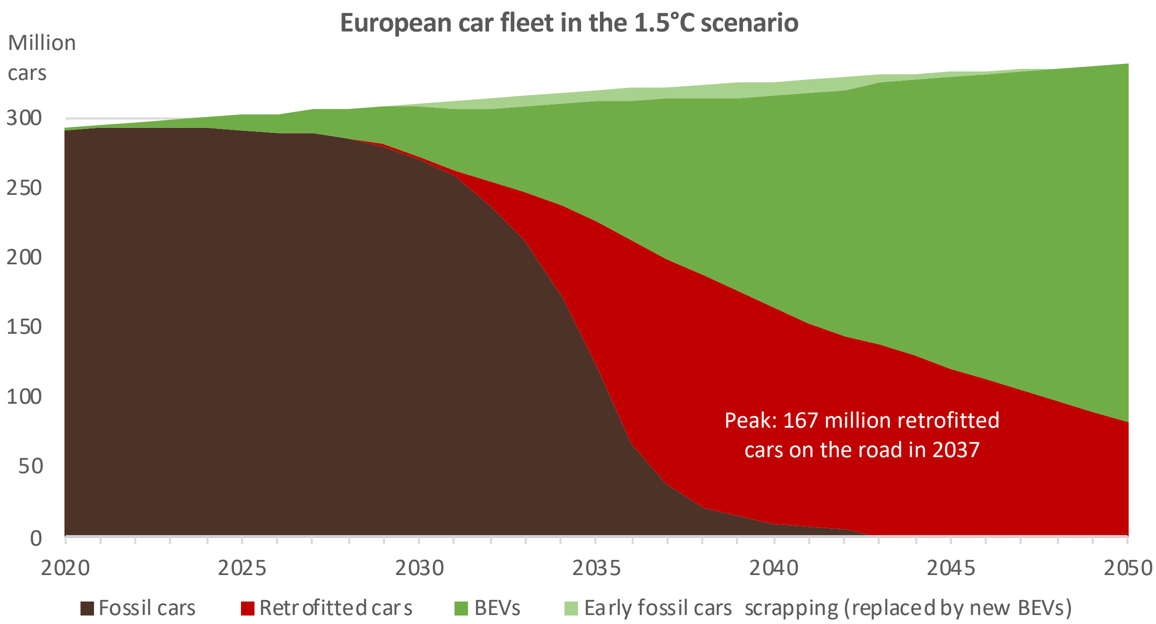
Scenario early-stage growth rate compared



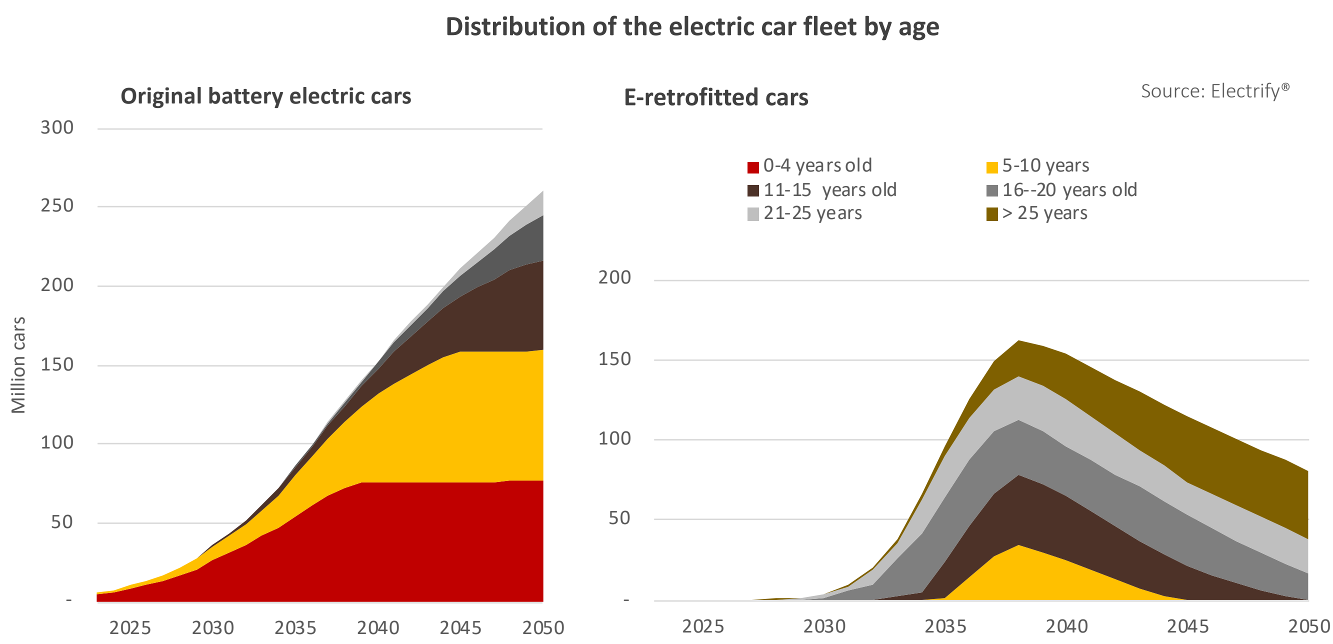
Most cars are retrofitted after the period of high growth. The number of cars retroffited exceeds the volume of new EV sales in the early 2030ies, for a few years. At its peak, the annual volume corresponds to the current size of the used car market. Overall, about 210 million cars are retrofitted after 2030, which is close to the total technically eligible fleet (236 million in 2030).

