Clean solutions for all

T&E's car decarbonisation roadmap

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Author: Yoann Gimbert
Modelling: Juliette Egal, Luca Poggi, Yoann Gimbert
Expert group: Griffin Carpenter, Julia Poliscanova, Lucien Mathieu, Thomas Earl

Editeur responsable: William Todts, Executive Director

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Further information

Yoann Gimbert
Emobility Analyst
Transport & Environment
yoann.gimbert@transportenvironment.org
Mobile: +32 488 27 19 97
www.transportenvironment.org | @transenv | fb: Transport & Environment

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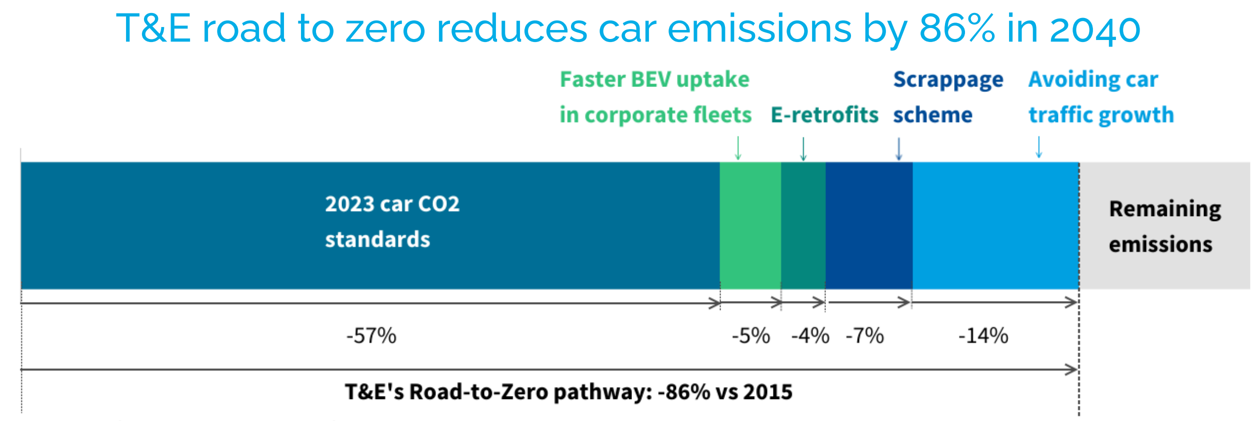
Executive Summary

The European Commission has just announced a -90% CO_2 reduction target across the European economy by 2040. To achieve this, we need to move beyond focusing only on new sales and clean up the entire car fleet. T&E's Road-to-Zero roadmap would secure the EU's climate targets while providing clean and affordable solutions to help all drivers make the transition away from polluting fossil cars.

- **The current 2023 car CO_2 regulation, including the 2035 internal combustion engine (ICE) phase-out, is the single most important emission reduction measure, as it will reduce emissions by 57% in 2040 compared to 2015.**
- **Additional measures are needed to phase out the remaining 73 million ICEs on our roads in 2050. The most effective and affordable options are scrapping old ICEs (and replacing them with battery electric vehicles, BEVs), followed by e-retrofits of ICEs.**
- **E-fuels are more expensive and inefficient than other options, and as such are not needed to reduce the CO_2 emissions of the existing fleet.**
- **Accelerating the BEV uptake in corporate fleets and avoiding the growth in car traffic by limiting new road construction or encouraging modal shifts are additional effective levers to reduce emissions in line with EU climate ambition.**

