E-retrofit outlook

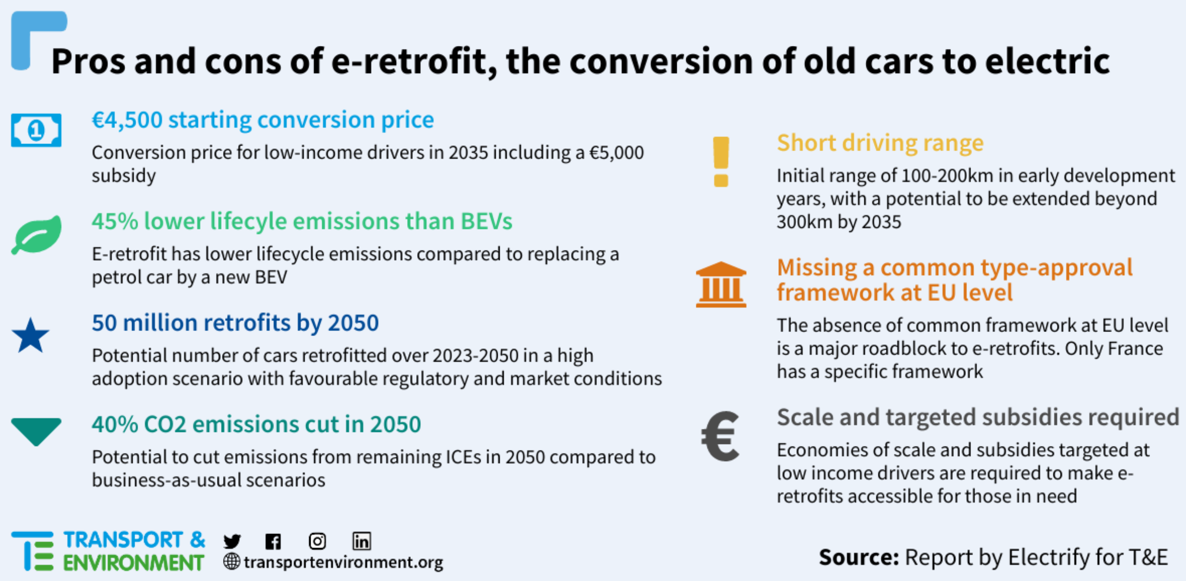
An option to decarbonise the car fleet

October 2023

Summary

To tackle CO_2 emissions from cars, the EU has successfully agreed rules to make all new car sales zero emission from 2035. Following this landmark decision, the focus of environmental policies will also need to shift toward decarbonising the ICEs already on the road as the electrification of new car sales alone will not achieve zero emissions by 2050[1].

E-retrofits are viewed as a possible option to replace old ICE vehicles and reduce CO_2 emissions from the existing ICE fleet. An e-retrofit is the conversion of an ICE vehicle into an EV by replacing the engine and fuel tank with an electric motor and battery pack. T&E commissioned a study to Electrify, a consultancy expert in the e-retrofit market, to assess the benefits and prospects of this technology (see summary infographic below).



[1] https://www.transportenvironment.org/discover/clean-solutions-for-all-tes-car-decarbonisation-roadmap/

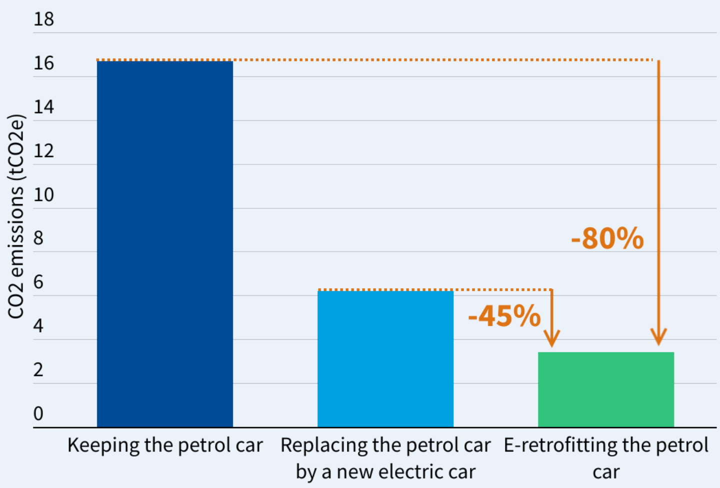
E-retrofit price could start below €4,500 by 2035 when supported by a targeted €5,000 subsidy.

Despite dominating the new car sales, Electrify estimates that the number of used BEVs priced below €9,000 will not be sufficient to meet the demand for very affordable second hand BEVs, even by 2050. As an alternative, under favourable market conditions and with a €5,000 subsidy, the starting price for a direct conversion of a customer's car could be as low as €4,400 by 2035 and below €3,000 by 2045. This would make e-retrofit an option for low-income households and would help to bridge the affordability gap while allowing them to continue to use their old cars and enter city restriction zones.

E-retrofit has the potential to grow from a niche to a larger market in Europe

Initially, due to range limitations (100-200 km), retrofitted vehicles are likely to be best suited for drivers with limited daily mileage and access to local charging. Over the next decade, battery energy density is expected to improve, extending the range of retrofitted cars beyond 300 km. Combined with a denser charging infrastructure, the e-retrofit market has the potential to grow from a niche market targeting mostly drivers in Western Europe to become an option for a wider mass market, including in Eastern Europe. However, the e-retrofit market would need to ramp up quickly as the number of eligible cars (those not too old to be converted, i.e. below 20 years old) will fall from 133 million ICE in 2035 to 17 million cars in 2050 as old ICEs are taken off the road.

Environmental benefit of e-retrofit



Total emissions for a person who decides to either keep their old ICE, or replace it with a new BEV (45 kWh battery, 200-350 km range), or e-retrofit it (20 kWh battery, 100-150 km range). The use phase is 125,000 km after a choice made in 2030 (ICE emissions before 2030 are not included).
Source: Electrify's analysis based on a segment-B car

Most environmental solution

Electrify has estimated the total emissions of small retrofitted cars in Europe assuming a driver converts a petrol car after 100,000km. The retrofitted car has 80% lower total emissions than keeping an old ICE. Compared to a newly produced BEV, e-retrofits would reduce emissions by 45% thanks to the longer use of the old car body and the use of smaller batteries compared to new BEVs.

E-retrofit faces financial and regulatory barriers

Drivers of ICEs that need or want to go electric will have a choice between retrofitting their old ICE or selling it to buy a new BEV, the attractiveness of each option will depend both on the prices of used BEVs and the resale price of the ICE. Higher running costs and implementation of zero and low emission zones are expected to make ICEs less attractive on the used car market. However, a subsidy of €5,000 would be required to provide the necessary incentive for e-retrofitting compared to reselling the old ICE to buy a used BEV. In addition, the current European type approval framework is not designed for e-retrofits, as it is primarily conceived for the approval of new vehicles. This absence of a common framework for e-retrofit is therefore a major roadblock for scaling up e-retrofit and thus reducing the costs of this option.

With support, e-retrofit could cut remaining ICE emissions by 40% in 2050

Electrify has developed a high adoption scenario where conditions are in place to achieve price parity between e-retrofitted vehicles and used BEVs in small and medium car segments by 2035. The annual number of conversions would progressively increase to 3 million units per year by 2040 which could be achieved if 7% of European garages converted one car per week. The cumulative number of e-retrofits could reach 50 million ICEs between 2023 and 2050. In 2050, 8% of all cars on the road would be retrofitted and they would save 41% of the remaining CO_2 emissions compared to a business-as-usual scenario. Over the whole period 2023-2050, 330 $MtCO_2e$ could be saved cumulatively, a reduction of 5% compared to a business-as-usual scenario.

E-retrofit: recommendations to address the barriers to mass-market e-retrofits

While e-retrofits can clearly be an option to decarbonise the existing fleet (alongside e.g. scrappage and social leasing), especially for low-income car-dependent drivers, important barriers need to be addressed to fulfil its potential. T&E recommends the following policy recommendations to unlock the mass market potential for the uptake of e-retrofitting:

- **A favourable regulatory framework at EU level**. The European Commission should propose a new EU regulation for the type approval of e-retrofitted vehicles. The regulation could follow the example of the series-approval implemented in France, streamlining the requirements to ensure the process is lean, fast and cost effective. In the short term, **the European Commission should issue a recommendation to Member States encouraging the adoption of national legislation for e-retrofits**.
- **Financial support**. As the BEV market booms, subsidies for new BEVs could be partly reallocated to e-retrofitting. The use of subsidies for e-retrofits is fully justifiable given their environmental and social benefits. **Subsidies for e-retrofits would be best targeted at low-income households to provide an affordable e-mobility option.**
- **Carmakers' support:** cars on the market are the auto industry's scope 3 emissions. Rather than subsidies, governments can instead set strict carbon budgets for carmakers and require them to clean up the fleet they place on the road. The industry can then either scrap a vehicle and provide a BEV alternative to the driver, or retrofit that vehicle to electric at their own expense. Such an approach would be aligned with the EU polluter pays principle.