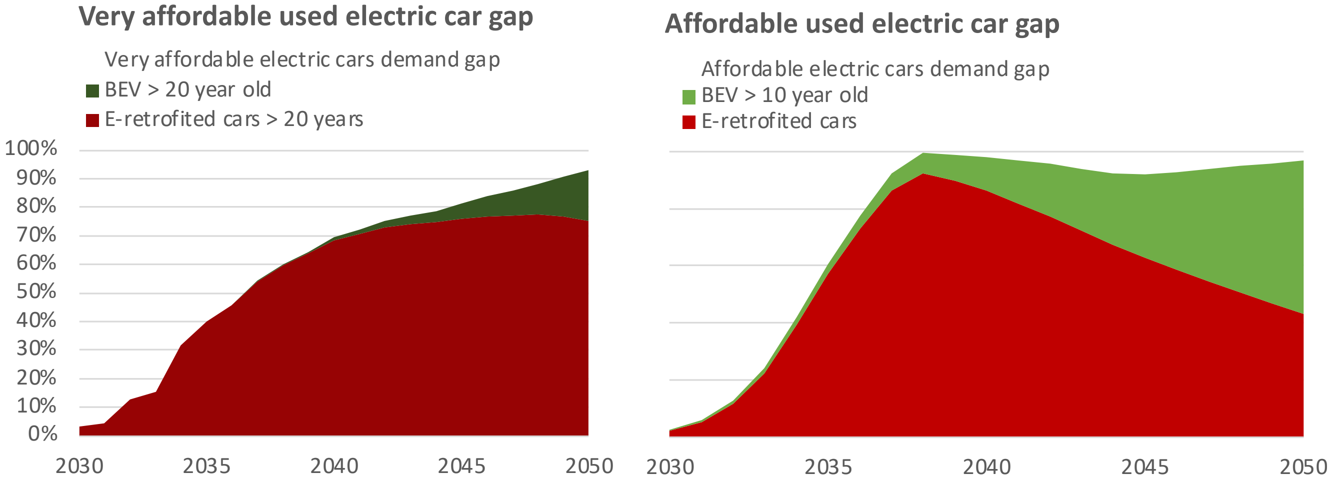


Composition of the fleet. E-retrofitted cars become the dominant powertrain between 2035 and 2040, replacing old fossil cars on the affordable used cars segment. Then, from 2040 onwards, used BEVs gradually replace e-retrofitted cars on this segment.



The e-retrofit market bridges the affordable used electric car gap between 2035 and 2040, when the pressure increases on low-income car owners. Retrofitted cars replace very affordable old fossil cars on the used car market, notably in Eastern Europe, until BEVs take over at the end of the period. As illustrated below, 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.