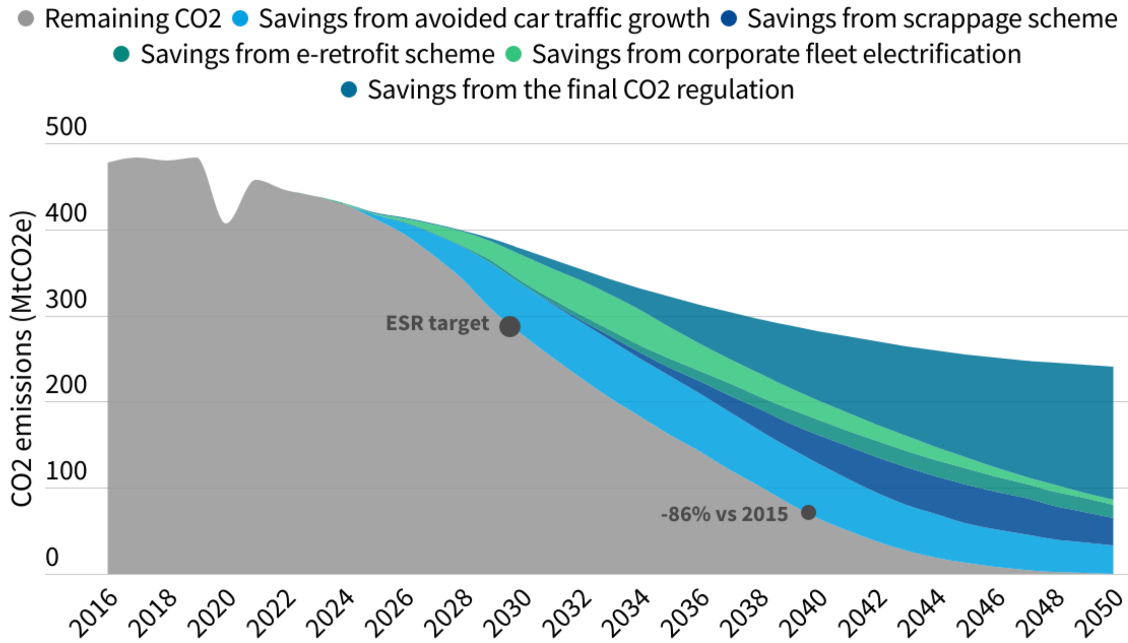


Emissions reductions in 2040 compared to 2015.
-86% vs 2015 for road transport is in line with the EU 2040 target (-90% vs 1990).
Source: T&E modeling of the EU27 car fleet tailpipe emissions.

This report presents T&E's car decarbonisation roadmap. It first shows that the 2035 ICE phase-out is an essential measure to decarbonise cars. However, the legislated car CO_2 standards need to be complemented to eliminate the emissions of the legacy ICE fleet and meet the EU's climate ambition to reduce road transport emissions by 86% (compared to 2015) while ensuring socially just transition.

Beyond the legislated car CO_2 standards affecting all new car sales, we analyse the impacts of accelerating the electrification of corporate cars and we assess options for decarbonising the ICEs that will be on Europe's roads in 2050, considering scrappage schemes coupled with alternative mobility options and e-retrofits.

T&E's road-to-zero pathway combines clean solution to meet EU's climate targets



The European Commission's impact assessment for the 2040 target mentions a 86% emission reduction for road transport in 2040
Source: T&E EUTRM modeling of the EU27 car fleet tailpipe emissions.

Accelerating the EV uptake in corporate fleets

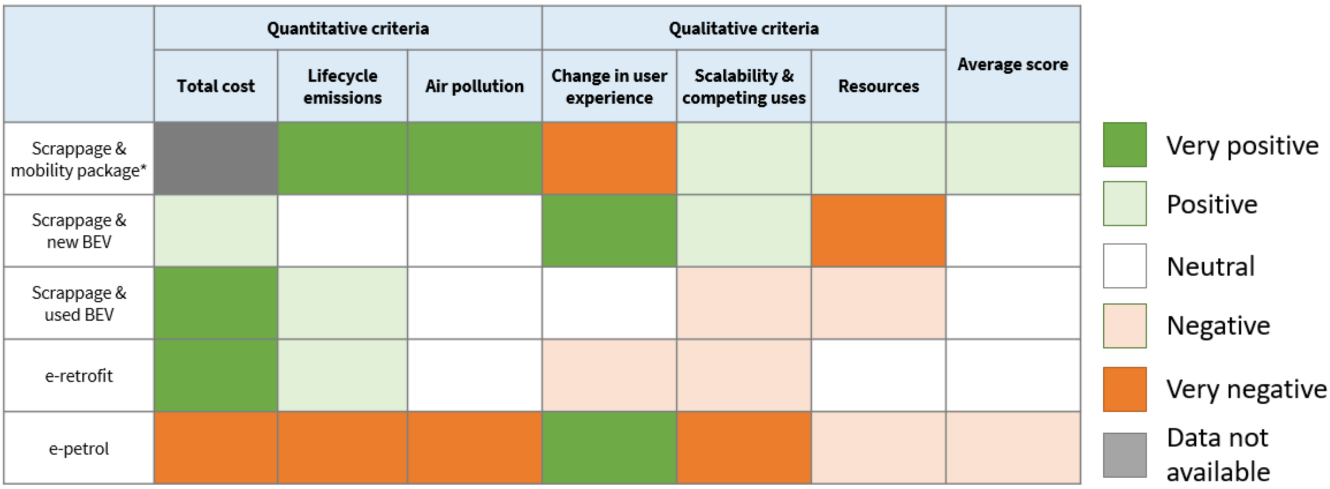
A faster uptake of BEVs is needed to meet EU's climate targets and all sales of new corporate fleet vehicles need to be BEV by 2030. Given the higher mileage of cars in corporate fleets and the high fleet turnover rate, decarbonising corporate fleet sales is very effective to bring additional CO_2 savings and second hand BEVs to the market. With these targets, annual fleet emissions could be reduced by an additional 5% in 2040.