1. Introduction

The transport sector is one of the largest emitters accounting for 26%[2] of total EU emissions in 2020 with cars responsible for almost half (46%) of the total transport emissions. In 2019, CO_2 emissions from cars were 25% higher than in 1990, and even in a COVID-19 year such as 2020, emissions were still 6% higher than 1990. To face this issue, the EU succeeded in enhancing its CO_2 regulation targeting sales of new cars. The new standards increase the required reduction in average CO_2 emissions from new cars to 55% in 2030 (from the previously agreed 37.5%) and crucially, require carmakers to only sell zero emission vehicles from 2035. Following this landmark decision, the focus of environmental policies has started to shift toward the decarbonisation of the internal combustion engine vehicles (ICE) already on the road.

E-retrofitting cars is one option for replacing old ICE vehicles and reducing CO_2 emissions from the existing ICE fleet. **E-retrofitting is when an internal combustion engine vehicle is turned into an electric vehicle by swapping out the motor and fuel tank for an electric motor and battery pack.** The rest of the vehicle, known as the "glider," remains untouched. The principle is - as opposed to scrapping the vehicle and getting a replacement - that the driver keeps their current car.

This option for removing ICE cars from the road has been used for years at a very small scale. Now, the solution is being scaled-up mainly in France where it is being facilitated by simplifications in the approval of e-retrofitted cars for use on the road. In 2021, the French Agency for Ecological Transition (ADEME)[3] confirmed its environmental benefit and identified the e-retrofit of small cars as an option for decarbonising road transport.

T&E commissioned Electrify[4] to undertake a study to better understand the scalability of e-retrofitting cars[5] for the European market. The main aim is to identify what financial, regulatory or other barriers could hold back e-retrofitting from realising its full potential. In this report, the European market consists of the EU27, the United Kingdom, Norway and Switzerland. This paper presents the key findings from the study and assesses the future potential of this technology.

2. The e-retrofit conversion concept

Today, the e-retrofit of a car is enabled by a company that designs and manufactures the conversion kit. They also ensure type-approval certification, which allows the e-retrofitted car to be legally driven on the road. This kit contains all of the necessary components (electric motor, power control unit, battery pack, wiring, …) to convert an ICE car into an EV. E-retrofitted vehicles cannot be fitted with battery packs as large as new BEVs because they are limited by the space freed up in the engine bay and at the rear of the

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[2] T&E analysis of GHG data reported by United Nations Framework Convention on Climate Change (UNFCCC) https://unfccc.int/topics/mitigation/resources/registry-and-data/ghg-data-from-unfccc

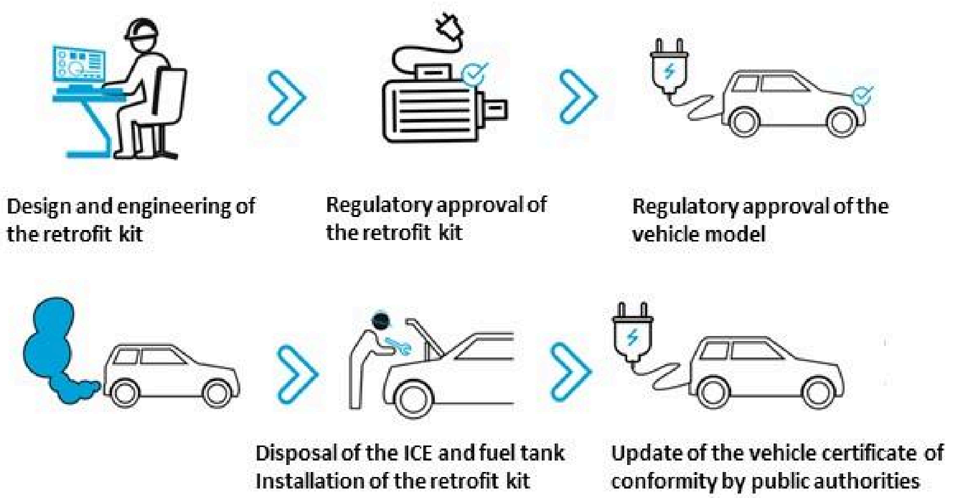
[3] https://librairie.ademe.fr/mobilite-et-transport/4590-etude-retrofit.htm

[4] The report can be downloaded on www.Electrify.cars/e-retrofitEurope

[5] Other types of vehicles such as vans, trucks and buses will also benefit from this new technology, this report is aimed at assessing the technology's viability in the car sector.

car by the removal of the fuel tank. The current range is about 100-200 km and this is expected to increase to about 300 km after 2035 when new battery technologies will be available.

The e-retrofit kit can be installed in cars either by the kit manufacturer or by a network of installers such as car repair shops. Today, e-retrofitting takes a week or more to complete as most retrofit companies are start-ups managing the installation on a small scale. This includes the time needed for retrofitting and any necessary repairs or upgrades (e.g. seats, electronics …). In the future, e-retrofit companies aim to reduce the installation time to a few hours by standardising the kit and the process for specific vehicle models.



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

Figure 1: e-retrofit process in France

In the starting phase of this industry, e-retrofit companies are prioritising the direct conversion of customer vehicles. In the long term, companies may seek to improve the process efficiency by directly sourcing the vehicles, this could progress to setting-up dedicated factories to enable the purchase and retrofit of vehicles in larger volumes.

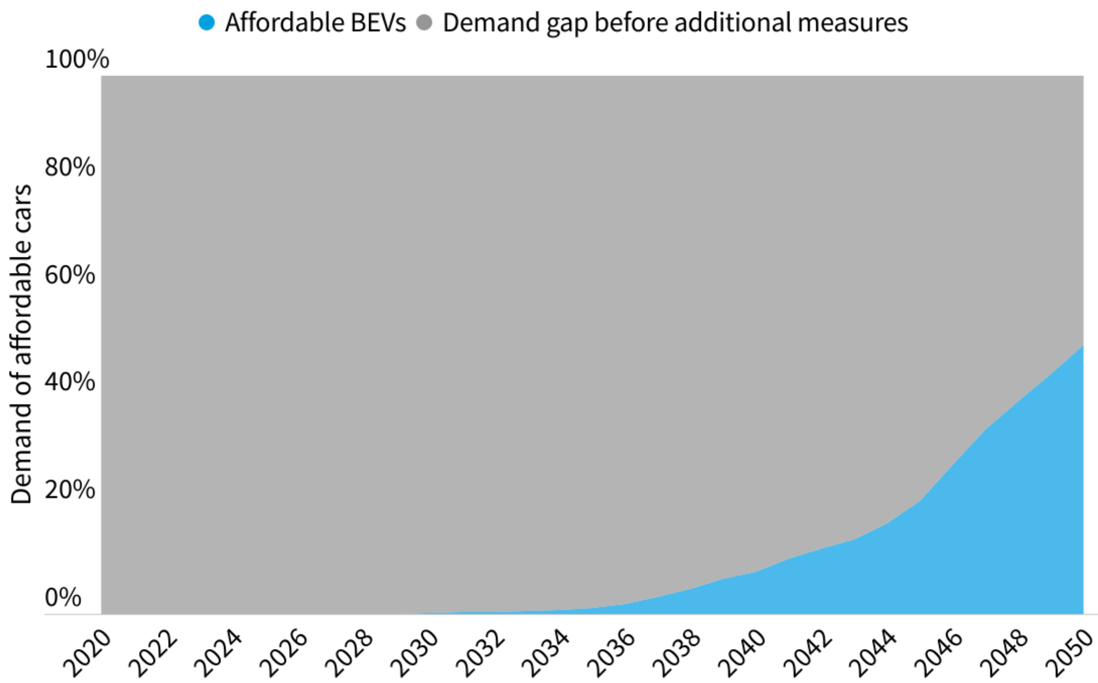
Today, in the car sector[6], e-retrofits are mostly used for vintage and classic cars with a high emotional and monetary value. Starting with the niche vintage and classic cars market appears to be a good launch market for the e-retrofit industry as conversion costs are usually not a limiting factor for these car owners. This would allow retrofit startups to progressively refine technologies and ramp-up capacity. As most e-retrofit companies are still at an early stage of development, e-retrofitting cars is currently an expensive service. The conversion price starts at €16,000 (VAT included, subsidies and the cost of the donor car

[6] E-retrofits are also possible for light commercial vehicles, trucks and buses. These sectors are not covered by this study.

excluded[7]). Despite the early stage of development, e-retrofitting cars already benefits from a high level of consumer interest in some markets. A 2022, IPSOS survey[8] found that e-retrofitting would be preferred to purchasing a new EV in key European car markets including France, the UK or Germany.