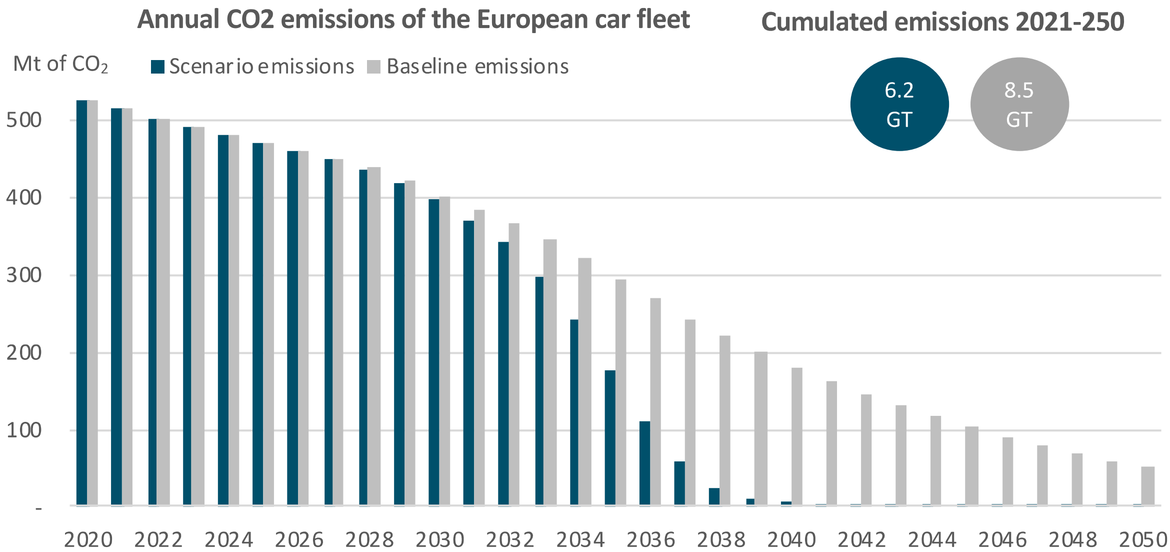




Source: Electrify®

CARBON BUDGET

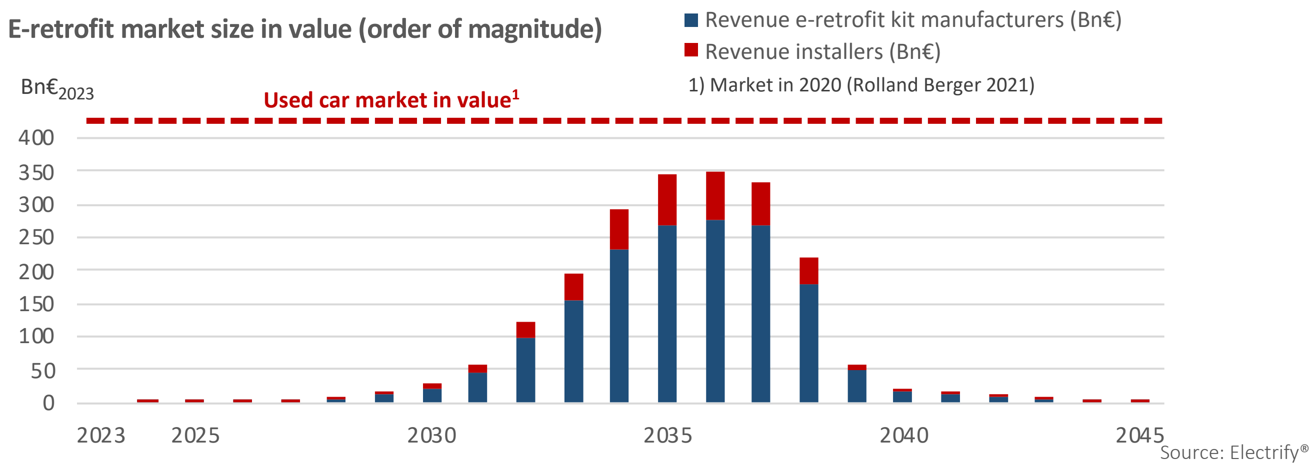
This scenario is designed to align the car fleet CO_2 emissions with the 1.5°C pathway (defined in chapter 1). The fleet reaches zero emissions in 2040, reducing cumulated CO_2 emissions (2021-2050) by 2.3 Gt (-27%) relative to the baseline scenario. The decarbonization effort takes place between 2030 and 2040.



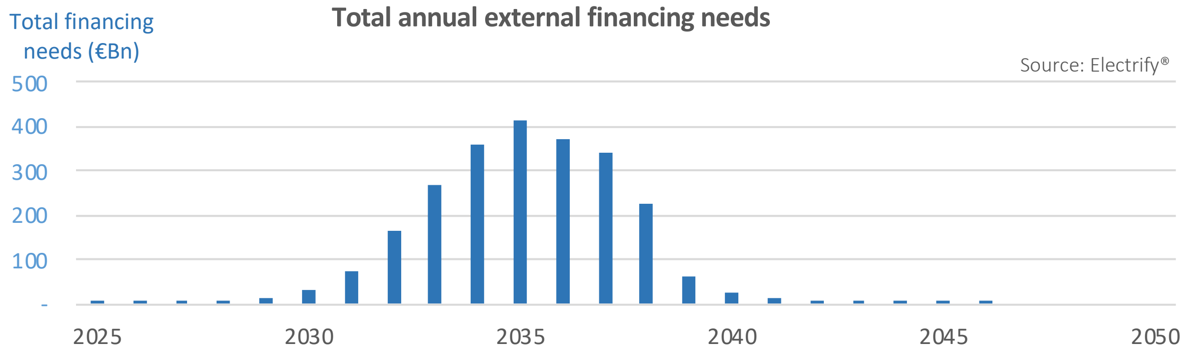
Source: Annex/Chap4.3.3 Electrify®

MARKET SIZE

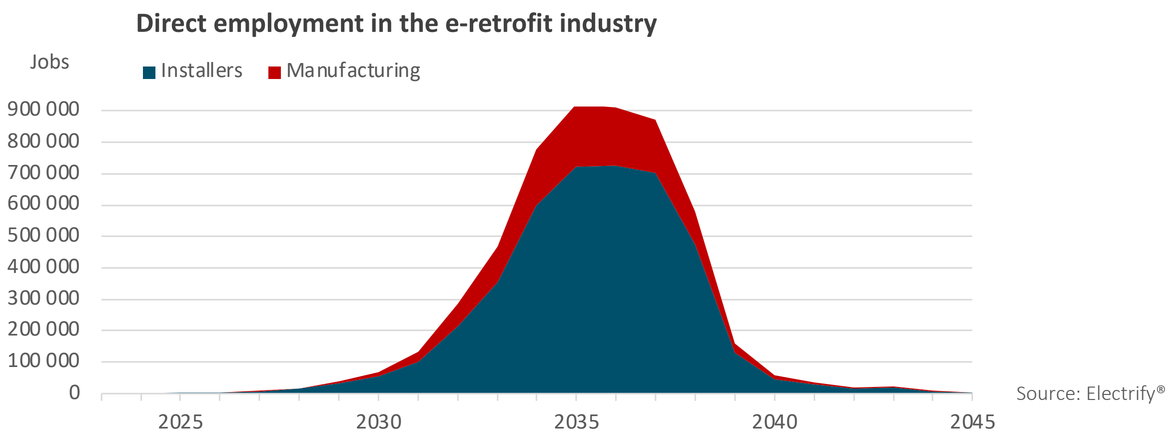
Revenues. In the 1.5°C scenario, the e-retrofit market size in value reaches a magnitude comparable to the car market during its four-year peak. In this scenario, we assume that a large majority of retrofitted cars belong to the mini and small segments until 2035. Then the cars retrofitted mirror the market, with a majority of large cars and SUVs.