Phasing out all remaining ICEs by 2050

The comparison of the different alternatives shows that scrappage schemes and e-retrofits - the conversion of a fossil car to electric car - should be prioritised as they are the most appropriate and effective solutions to phase out the remaining ICEs by 2050. On the other hand, the use of e-fuels in cars does not make environmental, economic and industrial sense.

A scrappage scheme, where the driver gives up car ownership and opts for a mobility package (public transport and shared mobility), would be a good option in areas where the infrastructure for public transport and active mobility is sufficiently developed. The scrappage scheme could also include subsidies for the purchase of a new BEV, or leasing it as part of a social leasing scheme, or for the purchase of a used BEV. E-retrofitting ICEs will provide an additional solution for low-income drivers and people who really need a car. Both scrappage and e-retrofits schemes will enable the removal of all old ICEs from the fleet by 2050 and reduce emissions by an additional 11% in 2040. E-petrol was found to have the highest cost to the owner, higher lifecycle CO_2 emissions and would not reduce urban air pollution. Crucially, e-fuels and the hydrogen needed to produce them will be required in hard to abate sectors (e.g. aviation and shipping), so there is no guarantee that e-petrol would be available for cars.

E-petrol makes no environmental, economic and industrial sense



*A mobility package would consist of other modes of transport such as public transport, active mobility, and electric car sharing

Remaining emissions would be reduced by avoiding an increase in car traffic

Between 2000 and 2018, passenger activity in EU cars has increased by about 17%, and the European Commission expects it to grow by 20% by 2050. The T&E roadmap aims to avoid this growth in car use relying on three main levers: stopping new road construction, shifting to public transport and active mobility in cities, shifting to rail for longer distances, and we also modelled the impact of fuel price increases on demand. To further reduce emissions, these measures would be combined with additional levers to increase car occupancy (e.g. carpooling) and reduce fuel consumption (shifting sales away from SUVs). These measures would reduce emissions by an additional 14% in 2040.

Key recommendations

1	The EU needs to maintain the 2035 ICE phase-out.
2	The European Commission is developing a new initiative for the greening of company fleets. The EU needs to set a target of 100% BEV sales in 2030 for corporate cars with an intermediate target of 50% in 2027 in order to achieve a faster ramp-up of BEV sales.
3	Policy solutions need to be specifically targeted at the existing car fleet, in particular e-retrofitting of old ICE cars and scrappage schemes for low-income households including support for mobility (e.g. public transport, car sharing) or a new or used BEV, while avoiding inefficient and expensive solutions such as e-fuels.
4	The European Commission should adjust its 2040 strategy and account for scrappage schemes and e-retrofits instead of e-fuels for the legacy fleet. To accelerate the phase out of the oldest ICEs, T&E suggests implementing sales or circulation restrictions on used ICEs after a certain age. Then, the European Commission should propose as soon as possible a new EU type-approval regulation for e-retrofitted vehicles.
5	Actions are needed to prevent the growth of car use by limiting new road building, shifting car use to other modes and increasing car occupancy.