3. The social benefits of e-retrofits

ICEs are already more expensive to own than BEVs and will become comparatively less economical in the future, due to falling BEV prices which are expected to reach parity with ICE in all segments by 2026[9]. The cost of running an ICE may be further increased by factors such as high fuel prices and taxes and the use of ICEs in cities is likely to be restricted due to low and zero emission zones. This is expected to drive demand for BEVs, including affordable BEVs in the used car market. However, BEVs are only slowly entering the used car market and the average age of BEVs in the fleet will be 9 years in 2050, compared to an average age of 12 years for the European car fleet today. Electrify estimates that the amount of "very affordable" used BEVs (4th and 5th hand vehicles priced below €9,000) will not be sufficient to cover the demand for affordable BEVs, falling short by 14 million in 2035 and 6 million in 2050.



Scope: 4th and 5th hand vehicles priced below €9,000
Demand gap: 14 million cars in 2035 and 6 million in 2050 would not be covered by used BEVs
Source: Electrify's modeling of European used car sales in a business as usual scenario

Figure 2: BEV share of the very affordable car market

[7] To have a fair comparison of prices, two equivalent approaches are possible: either the price of the conversion alone needs to be compared to the price of a new car minus the residual of the old ICE that would be sold, or to compare the price of e-retrofit (including the residual value of the ICE) with the price of a new car.

[8] https://www.ipsos.com/sites/default/files/ct/news/documents/2022-10/Deck%20Ipsos-Equip%20Auto%202022.pdf

[9] BloombergNEF. (2022). Long-term EV outlook

The shortage of affordable BEVs is likely to predominantly affect low-income households without access to viable alternatives. Active and public transport or car sharing are ideal alternatives to private car use in many areas. But these solutions might not be fully adapted to every region and use case. For a just transition, low income households will need to have the option of affordable private transport when alternative options are not possible. E-retrofits may be a technological solution which can support lower income households in their transition to e-mobility by providing affordable, albeit subsidised, BEVs. We look at other complementary policy solutions in section 8 such as scrappage schemes with social leasing would also bring smaller and affordable BEV en masse in the used car market.

E-retrofits could provide affordable BEVs

With the BEV market booming, subsidies for new BEVs could be partly reallocated for e-retrofitting cars as it provides additional environmental benefits (Section 4), create new jobs in Europe and they would be best targeted at low income households, providing an affordable e-mobility option. Under favourable conditions, where the e-retrofit industry reduces costs and is supported by environmental subsidies[10], the starting price for e-retrofitted vehicles (including the price of the glider) could cost less than €7,000 in 2035 (including a €5,000 subsidy). In comparison, today the starting prices for new BEVs are above €20,000[11] and Electrify estimates that this could drop to €15,000 in 2035 for a low-cost Chinese segment-A BEV. The price of an equivalent used BEV would be in the same order of magnitude as that of an e-retrofitted car, but there would be a risk of shortages as mentioned in the previous paragraph. The starting price for a direct conversion of a customer's car (excluding the price of the glider) would be €4,400 (with a €5,000 subsidy assumed) in 2035 and could drop below €3,000 by 2045. **This would make e-retrofit an option for low income households and would help to bridge the affordability gap**.

Table 1 - Evolution of the starting retail prices across scenarios

Low-cost retrofit with a 16 kWh battery for a 15-year-old segment A car in the high adoption scenario

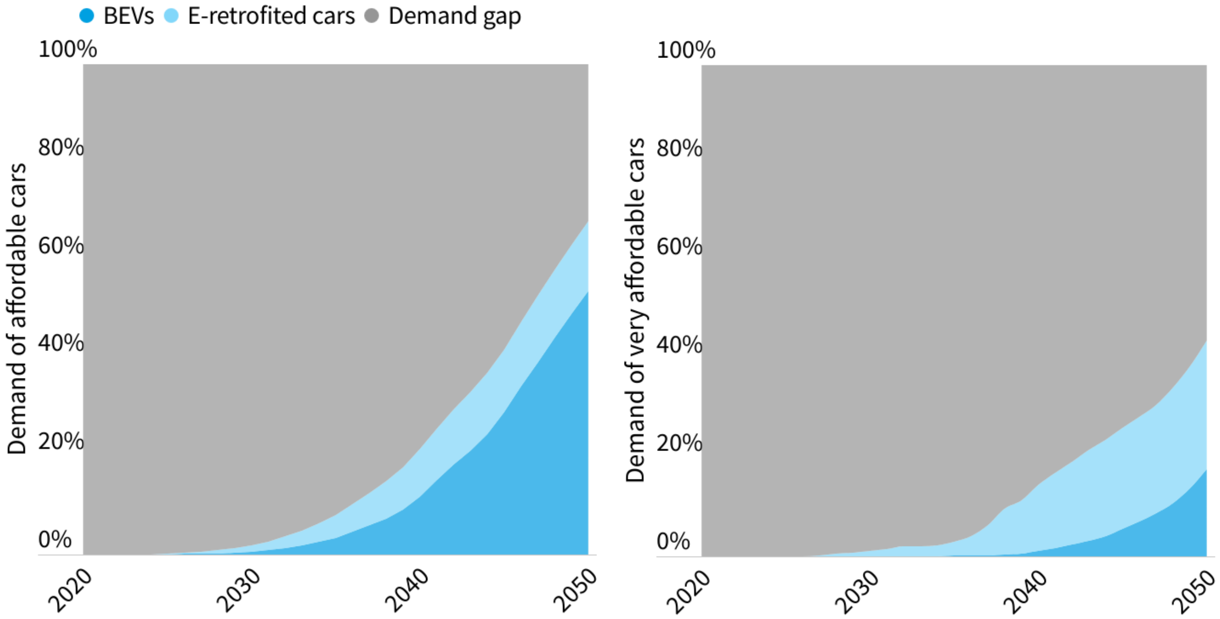
Date	Retrofit (Kit, battery, installation, without donor car)		Retrofitted car	
	Without subsidy	With subsidy	Without subsidy	With subsidy
2023	€15,700	-	€18,500	-
2030	€11,300	€6,248	€13,500	€8,500
2035	€9,400	€4,400	€11,600	€6,600
2050	€7,600	€2,600	€9,900	€4,900

Electrify expects that e-retrofitted cars could reach 14% of the affordable car market (cars older than 10 years sold in the used car market) by 2050 and 26% of the very affordable car market (used cars older than 20 years) under these conditions (Figure 3). E-retrofit is therefore one of the solutions that could fill the gap of affordables zero-emissions vehicles, while other solutions are mentioned in section 8. **Crucially, rather than scrapping someone's car, e-retrofits allow low-income and very low-income**

[10] High adoption scenario described in section 6.3.

[11] Price without subsidies from:
https://all-car-news.com/en/top-10-cheapest-electric-cars-2022/?utm_content=cmp-true

households to continue to use their old cars but enter zero and low emissions zones in cities and, more generally, helps compliance with Europe's climate ambitions.



Scope: European sales of affordable (10-20 year old) and very affordable cars (>20 year old) in the second-hand market
Source: Electrify's modeling of e-retrofit uptake in a high adoption scenario

Figure 3: e-retrofit potential share affordable car market in a high adoption scenario

E-retrofit could support jobs in the maintenance sectors

Aside from providing affordable EVs, e-retrofits have additional social benefits. According to a Boston Consulting Group study[12], new jobs in the EV supply chain will make up for the anticipated automotive job losses associated with the transition away from ICE's in the automotive sector. Nevertheless, the maintenance and repair sector[13] could be affected by the transition as BEVs have lower maintenance costs and time requirements. E-retrofitting cars could be a new revenue stream for this sector, providing new job opportunities. Most e-retrofit kit manufacturers plan to train and certify auto repair shops to install their kits. Electrify estimated the number of new jobs created based on the time required to remove the ICE powertrain and install the kit, including productivity gains as the e-retrofit market ramps up. In a high adoption scenario, **Electrify estimates that e-retrofits could create up to about 60,000 jobs[14] by 2038 in the maintenance sector as well as about 15,000 jobs to manufacture the kits**.