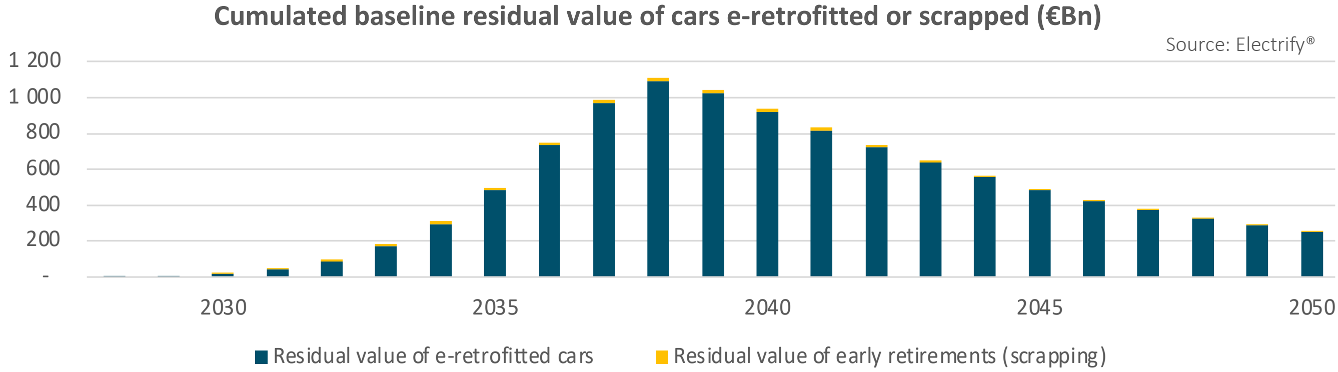
Financing needs. The total amount of financing to cover donor cars and retrofit operations reaches €350 Bn in 2035, which represents 85% of current used car sales (2020 figures).



Job creation. E-retrofit generates 900,000 jobs at its peak, which represents about 7% of automotive manufacturing jobs and 35% of jobs in maintenance and repairs. It is worth noting that job creation concentrates on ten years, which would create challenges to recruit and train the workforce and manage the end of the activity in 2040. However, if the industry takes-off in such a way, Europe is likely to develop facilities to retrofit imported cars and export them and retrofit/refit some cars multiple times.



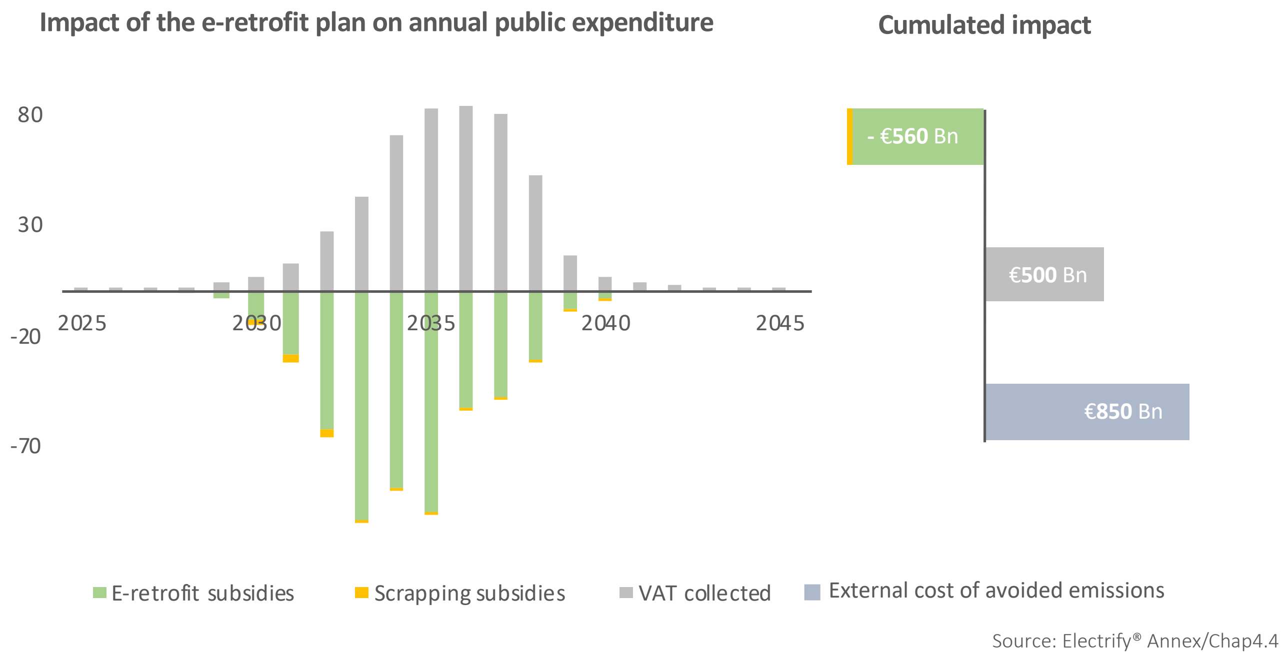
Residual value. The chart below shows the original residual value (in the baseline scenario) of all the cars retrofitted. Assuming e-retrofitted cars keep a similar resale value, the chart provides an estimate of the resale value of all retrofitted cars, each year. The total value declines rapidly due to the retrofitted fleet depreciation and attrition (scrapping and exports).