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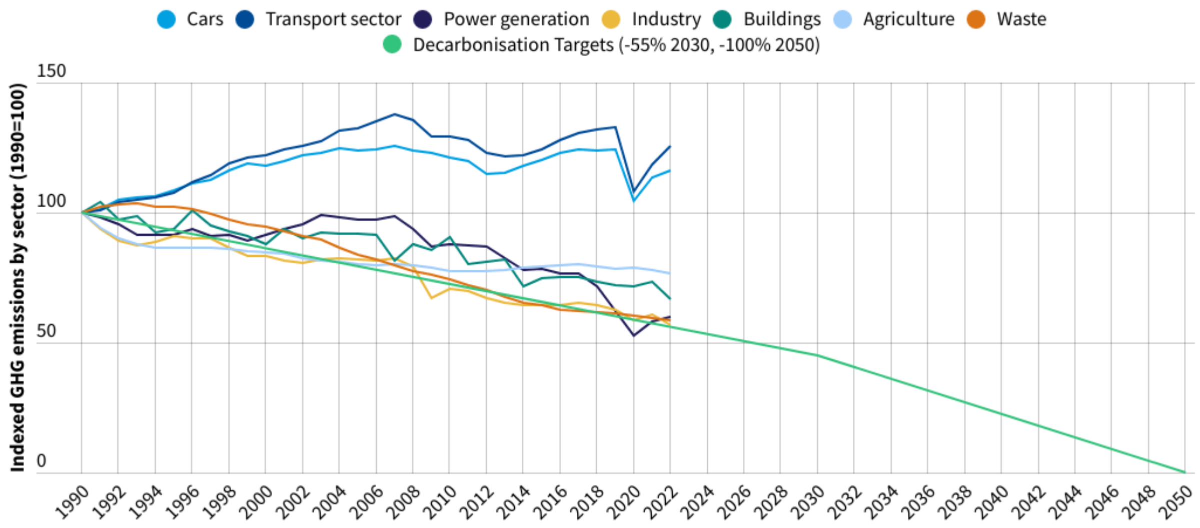
Acronyms and definitions

EC	European Commission
e-fuels	E-fuels are synthetic hydrocarbons refined from a power-to-liquid (PtL) process. The process combines hydrogen and carbon monoxide or CO_2 through a complex chemical reaction.
e-retrofits	E-retrofitting is the conversion of old ICE to electric. The engine and fuel tanks are replaced by an electric powertrain and battery packs.
ESR	Effort Sharing Regulation
ETS	EU Emissions Trading System
EUTRM	European Transportation Roadmap Model
EV / BEV	Battery electric vehicle
ICE	Internal combustion engine vehicle
Scrappage scheme	Scrappage schemes would be specific schemes designed to remove old fossil cars from the fleet. The driver could choose one of three alternatives to driving an ICE: buy a new BEV; buy a second-hand BEV; or stop using a car altogether and switch to a mobility package consisting of other modes of transport such as public transport, active mobility or BEV car sharing. This solution is aligned with circularity principles as the old ICEs would be recycled to feed into the production of new cars.
SUV	Sports utility vehicle
TCO	Total cost of ownership

1. Introduction

To face the climate crisis, the EU has set a net zero emission target by 2050 and put into action the European Green Deal, the EU's strategy for reaching climate neutrality. This includes an intermediate target to reduce emissions by 55% by 2030[1], with a sub target of 40% for sectors covered by the EU's Effort Sharing Regulation (ESR) which includes road transport. The EU also started the process to set a 2040 target into the European law and aims at -90% reduction compared to 1990 emissions[2].

The transport sector[1] is one of the largest emitters accounting for 27%[2] of total EU emissions in 2021. Within the whole of the transport sector, cars were responsible for almost half (45%) of emissions. As shown in Figure 1, 2019 CO_2 emissions from cars were 25% higher than in 1990, and even in 2020, a year marked by transport restrictions due to the coronavirus pandemic, emissions were still 6% higher than 1990. To lower CO_2 emissions from cars and bring the sector in line with the Green Deal climate ambition, the EU has reviewed the regulation covering CO_2 emissions from the sales of new cars. The new car CO_2 regulation agreed in 2023 increases the required reduction in average CO_2 emissions from new cars to 55% in 2030 compared to 2021 levels (from the previously agreed 37.5%) and crucially, requires EU carmakers to reduce new car emissions to zero by 2035.



Scope: EU27
Source: T&E analysis of UNFCCC GHG data

Figure 1: Historical GHG emissions in the EU

Following this landmark decision, this report aims to provide a clear picture of the decarbonisation pathways for all cars in the EU - not just those entering the market - while also looking at what emissions reductions can be expected from cars in 2040. The report examines all measures that can be used to reduce emissions: limiting the growth of transport demand (number of kilometres travelled in

[1] Including international bunkers.
[2] T&E analysis of GHG data reported by the United Nations Framework Convention on Climate Change (UNFCCC) [3]

passenger-km), modal shift (change in the split in distance travelled between car and other transport modes), increasing car occupancy (number of passengers per car), accelerating the uptake of zero emission vehicles (BEVs), reduced energy consumption (energy consumed per km depending on both the characteristics of the car and its use in real world conditions), reduction in lifetime of fossil cars (scrappage schemes), e-retrofits[3] (cars can be converted from ICE to electric power in order to reduce their emissions) and potential new fuels[4].