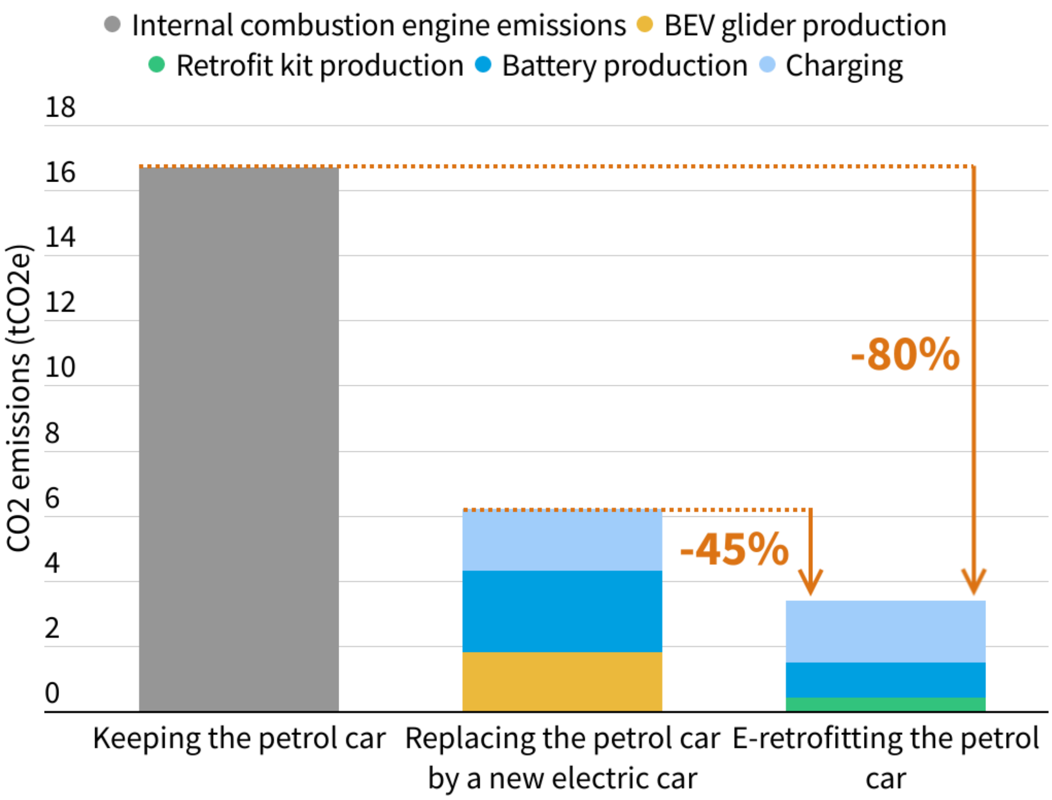
[12] https://www.platformelectromobility.eu/wp-content/uploads/2021/06/20210623-E-mobility_EU-Report_FULL_vfinal.pdf

[13] Electrify estimated that the maintenance cost of a BEV is on average 23% lower than for ICE cars from Lease Plan 2022 data.

[14] Number of jobs required to install the retrofit kit in Electrify's high ambition scenario

4. The environmental benefits of e-retrofits

Electrify used specific data on conversion kit components, Bilan Carbone® emission factors for production, and the T&A LCA[15] in order to estimate the lifecycle emissions of small retrofitted cars in Europe[16]. It is assumed that, post retrofit, the car will be used for another 125,000km before it is scrapped. As shown in Figure 4 below, **a retrofitted car has 80% lower total emissions than keeping an old ICE, and 45% less than purchasing a new EV**. These environmental benefits compared to new EVs are explained by the longer use of the car (the glider being reused), hence the avoidance of the immediate production of a new glider and the use of smaller batteries compared to new BEVs[17].



Emissions for a person who decides to either keep their old ICE, or replace it with a new BEV (45 kWh battery, 200-350 km range), or e-retrofit it (20 kWh battery, 100-150 km range).
The use phase is 125,000 km after a choice made in 2030 (ICE emissions before 2030 are not included).
Source: Electrify's analysis based on a segment-B car.

Figure 4: Total emissions of a small e-retrofitted car

On top of these results, the lifecycle emissions could be further improved by:

[15] https://www.transportenvironment.org/challenges/cars/lifecycle-emissions/how-clean-are-electric-cars/

[16] These results are based on a starting point in 2030 with a small ICE car produced in 2022. The car would be converted at a mileage of 100,000km, and the additional mileage after conversion to the end of life is assumed to be 125,000km.

[17] Due to size and mass constraints, the battery packs used in e-retrofit cars today are much smaller than new BEV packs. These smaller batteries enable a driving range up to 200 km.

- Replacing key components subject to wear and tear so that the e-retrofitted vehicle lifetime could be extended beyond the 125,000 km currently assumed post retrofit. We estimate that this would further reduce the emissions per km of the vehicle by about 28% in its whole lifetime[18].
- Both including used battery cells in the kit during manufacture or reusing new cells after a car's end of life could further reduce emissions. When the retrofitted vehicle is scrapped after 125,000 km post retrofit, the battery would still have remaining life and could be reused (e.g. for stationary storage at home, or potentially to retrofit another vehicle). In this case, the emissions related to the battery production would be distributed between two uses instead of one, leading to lower lifecycle emissions for both the e-retrofitted car and the secondary use. Including used battery cells in good condition (e.g. from written-off vehicles), or packs from another retrofitted vehicle during the manufacturing of the kit could also decrease lifecycle emissions. However, this option would require a strict regulatory framework to ensure the safety of used battery cells and packs.

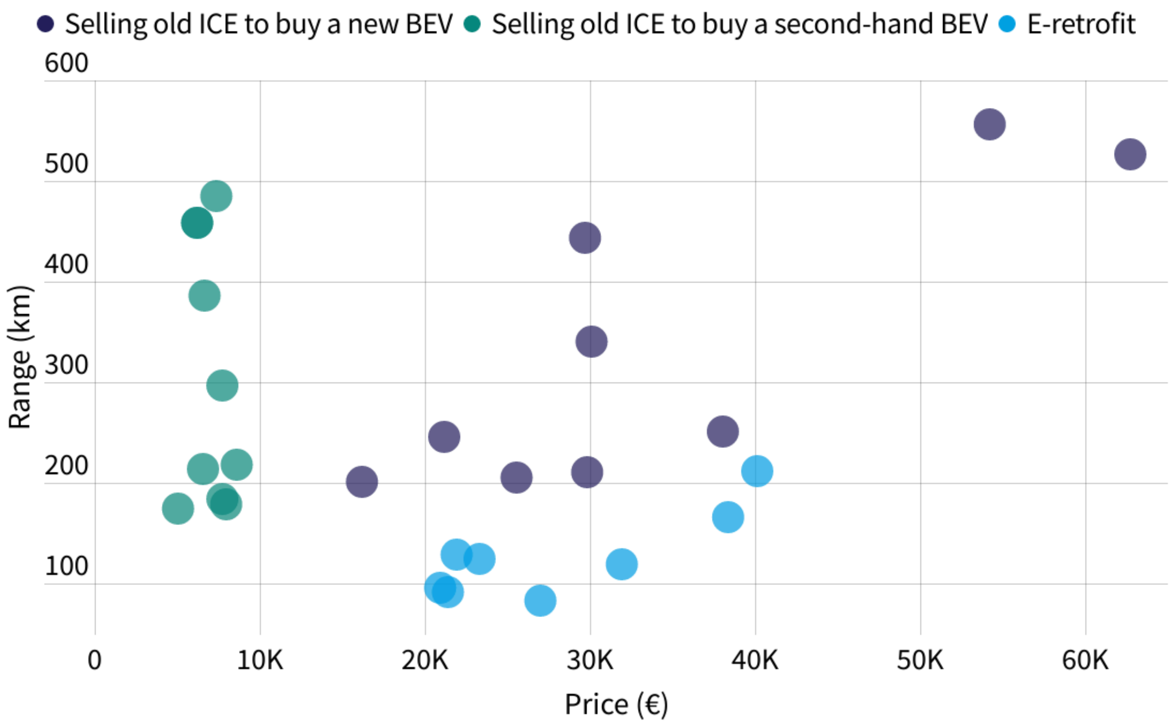
[18] Based on a total mileage of 325,000km compared to 225,000km in the baseline assumption.

5. Main barriers to mass market e-retrofits

At present e-retrofitting cars faces some challenges which could slow-down industry growth if they are not addressed.