Purchase and reuse of donor cars (most of them between the age of 10 and 25 years) represent a multi-billion-dollar market during the peak years, equivalent to about 5% of the current used car market in value.

COST FOR TAXPAYERS

Over the course of a few years, annual subsidies totaling just over €100 billion have been distributed, which is equivalent to 25% of the current annual fiscal income generated by road vehicles in Europe. During this time, public spending has reached a total of €560 billion. Nonetheless, a portion of this spending has been offset by the VAT collected, resulting in cumulative net spending of €60 billion. When factoring in the external cost of avoided emissions (central estimate of €850 bn – see Annex/Chap1.5, the overall impact on public finances is overwhelmingly positive.



9. CONCLUSION AND RECOMMENDATIONS

Key figures. The following figures are based on a model that was specifically developed for this paper. It is important to note that they should be considered as approximate estimates based on key assumptions, which are discussed in the Annex. These estimates should not be viewed as a forecast, but rather as scenario outputs that have been used to test different assumptions regarding public policy options and to simulate their potential effects.

CHALLENGES	**240 M**	There will still be 240 million fossil cars on European roads in 2035 and 85 million in 2050.
	8.5 Gt	The legacy European fossil car fleet will emit 8.5 Gt of CO2 from 2021 to 2050, exceeding the 1.5°C carbon budget by 2.3 Gt.
	2.5 Gt	The European fleet is expected to generate another 2.5 Gt of CO2 via used car exports to low-and-middle income countries.
	4 years	The average age of used EV cars in 2035, compared to a 12-year-old average for the current European car fleet.
	20,000€	Based on historical trends, the average used EV in 2035 will cost 20,000€ (compared to 13,000€ for the average used car today).
	1%	In 2035, the demand for third hand affordable used cars and older (> 16 years) will exceed 100 million vehicles and won't be met with used EVs, their total stock being limited to 0.8 million (<1%)
E-retrofit	**40%**	E-retrofit saved 40% of CO2 emissions compared to purchasing a new EV and 70% compared to keep using the fossil car.
	16,000€	The cost of e-retrofit operation today for a small car starts at €16,000 (VAT included, subsidies and resale value of the donor car excluded).
	7,500€	We expect the starting cost to drop to €7,500, €8,500, and €9,700, respectively, by 2040 in the most optimistic (1.5°C Scenario), intermediary (High Adoption), and less optimistic scenario (Low Adoption).
	5,000€	With high subsidies (5,000€) and a collapse of old donor cars resale value (up to -80%), we estimate that the net retail price (donor car and VAT included) could drop below €5,000, making it very affordable.
	12,000€	Without these policy-driven factors, the net price bottoms at 12,000€ which does not make e-retrofit a competitive solution against used EVs.
Volume	**210 M**	210 million cars would need to be retrofitted to align with a 1.5°C pathway, which is possible in theory but require a used fossil cars ban.
	50 M	50 million cars are retrofitted in our High Adoption Scenario, which requires a €275 Bn "Marshall Plan".
	8 M	Without policy intervention, 8 million cars, mostly vintage and sports/luxury cars are retrofitted in our low adoption scenario.
Impact (High Adoption Scenario)	**25 Bn**	In the High Adoption Scenario, the market size reaches €25 Bn in sales in 2040.
	50 Bn	In the same scenario, e-retrofit financing mobilizes up to €50 Bn per year
	60,000	It creates between 50,000 and 70,000 jobs from 2035 to 2050.
	0.3 Gt	0.3 Gt of CO2 are avoided (2021-2050), falling short of the 2.3 Gt reduction needed to align with a 1.5°C pathway.
	165 Bn	The net cost for taxpayers (subsidies – VAT) amounts €165 Bn, partly offset (-€130 Bn) by the external cost of avoided emissions.

Key findings. The research conducted on e-retrofitting shows that it has significant potential for reducing carbon emissions from legacy fossil fuel cars. The following are the main takeaways from the study:

- Policymakers are faced with a difficult choice: either to let old fossil fuel cars on the road until the end of their natural lifetime and overshoot the 1.5°C carbon budget, or mandate an early retirement of fossil fuel cars to meet climate targets, which may result in a shortage of affordable used electric cars.
- E-retrofitting can play a critical role in bridging the gap between these two scenarios, but it needs to become more affordable, and consumers need to become more comfortable with low-range EVs.
- Specific subsidies are required to make e-retrofitting cost-competitive, and regulatory constraints must trigger a drop in fossil cars' residual value while inflating the resale prices of used electric cars.
- Time is of the essence: there is a small window of opportunity to deploy e-retrofitting at scale before the 1.5°C carbon budget is exhausted. Policy action must start by 2028.
- Comparing scenarios reveals that policy action based solely on subsidies, without a fossil fuel car ban for used vehicles, could increase costs to taxpayers by a factor of five, while achieving only one-fourth of the carbon emission reductions.