In Section 2, we analyse the impact of the new car CO_2 standards on the CO_2 emission of the EU car fleet until 2050 and the remaining gap between emissions from cars and the EU climate targets. Based on this new baseline, we assess what remains to be done for the EU car fleet to meet current and future EU climate targets. The report provides a decarbonisation pathway for the EU car fleet with a focus on the remaining internal combustion engine vehicles (ICEs) that would be on the road in the 2040s. The report covers a wide range of solutions such as additional acceleration of battery electric vehicle (BEV) sales (Section 3), e-retrofits and scrappage schemes (Section 4), as well as measures aimed at limiting the growth in fossil car traffic (Section 5). Through a combination of all measures, we define a decarbonisation pathway aimed at reaching zero emissions in 2050. The pathway reaching zero emissions in 2050 can then be used to estimate the emission reduction that will be achieved in 2030 and 2040 to inform on the fair share of emission reductions to be allocated to the car sector.

INFOBOX 1: EU climate targets

The EU climate goal in 2050 is a net zero emissions target. This means that *negative emissions, or carbon removals,* could be theoretically used to offset remaining positive emissions. Following the precautionary principle, we assume that car fleet emissions need to go to zero tailpipe emissions in order to achieve this target given that the technology to achieve this exists in battery electric vehicles and the uncertainty and risk of relying on carbon sinks or carbon capture and storage to reduce CO_2. We also assume that emissions of upstream sectors such as the electricity generation used for BEV charging and manufacturing will transition to zero emission as well. In 2030, the European Green Deal includes an intermediate target to reduce emissions by an average 40% reduction for sectors covered by the ESR, which includes road transport. In 2040, the European Commission (EC) announced its ambition to reach at least a -90% emission reduction compared to 1990 levels. The EC's impact assessment for the 2040 target[4] mentions that road transport emissions would need to fall by 77-86% compared to 2015.

[3] A report on the e-retrofit outlook is published alongside this report.
[4] More information on biofuels and e-petrol can be found in Annex D.4

2. The car CO_2 regulation: essential but not sufficient

In this section, we calculate the emissions from the car fleet in a baseline scenario when new BEV sales are driven by the CO_2 standards. Then, we analyse to which extent this regulation supports the decarbonisation of the car fleet to meet EU climate targets.

INFOBOX 2: EUTRM, T&E's car fleet emission model

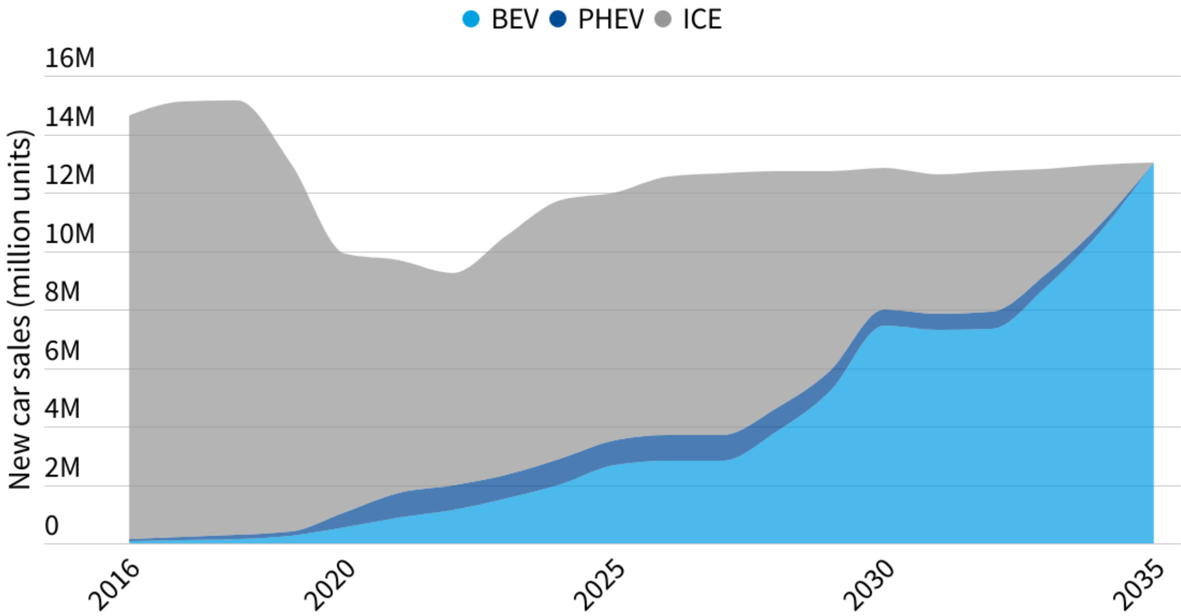
For this report, the modelling of car fleet emissions is based on T&E's Internal European Transportation Roadmap Model (EUTRM). EUTRM makes use of the most recently available data such as the 2021 car fleet composition and the latest car activity forecast from the European Commission (EC) to model the turnover of the whole car fleet on EU27 roads. Based on historical data on fleet behaviour (e.g. fuel consumption, emissions, car retirement age, mileage changes depending on car age, powertrain distribution in new sales, etc), the model's outputs include the fleet composition and the associated CO_2 emissions until 2050. Annex D.1 provides additional information on the modelling.