5.1. Cost: the main barrier to the deployment of e-retrofit in the mass market

Today, compared to selling an old ICE and buying a used BEV, retrofitted vehicles are more expensive for a shorter driving range (Figure 16 below). For instance, the conversion price of a Twingo[19] is about €18,000[20], or about €11,000 euro (+166%) more expensive than buying a cheap used electric car[21].



E-retrofit price including residual value of the old ICE and subsidies

Source: Electrify analysis from public data

Figure 6: Range and price of a selection of electric cars in 2022

The main factors for these high prices are:

- **Battery pack manufacturing cost:** e-retrofit startups are manufacturing their own battery packs in small volume which carry a large premium compared to OEMs' mass manufactured packs.
- **Kit manufacturing and installation processes** which are not optimised due to the current low volume market.

[19] Twingo 2 from 2012 converted with a 16kWh battery by Transition One. Price reported by Electrify.

[20] Including the old car residual value and excluding potential subsidies.

[21] Electrify reports that the price of a used Peugeot Ion (from 2013, 16 kWh battery, 75000 km) would be €6,700 in the used car market.

To bring e-retrofit to the mass market in the future, costs could be lowered by:

- **Falling battery prices**: BloombergNEF[22] forecasts that the average battery pack prices are expected to drop by 59% between 2022 and 2035.
- **Decrease of the premium on e-retrofit battery packs**: with economies of scale and the design of more standardised packs which could be used across several vehicle models, e-retrofit companies could reduce the premium paid compared to OEMs packs. Cooperation with OEMs or suppliers to buy their smallest battery packs, or existing components, would support the cost decrease. If e-retrofit companies are authorised to recover used battery packs or cells, costs would further decrease.
- **Kit manufacturing and installation costs reduction**: with economies of scale, mass production of the kit by e-retrofit companies or through partnerships with industrial actors would reduce kit costs. Buying used ICEs in batches and retrofitting them in factories would unlock a further reduction of costs.
- **Subsidies:** in 2022, some countries such as Croatia, Greece, Malta and Romania offered purchase grants above €9000[23] to buy a new BEV when scrapping an old ICE. With the BEV market booming, subsidies for new BEVs are expected to drop and could be reallocated for e-retrofitting. Use of subsidies for e-retrofits is fully justifiable given the environmental and social benefits of e-retrofits. E-retrofit subsidies would be best targeted at low income households, providing them an affordable e-mobility option. In France, subsidies of up to €5,000 are already given for the e-retrofit conversion alone[24] and total subsidies (including scrapping and zero emission zone local subsidy) could reach up to €12,000 according to Electrify[25].

The overall attractiveness of e-retrofitted cars will also depend on changes in prices in the used car market. Drivers will have the choice between converting their car or selling it to buy a new BEV, the attractiveness of each option will depend both on the prices of used BEVs and on the residual value of the ICE. Due to higher running costs and implementation of zero emission zones[26], ICEs are expected to eventually lose attractiveness in the used market. This could result in faster depreciation and it will become less financially attractive to resell an used ICE. Electrify assumes that extra-EU ICE exports would need to be restricted as such exports could impact the resale market price. Conversely, lower operating costs and environmental awareness will lead to increased demand for used BEVs, potentially resulting in slower depreciation and lower affordability of used BEVs. Lack of ambitious EU CO_2 reduction targets in the 2020's and early 2030's could also hamper supply of new BEVs in the EU resulting also in a limited

[22] BloombergNEF. (2022). *2022 Lithium-Ion Battery Price Survey*
[23] https://www.transportenvironment.org/discover/the-good-tax-guide/
[24] https://www.service-public.fr/particuliers/vosdroits/F35285
[25] Today, low-income drivers living in Paris can accumulate different subsidies (the French subsidies for the conversion, the scrapping subsidy of the old ICE and a specific subsidy for low-income drivers living in Paris' low emission zone).
[26] Zero-emission zones (ZEZs), which will no longer allow the use of vehicles with internal combustion engines, are emerging. Two small scale zero-emission schemes already exist in Oxford and part of Central London, and there are plans for a total of 35 ZEZs to be implemented by 2030.
https://cleancitiescampaign.org/research-list/the-development-trends-of-low-and-zero-emission-zones-in-europe/

supply to the used market. Therefore, owners of used ICEs could find themselves in a situation where reselling their ICE would be financially unattractive, the price of used BEVs might be prohibitive or the supply limited. This may encourage drivers to retrofit their cars instead.

5.2. Lack of an easy pathway for approval of e-retrofits in Europe

Today, the European type-approval framework is not designed for e-retrofits, as it is primarily conceived to approve new vehicles. This means that the current regulatory framework for approving cars for use on EU roads is a major roadblock for scaling up e-retrofit.

Some Member States already apply simplified approval procedures for individual vehicle conversions (Netherlands, Germany, UK), while France introduced the first regulation for series e-retrofit approval in 2020[27]. The French framework grants approval to e-retrofit kits which are specific to one model family (e.g. different variants of the VW Golf VII). This includes approval of any technical changes (e.g. in terms of weight, power, size). Belgium is considering to adopt similar series approval rules[28].

In France, the time required for approval of e-retrofits for a new model is estimated to be between 24 and 36 months for new companies, which increases the time to market of retrofit products and increases costs. This could be reduced to 6 months with a streamlined process. To encourage widespread retrofitting, the Electrify study found that the EU and Member States would need to put in place a favourable regulatory framework. As of today, such a measure is included as a non-binding recital in the EU car CO_2 standards[29], which aims to encourage e-retrofit in the EU and asks the Commission to undertake an assessment of ways to facilitate retrofitting as a solution in the Member States. The European Commission could further this by proposing a new regulation with harmonised requirements for series approval of e-retrofits and in the short term issuing a recommendation to all Member States to adopt series approval rules for e-retrofits following the French example or a variant of it.

The French regulatory framework

The French national regulatory framework for e-retrofitted vehicles creates a model on how to overcome the EU type-approval barrier and provides the opportunity to scale by defining the conditions for series approval. The law allows the conversion of a car from 5 years after its registration and identifies two regulated entities: the manufacturer of the conversion kit and the installer. The manufacturer needs to obtain the approval for a prototype (i.e. a type of vehicle from a certain vehicle's series, e.g. Golf VII, converted with a conversion kit), and then produces the conversion kit (components) as well as the specifications for the standard conversion process. Each single e-retrofitted

[27] https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041780558
[28] https://www.brusselstimes.com/349901/belgium-prepares-to-embrace-electrical-retrofitting-of-petrol-cars
[29] "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 by assessing how to facilitate the deployment of such solutions in Member States." https://data.consilium.europa.eu/doc/document/ST-14869-2022-INIT/en/pdf

car will not need to be type-approved, as what is approved is only the prototype. The approval of the prototype is designed in a way to ensure respect of the EU type-approval requirements, and in particular of the safety requirements. For instance the battery pack is subjected to a crash test, simulations are required to ensure the resistance of the pack attachment points to the vehicle, the mass of the retrofitted car should not exceed 20% of the original car and the difference of weight distribution between front/rear axle should not exceed 10%. The conversion of a vehicle can only be carried out by an installer in France authorised by the manufacturer, which has received specific training. An installer can be authorised for one or more types of vehicles. The manufacturer guarantees the preservation of the integrity of all the elements of the vehicle converted and assumes responsibility for their deterioration. The installer is responsible for verifying that the vehicle conversion conditions are compatible with the safety requirements of the approval of the vehicle; in addition, they ensure that the vehicle to be converted is in good mechanical condition. At the end of the conversion, the installer provides the manufacturer with a conversion certificate. The manufacturer issues and signs a certificate of conformity, which is sent to the holder of the registration certificate so that the registration certificate of the converted vehicle can be updated.

5.3. The lower driving range

E-retrofitted vehicles cannot be fitted with battery packs as large as new BEVs. The current range is 100-200 km and this is expected to increase to about 300 km after 2035 when more energy dense battery chemistry will be available. This issue of limited electric range can be a real barrier for some long distance drivers, but for a majority of drivers, a range of 100-200 km is sufficient to address their daily commute needs. Furthermore, as charging infrastructure networks are deployed and drivers get more accustomed to BEV use, we expect range anxiety to also reduce. These issues are expected to be less significant when the density of charging infrastructure is increased and when fast-charging is easily accessible during longer trips across Europe. For instance, all main motorways will need to have a charging hub every 60 km by 2025, and this requirement will be extended to all secondary highways by 2030[30].