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

Limitations and future directions. This research report is based on a review of literature, desk research, and interviews with e-retrofit companies. Its limited scope and limitations call for further research:

- The analysis of the roadblocks focuses on endogenous factors, assuming that the potential bottlenecks for the EV market in general, such as the capacity to scale up battery production, deploy charging stations and adapt the electricity grid in time are addressed.
- Given that the industry is still in its infancy and series retrofitting for affordable cars is currently only a project for a few companies, the findings presented in this report come with a significant level of uncertainty. An update will be needed when the first affordable cars hit the road in 2024.
- In this report, we do not discuss potential new or renewed competition from technologies, such as biofuels and synthetic carbon neutral fuels. These alternative technologies are discussed in other upcoming publications authored or commissioned by Transport & Environment.

- Our findings suggest that the market for buses, heavy trucks, and vans will likely take off before the passenger car market. It would call for specific research on these segments. The French environmental agency (ADEME) will commission a study on the matter in 2023.
- The report focuses on the European market. Other markets, such as the US, India, and China seem as advanced as Europe. Studying them could provide further insights.

Key recommendations. Based on these findings and in the context of the EU regulation that calls for an assessment of ways to facilitate the deployment of e-retrofit in the Member States, we recommend the following actions:

- **Data availability:** The research has revealed major gaps in public statistics that prevent the enforcement of potential regulations on vehicle-in-use and end-of-life. Addressing this issue should be a priority, whatever the policy direction. Our research also highlights the shortage of affordable used EVs in a scenario of transition to full electric road mobility. These issues can be addressed through EU-funded research grants such as the Horizon program.
- **Policy debate:** There is no official EU position on what a Paris-aligned pathway would look like for the European car fleet, and what the objectives are on the topic. These challenges call for a structured policy debate at the European level, championed by senior decision-makers at the European Commission, such as a High-Level Expert Group on affordable mobility.
- **Harmonize regulation:** So far, most countries do not have any regulation on e-retrofit, and pioneer countries develop their own regulatory framework. This situation calls for harmonization at the European level, with the EU providing at least guidance to member states on national e-retrofit regulation and potential tax incentives.
- **Public funding:** Limited access to seed funding for e-retrofit companies and pre-financing for pilot retrofit programs is an immediate obstacle. Demonstration projects need to take place today to pave the way for potential large-scale projects at the end of the 2020s. Public policies need to be introduced to create the conditions for raising private capital.
- **Mobilizing car manufacturers:** Car manufacturers could play an important role in the deployment of e-retrofit, both as potential players in this new market and as manufacturers of the cars that will be retrofitted. Short-term actions include sharing the detailed specifications of vehicles and providing access to the software components of mechatronics systems. A debate could also be initiated on the responsibility of car makers in mitigating the in-use emissions of their vehicles. The first step in this direction would be to request car manufacturers to come up with objectives and roadmaps in the context of their climate disclosure obligations.

For further information on the e-retrofit industry and related challenges, visit Electrify.cars

10. TECHNICAL ANNEX

The technical annex is a 200-page slide deck discussing the assumptions used in the report and providing more details outputs for each indicator. The technical annex and additional material can be downloaded on

www.Electrify.cars

CHAPTER I - EU CAR FLEET TRANSITION

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ENDNOTES

[1] Regulation of the European Parliament and of the Council amending Regulation (EU) 2019/631

[2] Fit for 55: a review and evaluation of the EC proposal (ICCT 2022).

[3] Sources: IEA 2022 EV Outlook, T&E (Dec 2022), manufacturers (Dec 2022), IICCT (Jan 2022). Each square represents the brand market share in 2020.

[4] Source: European union co2 standards for new passenger cars and vans (ICCT, April 2022)

[5] European Climate Law, entered into force in July 2021

[6] Fit for 55 package, updated in 2022.

[7] Net Zero by 2050, A roadmap for the Global Energy Sector (2022, IEA) and updated scenario in the World Energy Outlook 2022 (IEA). Scenario consistent with limiting the global temperature rise to 1.5 °C without a temperature overshoot, **with a 50% probability**.

[8] The carbon budget is significantly reduced (< 5 Gt of CO_2) if the probability to keep global warming under 1.5°C is increased to 66%. It further drops (2 Gt) if the allocation is based on the share of global population rather than on a grandfathering approach. See Annex for details.

[9] Our baseline scenario assumes that the car fleet size aligns with the EC reference scenario and car activity modelled by T&E based on population and GDP long terms trends (see Roadmap to Decarbonizing European cars - 2018). Measures aimed at reducing car activity (modal shifts, car sharing …) are not accounted in this scenario.

[10] The lifetime cost of driving a car, Gössling et al, 2022 The definition extends beyond the standard definition of Total Cost of Ownership, including costs for parking, driver license, etc.