2.1. Car CO_2 standards will drive BEV uptake in the fleet to 75% in 2050

EU car CO_2 standards are the main driver of the transition to e-mobility in the EU and are expected to set the pace for EU BEV sales up to 2035. We modelled the minimum sale of new BEVs[5] required to meet the 2023 car CO_2 Regulation[6]. Based on the analysis, BEV sales are projected to increase from 14% of new sales in 2023 (1.5 million units) to 22% in 2025 (2.7 million units), 58% in 2030 (7.4 million units), before rising to 100% in 2035 (13 million units).

[5] The European Commission assumes there could be some hydrogen fuel cell electric vehicles available, but production forecasts acquired by T&E (GlobalData's Light Vehicle Production Forecast) shows there would be minor production of these vehicles by 2030, and we therefore assume zero emission vehicles to be BEVs for this analysis.

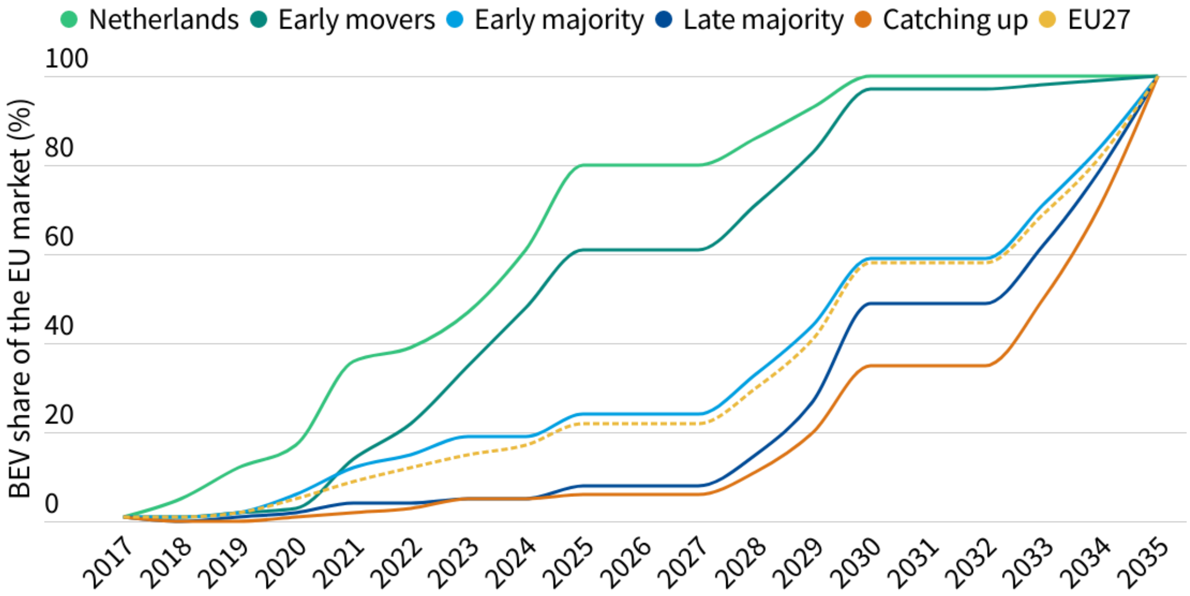
[6] The methodology was described in T&E's 2022 car CO_2 report[5]. Our new scenario includes the latest development on the zero and low emission vehicle benchmark agreed in the final regulatory text as well as update of the 2021 reference parameters. The total car sales number is projected within the EUTRM model.