In the 2030s, developments of new battery technologies with higher energy density, such as solid state batteries[31], could become a game-changer for the e-retrofit sector as the technology will enable greater electric range for the same battery size (in e-retrofit applications, battery size is restricted due to limited flexibility in fitting the battery in the vehicle). Even though e-retrofitted cars are not expected to compete with new or second hand BEVs in terms of performance, they could become competitive with used BEVs in terms of cost. Cars e-retrofitted after 2035 could be fitted with more advanced batteries compared to used BEVs produced in the 2020s, therefore the gap in the range between retrofitted cars and used BEVs will be reduced.

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30 https://www.transportenvironment.org/discover/eu-deal-on-truck-charging-clears-the-way-for-ambitious-CO2-targets-2/

31 https://www.transportenvironment.org/discover/will-future-batteries-be-greener/

5.4. Technical considerations

The main technical limitation of e-retrofits is the management of electronics safety systems fitted in cars, for instance the electronic stability program (ESP) that controls braking as well as more advanced driver-assistance systems such as adaptive cruise control. As e-retrofitting modifies the electronic system and wiring, it will require a recalibration of these systems. E-retrofit companies will have to spend additional R&D capital to develop technical solutions to enable this. Partnerships with car manufacturers and parts suppliers to get access to the software systems could benefit retrofit companies and potentially reduce R&D costs. Additionally, the European Commission could set up a cross industry task force (including carmakers and e-retrofit companies) to investigate the technical barriers and solutions to e-retrofits including how ICE vehicle design could be improved to make future e-retrofits of the vehicles technically easier.

Current e-retrofit solutions are not designed for plug-in hybrid vehicles (PHEVs) as more CO_2 could be saved from retrofitting conventional ICEs and the volume of PHEVs sold is lower than of pure ICE vehicles. Nonetheless, retrofitting PHEVs could be considered in the future as these vehicles are already fitted with an electric powertrain, potentially simplifying the e-retrofit process.

6. E-retrofit uptake scenarios

6.1. Market potential

In the next 10 years, e-retrofits have the potential to grow from a niche to a larger market in Europe. Due to range limitations (100-200 km), retrofitted vehicles will likely be best suited for households that have access to local charging and have limited daily mileage. Corporate and municipality fleets with low daily mileage could also benefit from this solution. In both cases, the implementation of low and zero emissions zones[32] in cities in the medium term is expected to be a key driver of adoption.

In the next decade, battery energy density is expected to improve, and the range of retrofitted cars is projected to increase from 100-200 km in the 2020s to beyond 300 km after 2035. Combined with denser and faster charging infrastructure network, expected as a result of the Alternative Fuels Infrastructure Regulation (AFIR)[33], and drivers developing new habits, the shorter range will be a less limiting consideration. In that case, e-retrofits would become adapted to most common use cases. Moreover, as described in section 5.1, e-retrofitted car prices are expected to decrease and these vehicles could become a solution for low-income households. **From an initial niche market targeting wealthy drivers**

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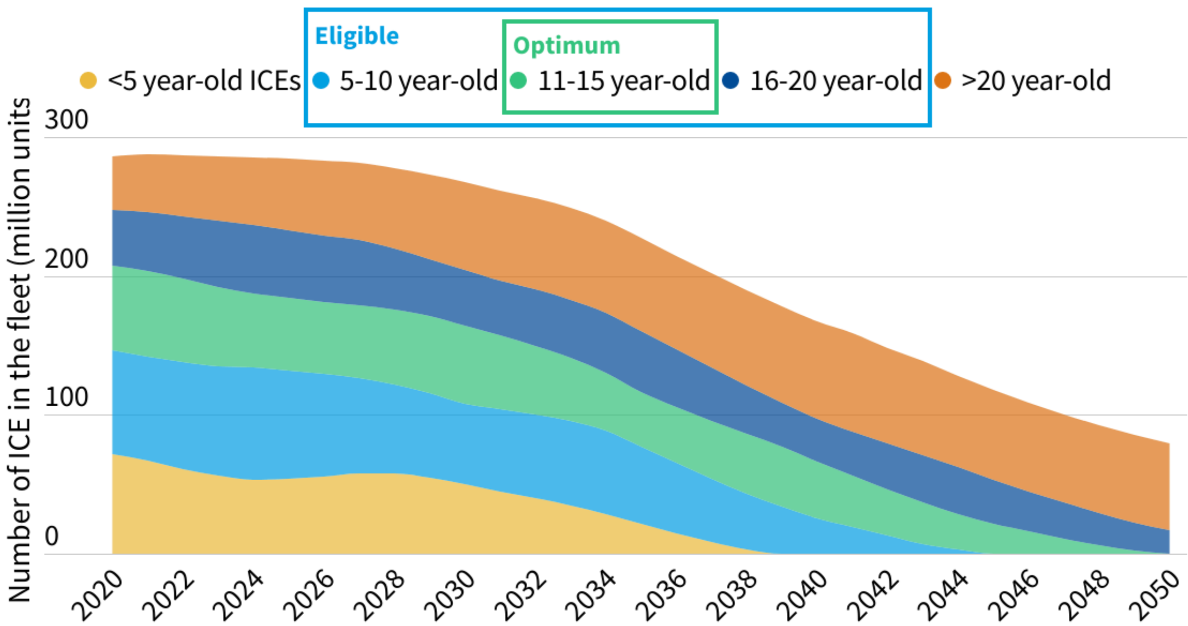
32 https://cleancitiescampaign.org/wp-content/uploads/2022/07/The-development-trends-of-low-emission-and-zero-emission-zones-in-Europe-1.pdf

33 For instance, all main motorways will need to have a charging hub every 60 km by 2025, and this requirement will be extended to all secondary highways by 2030. https://www.transportenvironment.org/discover/eu-deal-on-truck-charging-clears-the-way-for-ambitious-CO2-targets-2/

in Western Europe, e-retrofitting has the potential to become an option for a wider market, including Eastern Europe.

The optimum age window for retrofitting is considered to be 10 to 15 years. The eligibility window could be stretched up to 20 years old[34]. Beyond, e-retrofit becomes suboptimal due to the limited remaining lifespan of the glider in good safety condition. In its scenarios, Electrify excluded cars older than 25 years, except for classic vintage cars, with heavy retrofits. On the other end of the spectrum, the window can be stretched to 5 year-old cars. For vehicles less than 5 years old, e-retrofitting is currently not authorised in France where a regulatory framework is in place. Given the relatively high resale value, a conversion is unlikely as owners would prefer to resell the ICE vehicles. In 2035, there will be about 230 million ICEs in the European car fleet. Based on these considerations, 17% of these cars (40 million ICEs) will be in the optimum e-retrofit range (11-15 year old) and 61% (139 million ICE) will be in the eligibility range (5-20 year old). In 2040, the number of eligible cars will decrease to 97 million ICEs (58% of the fleet) while 17 million eligible cars would still be in the fleet in 2050 (21%).



Source: Electrify's European ICE fleet modelling and eligibility range for e-retrofitting

Figure 5: Age distribution of the EU ICE fleet (in the absence of additional measures)

6.2. Low adoption scenario

Electrify defined different scenarios for the ramp-up of e-retrofits in Europe[35] as well as an outlook of the conversion costs depending on the rate of uptake.

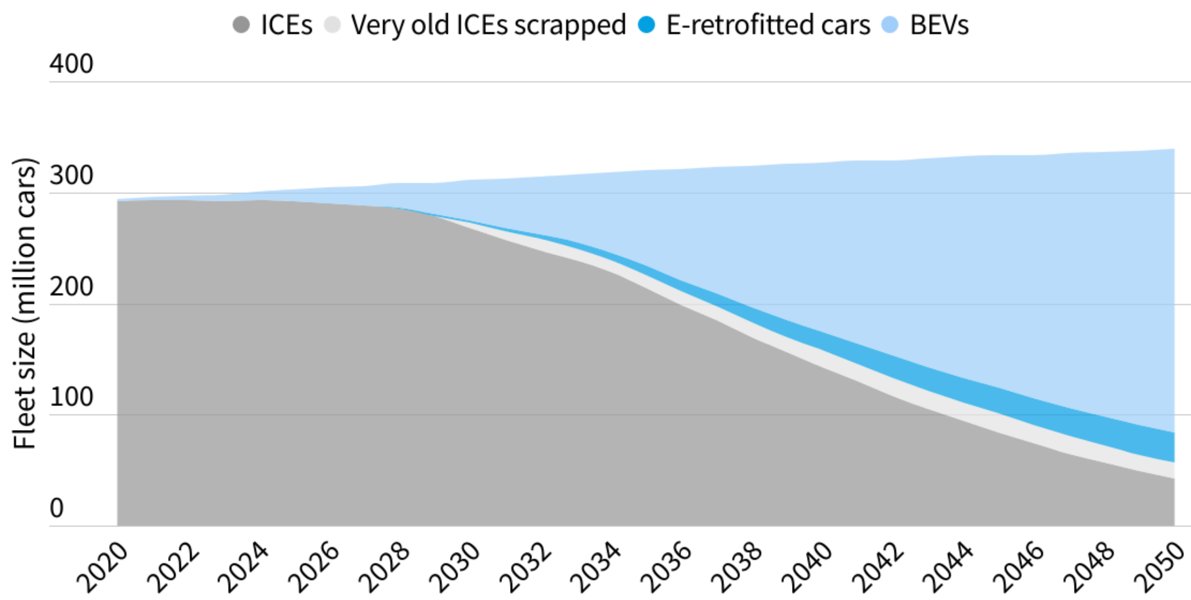
[34] In the case of 20-year-old cars, additional refitting and mechanical part change would be required and this increases the cost of the operation, making it less attractive for consumers.