[11] Wimoov/FNH survey, 2022.

[12] Low-income households are defined as earning less than €1,285/month for a single person. Lower middle-class is defined as earning between €1,285 and €1,840 of monthly revenues for a single person. Source: Consumption and lifestyles survey, Credoc 2022

[13] IEA EV outlook (2022), Jato (2022).

[14] Bloomberg NEF 2022 EV Outlook.

[15] The Total Cost of Ownership (TCO) is highly sensitive to the use case and the assumptions made (km per year, public charging price, tax incentives, depreciation rate, etc.): for Germany, a small electric car purchased in 2022 could be considered 68% cheaper to 49% more expensive, depending on the scenario and the author. For instance, for a small car in Germany: the Study on the implications of EU policies for the affordability of car use in the future (Transport & Mobility Leuven for FIA, Nov 2022) finds that an EV is 32% cheaper for the first owner than owning an ICE for the base case, but could be 68% cheaper in the best case and 49% more expensive in the worst case scenario. The base results are in line with the results of the study "Electric Cars: Calculating the Total Cost of Ownership for Consumers" (BEUC 2021). However, calculations made on the German website ADAC shows parity, and LeasePlan (2022 - annex) concludes that an EV is more 16% more expensive for the first owner.

[16] www.primealaconversion.gouv.fr

[17] The role of the used car market in accelerating equal access to electric vehicles (ICCT, 2021)

[18] Electric Cars: Calculating the Total Cost of Ownership for Consumers (BEUC, 2021); Study on the implications of EU policies for the affordability of car use in the future (FIA, 2022).

[19] Sustainable Transport Infrastructure Charging and Internalization of Transport Externalities (European Commission, June 2019)

[20] Mehlhart and Kosińska 2017, Trinomics, Oeko-Institut 2020

[21] Effectively tackling the issue of millions of vehicles with unknown whereabouts (German Environmental Agency, 2022)

[22] Source: A Global Overview of Used Light Duty Vehicles: Flow, Scale, Regulation (UNEP, 2020)

[23] Cars "naturally" reach their absolute residual value between 15 and 30 years depending on the brand (CarVertical 2022), and have a Cumulated Survival Probability of 19+ years in Europe and up to 35 years in Eastern Europe (Held, 2021).

[24] New EU type-approval rules for safer and cleaner cars (EC, 2020)

[25] EU regulation, articles 36 and 43.

[26] Interpretation of the European Commission P-000850-16, 2016

[27] Regolamento recante sistema di riqualificazione elettrica destinato ad equipaggiare autovetture M e N1. (15G00232)

[28] https://www.bmwk.de/Redaktion/EN/Artikel/Industry/regulatory-environment-and-incentives-for-using-electric-vehicles.html

[29] Arrêté relatif aux conditions de transformation des véhicules à motorisation thermique en motorisation électrique à batterie ou à pile à combustible.

[30] "Type": same manufacturer, same body structure,; "variant": same number of doors, same number of power axles same engine size ; "version": same weight, power output. Nb: the list of features is not comprehensive.

[31] Amendments adopted by the European Parliament on 8 June 2022 on the proposal for a regulation of the European Parliament and of the Council amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition

[32] Examples of average retail prices for Western Europe. Internal costs for the e-retrofitters can be much lower.

[33] Description based on Comma.Ai (used by 6 000 drivers to date). Other startups include Ghost Automation and Waymo.

[34] This effect is likely to be limited. IIHS found that EVs that are usually new models with limited track record are not involved with more safety incidents than other vehicles and are even associated with less claims.

[35] Based on a survey of 300, 000 vehicle owners, Consumer Reports (US) concluded that reliability issues with all-electric vehicles are more frequent, since most automakers, with the exception of Tesla, launched fully electric models just in recent years and have a tendency to use EV models as a technological testbed. Used market price data for EV suggest that it can negatively impact the resale value: first generations of used EVs suffering a -40% depreciation compared to their ICE equivalent Iseecars.com (2022), WhichEV.net (2022). However, the problem seems to fade away when EV brands build a track record.

[36] *Electric car life cycle assessment based on real-world mileage and the electric conversion scenario* (Helmers et al, 2017)

[37] See also *Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK* (Watts et al. 2021) and *Life Cycle Environmental Benefits from the Use of Retrofit Electric Vehicles in Western Australia; Australian Life Cycle Assessment Society*, Biswas (2013).

[38] Comparison of LCA tools for Passenger LDV BEV (IEA, 2022)

[39] Lifespans of passenger cars in Europe: empirical modelling of fleet turnover dynamics (Held et al, 2021).

[40] How Clean are Electric Cars (T&E, 2022)

[41] A previous study by Algoé for France estimated the necessary time between ratio at 14 to 15 jobs per car.

[42] 1,353,000 jobs in "maintenance and repair of motor vehicles" in the EU as of 2020 according to ACEA.

[43] Notably see Jaguar's announcement (2018)

[44] See VW's announcement (2019) and BMW's (2022).

[45] See announcement video here.

[46] GM Opens Broad Application of EV Component Sets, Advancing the 'Everybody In' Electrification Approach (12/2021)

[47] The 'glider' is the vehicle without the powertrain.