Scope: EU27
Source: T&E modelling based on the minimum BEV share needed to meet the 2023 car CO2 standards

Figure 2: BEV uptake in new car sales

While the car CO_2 regulation implies an average BEV share of new sales to meet the CO_2 target at EU scale, each country will not follow the average trend. For instance, based on the development of the BEV market in the past years and the national ICE phase-out targets, we can expect that EU countries would be divided between five main groups with different uptake speed. These different speeds mostly reflect the difference in incomes and charging infrastructure deployment in each country group. Figure 3 shows the average BEV share in each of these groups. Some Southern and Eastern countries are therefore expected to lag behind the average market during the whole transition until the ICE phase-out in 2035.



Scope: EU27

Source: T&E modeling of the minimum required to meet the car CO2 regulation adjusted per country group: NL, early movers (including Northern countries), early majority (including France and Germany), late majority (including Italy and Spain), Catching up (including most Eastern European countries)

Figure 3: BEV uptake in new car sales per country group in the regulation scenario

Based on the fleet turnover, modelled BEV sales can be combined with the EUTRM model to provide the share of BEVs in the whole fleet. BEVs increase from 1.2% of the EU fleet in 2022[6], to 11% in 2030 (27 million units), 45% in 2040 (110 million units) before rising to 73% in 2050 (195 million units).

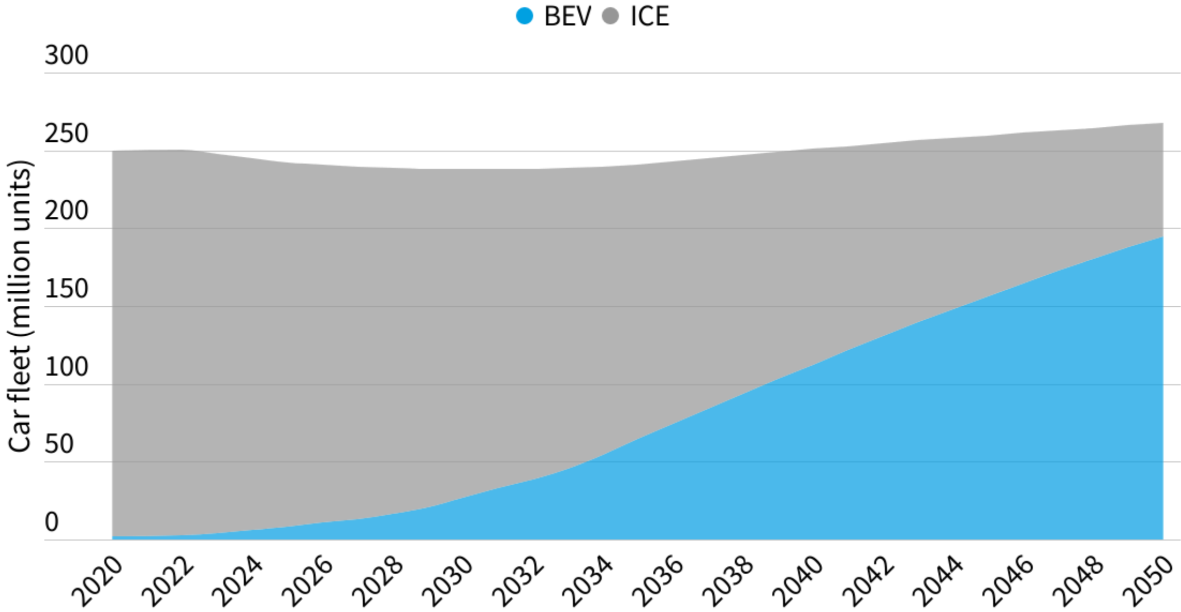
However, even with a phase-out of new ICE sales in 2035, 73 million ICEs will still be on EU27 roads in 2050 assuming the current renewal rate of the fleet[7]. The large number of vehicles left on the road in 2050 is due to many cars exceeding the average 15 year lifespan of cars. Modelling of fleet turnover[7] found that the average lifespan in Eastern European countries is 28 years, nearly twice the value considered by policymakers[8]. Based on the EUTRM model output, we estimate that the BEV share of the fleet could still be below 50% in some Eastern countries such as Poland in 2050 due to their older car fleet[9] and a market dominated by used car imports[10]. Therefore, an ICE phase-out in 2035 is not sufficient in itself to phase out all ICEs from EU roads by 2050.

[7] The current historical trends show that the average lifespan of cars tends to increase over time. These trends could lead to at least 80 million old ICEs remaining on the road in 2050.

[8] 15 years as reported in the EC impact assessment of the Car CO_2 standards[8].