[35] In Electrify's report, the European scope is EU27+UK+NO+CH

In a business-as-usual scenario where no additional regulations are put in place to reduce existing car fleet emissions, no widespread subsidies specific to e-retrofit are put in place, and if e-retrofit companies fail to ramp-up their production volume to reach economies of scale, then a maximum of 5.5 million cars would be retrofitted before 2050 (and 2.5 million between 2050 and 2070). Most conversions are expected to take place after 2045 if policymakers need a last-minute solution to deal with a large remaining ICE fleet. In the meantime, the use case would stay limited to vintage cars and low-range use cases due to continuing high costs of e-retrofits.

6.3. High adoption scenario

This scenario was designed by defining conditions to reach price parity between e-retrofitted vehicles and used BEVs in most car segments by 2035. In this scenario, the annual number of conversions would reach 3 million units per year by 2040, which represents about 9% of today's used car market in volume. **The cumulative number of e-retrofits would reach 50 million ICEs (older than 10 years) between 2023-2050.** This would result in 27 million retrofitted vehicles in the European car fleet in 2050[36] as shown in Figure 17 below.



Very old ICEs scrapped refers to cars older than 35 years.
Source: Electrify's modelling of the European car fleet composition with a high adoption of e-retrofit

Figure 7: e-retrofitted cars growth in the European fleet in a high adoption scenario

Conditions to achieve the high adoption scenario

Electrify's scenario is based on the assumption that ICEs older than 35 years would not be allowed on the European roads, that they would need to be retrofitted earlier in their lifetime. A specific scrapping scheme would need to support the removal of the remaining very old ICE that were not e-retrofitted and Electrify assumes that extra-EU ICE exports would need to be restricted. These conditions would lead to

[36] Vehicles retrofitted in the first part of the period would be retired before 2050.

the early scrapping of 63 million ICEs by 2050 and cause the ICE residual values to drop by 20% relative to the business-as-usual scenario. As discussed in section 5.1, the decrease in resale price of used ICEs would support the adoption of retrofit as ICE owners would earn less from selling the used ICEs.

Despite this reduction in the residual value of ICEs, additional conditions are required to further incentivise e-retrofitting. Electrify's scenario assumes strong financial support from public authorities, with a €5,000 subsidy for all e-retrofits, and zero emissions zones would need to be established in cities across Europe from 2035 onwards to drive car users aways from ICEs. However, subsidising all retrofits with public money is not an efficient use of limited resources and budgets. Other alternative measures can drive the market towards delivering this high adoption scenario. Electrify's model assumes that only economically rational retrofits are made (i.e. the retrofit is cheaper than the cheapest second hand electric car), and that middle-income households would not retrofit their car, so subsidies would only benefit low-income drivers. In reality, any drivers might want to e-retrofit its cars, for instance for environmental reasons or because of circulation restrictions, and it would not be necessary to provide a €5,000 subsidy to all e-retrofitted cars[37]. Below are highlighted some of the measures which could help unlock the right market conditions to achieve a high potential scenario:

- The €5,000 subsidies must be targeted at cars owned by low-income households. In this case, the use of subsidies for e-retrofits is fully justifiable given their environmental and social benefits. It is expected that the targeted subsidies would need to be focused in higher proportions in the Central and Eastern European countries (compared to Western European countries). This is due to the higher proportion of older second hand ICEs in the fleet and higher proportion of low-income households.

- Regulatory conditions can provide additional reasons for drivers to choose e-retrofit. European Member States could create conditions that discourage ICE use as part of their national energy and climate plans (NECPs). The introduction of the EU emissions trading system for buildings and road transport (EU ETS 2) is expected to make ICE ownership more expensive, thus discouraging it further.

- Phasing out the ICE fleet towards 2050 should not be the sole responsibility of public authorities and can be shared with OEMs. Carmakers have placed the cars on the market and as such are responsible for their carbon pollution as part of their scope 3 emissions. Rather than subsidies, governments could instead set strict carbon budgets (or limits on the use of old vehicles) and require them to clean up the fleet they place on the road. This would require carmakers to either scrap a vehicle and provide a BEV alternative to the driver, or support the funding of e-retrofits. Such an approach would be in line with the EU's polluter pays principle.

[37] Electrify modelling compares the price of the retrofit with the price of the cheapest BEV. This is relevant with regards to the switch of the lowest income drivers as most of the drivers could make the switch and scrap their old ICE without opting for the cheapest option (e.g. purchasing an average price 2nd or 3rd hand BEV).

In this scenario, the starting conversion cost of a small car (excluding the ICE residual value) would drop below €9,500 by 2035 (and down below €4,500 when a €5,000 subsidy is included). This would make e-retrofit a solution for the affordable market as discussed in section 3. Although subsidies should be targeted for the low income drivers, the consultants find that even in the scenario where a €5,000 subsidy is allocated for all the e-retrofits, the overall cost-benefit balance (including externalities) of removing the ICE cars from the road is largely positive. Indeed, in the theoretical scenario where the €5,000 subsidy is given for all e-retrofits in combination with a scrappage scheme for remaining ICE older than 35 years old[38], then the total cost of the scheme would reach €275 billion all over Europe between 2023 and 2050. But €110 billion would be collected by Member states from the VAT on the conversion price, so the net cost of the program would be limited to €165 billion. This cost could be in part shouldered by public authorities (e.g. via revenues from pollution, like the Social Climate Fund) or by the industry (as part of a polluters-pay responsibility as mentioned above). The annual level of subsidies at its peak reaches €15 billion, which is about 4% of the current fiscal income from road vehicles in Europe[39]. If external costs related to climate change and pollution are factored in[40], Electrify estimates that this plan could save Europe up to €70 billion overall.

The challenge of industrial growth

Another challenge in achieving this high adoption scenario is related to scaling at speed. The scenario assumes a fast industrial growth in the 2020s with 840,000 cars to be retrofitted per year by 2030, or slightly above the annual production of a carmaker such as Renault[41]. Nevertheless, the industrial activity would be quite different from a carmaker as conversion kits could be produced by different suppliers while the conversion could be managed by a broad network of garages over Europe. By 2040, the annual volume of conversion would need to reach 3 million, implying a year-on-year growth below 25% between 2030 and 2040, which is consistent with other emerging technologies[42]. Based on Eurostat data, Europe had about 223,000 dealerships[43] in 2018. Dealerships would have more financial capacity to invest in the e-retrofit equipment compared to smaller repair shops only involved in repair activities. To get to 3 million e-retrofit a year by 2040, Europe would need 63,000 dealerships working 48 weeks a year and doing one e-retrofit operation per week. This would mean that 28% of EU dealerships would need to

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[38] Electrify's scenario assumes that no ICEs older than 35 years are allowed on the roads after 2035. A scrapping subsidy of €1,000 is given from 2030 to 2035 and €300 from 2036 to 2050.

[39] ACEA reports that European motor vehicles generate almost €375 billion per year in taxes (VAT on sales and repair, registrations taxes, ownership taxes, fuels…)
https://www.acea.auto/figure/fiscal-income-from-motor-vehicles-in-major-european-markets

[40] Based on a high estimate of 719€/tCO_2eq and a 330 MtCO_2eq savings over the 2023-2050 period.

[41] Based on GlobaDatas' Global Light Vehicle Engine Forecast (Quarter 1, 2023), Renault produced about 750,000 cars in EU/EFTA in 2022 (excluding vans). Data for EU27+UK+NO in 2018.