[48] The fleet and sales figures used in this report for "Europe" cover the EU, Norway, Switzerland and the UK (see annex for fleet size calculation).

[49] AXA Classic car Market Review (2019)

[50] Vehicle for Disable Market, Markets & Markets (2019)

[51] It is to be noted that competitors and observers interviewed in the context of the preparation of this study are skeptical about the ability of the industry to reach such low retail price levels. In all cost scenarios our assumptions are aligned with more conservative assumptions.

[52] See Odyssee database for distance travelled by car (2019), European Energy Agency for usage patterns, and Eurostat for commuting time (2019).

[53] Households and the environment in the European Union - Monitoring report No 12 (2020)

[54] We applied differentiated ratios (30%, 25%, 10% 5%) to different countries based on the motorization rate and GDP per capita and then calculated an average ratio for Europe, weighted based on the size of the fleet in 2020. The assumption is that 18% of European households have a second car.

[55] The online boom in used-car sales, Roland Berger, 2021

[56] Autovista 2022 forecasts

[57] Transport & Mobility Leuven (2016), Eurostat (2022), Market data for 2016 extrapolated to 2020 fleet. Prices and income levels in €2023. See annex for details.

[58] Source: governmental website.

[59] Fleet management in Europe (Deloitte, 2017)

[60] ACEA 2020 data for EU+ Switzerland, Norway and UK.

[61] Renault Flin Refactory, website

[62] Other small vans (same price): Peugeot Partner, Mercedes Citan, Opel Combo.

[63] Other mid-size vans (same price): Peugeot Expert, Citroen Jumpy, Mercedes Vito, Opel Vivaro, Ford Transit Custom.

[64] Other large-size vans (same price): Peugeot Boxer, Mercedes Sprinter, Opel Movano, Fiat Ducato.

[65] Over 3.5 tons, 2020 data for EU, UK, Norway and Switzerland.

[66] European Environmental Agency Briefing 2022

[67] Source: European Environmental Agency (July 2019 July 2020)

[68] Total sales of 346 units in 2021 in EU, Switzerland, and Norway according to IHS Markit, including 4 units in Poland.

[69] Zero Emission Technology Inventory (ZETI) database. Dec 2022 for 2023 delivery.

[70] Source: Clean Logistics SE profile by First Berlin Equity Research (2022)

[71] Techno-economic uptake potential of zero- emission trucks in Europe (TNO, Oct 2022)

[72] Sustainable Bus, Feb 2022

[73] Source: IAA transportation.

[74] A full analysis of the economics for buses is beyond the scope of this paper, the conclusions below are based on existing studies, notably Algoé's conclusions on a limited sample of vehicles.

[75] Zero Emission Technology Inventory (ZETI) database. Dec 2022 for 2023 delivery.

[76] Global market share in value, Industry Analysis and Forecast (2020-2026), MMR (2022)

[77] Update on zero-emission zone development progress in cities (ICCT, 08/2022).

[78] According to the OECD definition, an urban area is a functional economic unit characterised by densely inhabited 'cities' with more than 50,000 inhabitants and 'commuting zones' whose labour market is highly integrated with nearby cities. Data: Cities in Europe (PBL 2017).

[79] Clean Cities - The development trends of low- and zero-emission zones in Europe (2022)

[80] Scrapping subsidies during the financial crisis — Evidence from Europe (Grigolon et al., 2015)

[81] 2022 Tax Guide and 2022 EV Tax Benefits & Purchase Incentives, ACEA

[82] www.primealaconversion.gouv.fr

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

[84] Internal combustion engine to electric vehicle retrofitting: Potential customer's needs, public perception and business model implications (Hoeft, 2021)

[85] Source: Statista June 2022, market share of connected cars. 95% in 2022, 98% in 2026

[86] Proposals to boost zero-emission vehicles in corporate and urban fleets (Platform for Electro-Mobility, Sept 2021)

[87] For our scenario analysis, reselling within the European market is considered neutral since it does not change the composition of the fleet. The case of exportation outside the EU is discussed in Chapter 1.3.

[88] Source: Clean Logistics SE profile by First Berlin Equity Research (2022)

[89] The cost of the retrofitted vehicle includes the donor car (10 years old, 100 000km) average market value. It is compared to the closest EVs, used (10 years old or more recent) and new (entry version), in 12/2022 in France. See the Appendix for details.

[90] Global E-Axle Market 2022-2027, Mobility Foresights

[91] Solid-State Battery Roadmap 2035+ (Fraunhofer, 2022)

[92] 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).

[93] Transition One, a startup discontinued in 2023, was targeting conversion of Twingo 2.
[94] Charting the global energy landscape to 2050: Sustainable fuels (McKinsey & Company, 2022)
[95] Renewable electricity requirements to decarbonise transport in Europe with electric vehicles, hydrogen and electrofuels (Ricardo, 2020)
[96] Clean solutions for all - How to clean up the entire car fleet in Europe (T&E 2023)
[97] On the charts, 100% represents the demand for affordable (>10-year-old) and very affordable (>20-year-old) cars. The percentage of the current fleet in this age group is used as a proxy for the demand. In the baseline scenario, the gap will be filled by used fossil cars. See page 25 and annex.