[42] For instance, between 1995 and 2005, the global wind turbine installation annual growth was between 32% and 25%.
https://www.nature.com/articles/s41560-022-01097-4/figures/7

[43] In 2020, the EU had 836,800 enterprises classified in the "motor trade and repair" category (excluding businesses that do only wholesale/retail trade) of which 207,723 specifically sell cars and light motor vehicles (likely to be mostly car dealerships with repair services).
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Distributive_trade_statistics_-_NACE_Rev._2&oldid=585581#Structural_profile

manage e-retrofits. Including all enterprises classified in motor trade and repair (including repair shops with no sale activity), 7% of Europe's garages would need to provide e-retrofit conversion services (one e-retrofit a week).

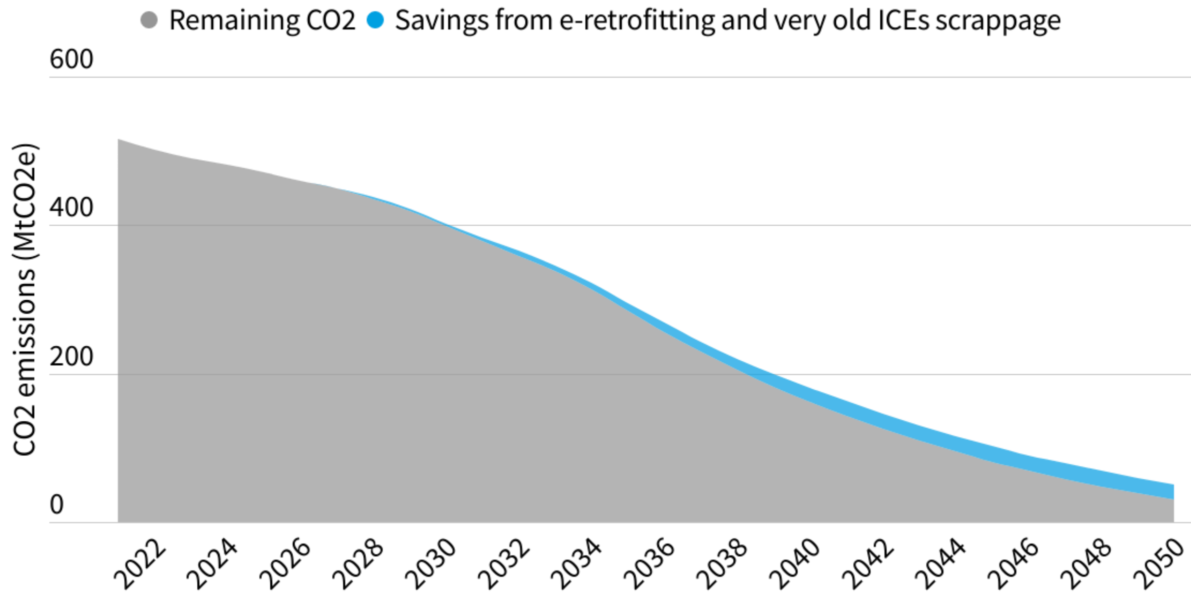
6.4. 1.5°C scenario

Based on the eligible range (Section 6.1), Electrify has modelled an illustrative scenario in which e-retrofitting would be the only lever used to meet a 1.5°C carbon budget[44]. In this theoretical scenario, about 210 million cars would need to be retrofitted after 2030, which is close to the total technically eligible fleet (236 million in 2030). However, the feasibility of this maximum scenario would be limited by the required industrial growth (almost 35 million retrofits per year in 2035) while the required market and policy conditions are also unlikely.

7. CO_2 savings from e-retrofit

Based on Electrify's CO_2 model in the high adoption scenario, 21 $MtCO_2$ or 41% of the remaining CO_2 emissions in 2050 alone will be saved by both retrofitting used ICE cars to BEV and an early scrapping of cars older than 35 years old. In 2050, 27 million retrofitted vehicles would be driving on EU roads (8% of the total car fleet based on Electrify projections). Over the whole period 2023-2050, cumulative 330 $MtCO_2e$ could be saved, a 5% reduction in total CO_2 emissions compared to a business as usual scenario. This cumulative emissions reduction is based on both the 50 million cars retrofitted in the 2023-2050 period and the 63 million cars older than 35 years would need to be scrapped in the same period. Nevertheless, 35 year old cars have very low mileage and 93% of the savings would come from e-retrofit.

[44] Modelling of carbon budget for cars based on Electrify methodology and a 50% probability to achieve the 1.5°C target.



Source: Electrify's modeling of CO2 savings in a high adoption scenario of e-retrofit and with early scrappage of cars older than 35 years in Europe

Figure 8: Emissions savings from e-retrofit and scrapping of cars older than 35 years

8. E-retrofits as social equity measures to achieve full electrification

Social acceptability will be a key factor to ensure the transition to e-mobility. E-retrofits are one of multiple solutions to deal with the pollution from the existing fleet. For instance, another alternative would be to introduce aggressive scrappage schemes to drive a faster electrification of the fleet through faster turnover, whereby car owners scrapping their car would be eligible for a subsidy to purchase a new BEV. But ambitious scrappage schemes could face challenges in terms of social acceptability as every household might not be able to buy a new or even an used BEV, especially given the risk of shortage of cheap BEVs mentioned in section 3. For some use cases, a scrappage scheme could be better combined with mobility subsidies, promoting a switch to public transport, active mobility or car sharing. However there may still be situations where mobility subsidies would not be appropriate. The e-retrofit comes as a very relevant solution for those cases. Nevertheless, Electrify's high adoption scenario for e-retrofit is based on optimistic market conditions, support from public authorities with subsidies for e-retrofitted vehicles targeted at low-income households, and the e-retrofit market growth could still face delays for multiple reasons including technical and regulatory bottlenecks or public acceptance.

Roadmaps should also consider other complementary solutions such as social leasing. A social leasing scheme[45] would be a solution to provide access to cheap BEVs for low income households. The principle of this scheme would be to provide low income households with the leasing of cars of limited size and price, ranging from micro cars such as the Citröen Ami to the smaller hatchback C segment models. The

[45] https://www.transportenvironment.org/discover/inventing-the-e100-a-month-electric-car/

concept has already been considered by French authorities[46] and T&E France published a study on social leasing in May 2023[47]. By designing those model variants with the minimum level of equipment and cutting the marketing expenses, carmakers would be able to provide new car variants well suited for this scheme at a discount cost. This scheme would require an update to industrial and fiscal policies in Europe to ensure those models are available and benefit from the necessary support from Member States or from the EU Social Climate Fund. Low-income households, who require the use of a car either for their job or because they live in specific geographic areas, will therefore be able to benefit from a scrappage subsidy if they own an old ICE, and benefit from the social leasing scheme to have access to a zero emission vehicle. Ideally, all households in this situation regardless of whether they own a car to scrap or not should receive this type of support.

In the end, the main goal from policymakers should be to support a broad range of affordable clean alternatives to ICEs and let drivers choose which solution suits their needs. T&E's future publications will describe in detail a roadmap including a package of the most relevant solutions to decarbonise the existing car fleet in a fair and equitable way.

9. Recommandations

E-retrofits need to reach scale to bring down costs and thus benefit low income drivers in need of an affordable solution. To achieve this potential, T&E recommends to address the barriers to the mass-market of e-retrofitting by providing the following:

- **A favourable regulatory framework** at EU level. The European Commission should propose **a new EU Regulation for the type-approval of e-retrofitted vehicles as soon as possible**. The Regulation could follow the example of the series-approval implemented in France, streamlining the requirements to ensure the process is lean, quick and with low costs. **In the short term**, the European Commission should issue a **recommendation to Member States encouraging the adoption of e-retrofit series-approval legislation** at national level based on the French example (e.g. Belgium is currently working on this) or on a harmonised EU guideline that member states can follow.

- **Financial support**. With the BEV market booming, subsidies for new BEVs could be partly reallocated for e-retrofitting. The use of subsidies for e-retrofits is fully justifiable given their environmental and social benefits. E-retrofit subsidies would be best targeted at low income households, providing an affordable e-mobility option.

- **Carmakers' support**: ultimately, carmakers have placed the cars on the market and as such are responsible for their carbon pollution. Rather than subsidies, governments can instead set strict carbon budgets (or limits on vehicle age) for carmakers and require them to clean up the fleet

46 https://europe.autonews.com/automakers/france-prepares-100-month-ev-leasing-plan

47 https://www.transportenvironment.org/discover/un-leasing-social-avec-des-voitures-100-electriques-fabriquees-en-france-et-en-europe-cest-possible/

they place on the road. This would mean it would be carmakers responsibility to either scrap a vehicle and provide a BEV alternative to the driver, or retrofit that vehicle to electric at their own expense. Such an approach would be aligned with the EU polluter pays principle. Carmakers should also make sure their last generation of ICE can be easily retrofitted.

Further information

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