[9] According to Eurostat, 41.3% of the Polish fleet is older than 20 years in 2021 while Poland has the highest motorisation rate (number of cars per inhabitants) in the EU.

[10] For each 100 cars which supply Polish passenger car parc every year, between 60-70 are used cars imported from abroad[9].



Scope: EU27
Source: T&E EUTRM modelling based on new ZEV sales required to meet the car CO2 regulation

Figure 4: BEV uptake in new car fleet in the regulation scenario

2.2. Cars CO_2 standards have significant impacts on CO_2 emissions

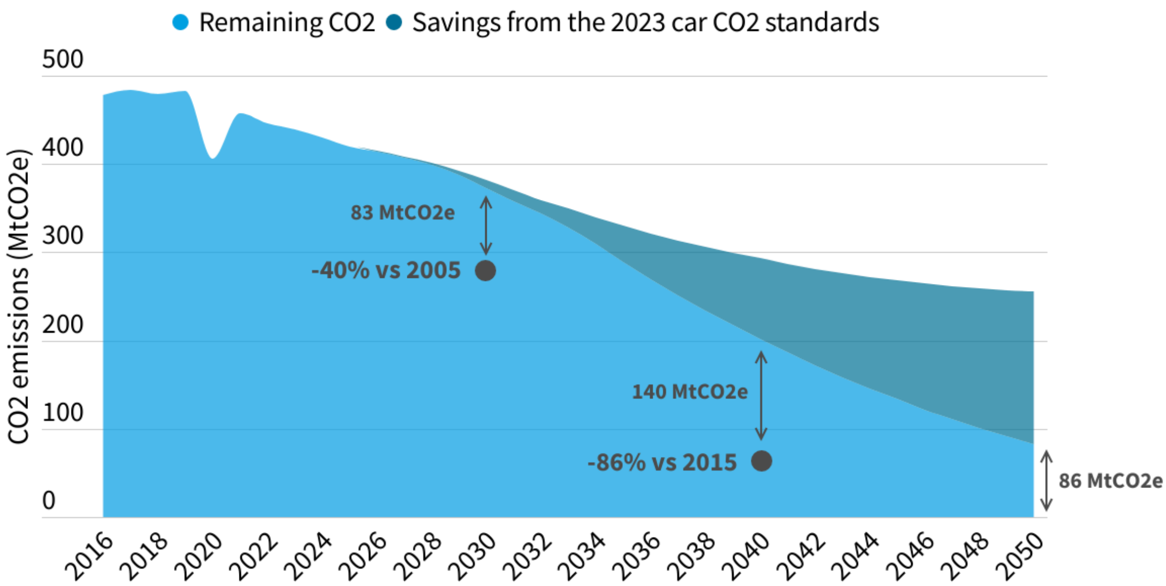
Compared to the previous car CO_2 regulation, the improved 2023 EU car CO_2 standards reduce annual fleet CO_2 emissions by 2% in 2030 (-7 $MtCO_2e$), 28% in 2040 (-80 $MtCO_2e$) and 64% by 2050 (-155 $MtCO_2e$). Overall, cumulative CO_2 emissions over the 2023-2050 period are reduced by 20% (-1,800 $MtCO_2e$). These significant impacts prove that the car CO_2 regulation is essential in bringing down CO_2 emissions and thus should not be weakened in the 2026 review.

However, as shown in Figure 5, without any other measures in place, we calculate that car emissions in 2030 will only be 23% lower than 2005 emissions. This falls short of the EU average ESR target which requires a 40% average emissions reduction in 2030 as an 83 $MtCO_2e$ gap remains between the regulation scenario and the target. Therefore, the CO_2 emissions from the car fleet are expected to pose challenges to Member States 2030 climate targets and additional regulatory measures are needed to further reduce the EU27 car fleet's emissions.

In 2040, we calculate that the car CO_2 standards would reduce emissions by 57% compared to 2015 level, falling short of reaching the 86% emission reduction required for road transport in the EC's impact assessment. A 140 $MtCO_2e$ gap remains between the regulation scenario and the emission reduction from the EC's impact assessment (-86% reduction vs 2015).

Longer term, the current regulatory trajectory results in the EU car fleet still emitting 86 $MtCO_2e$ in 2050, when the EU plans to reach net zero emissions across all sectors. This is an 82% reduction in CO_2

emissions compared to 2015, but additional measures for the EU car fleet are required to reach the EU's 2050 net zero emission target.



The European Commission's impact assessment for the 2040 target mentions an emission reduction of 86% for road transport in 2040.
The Effort Sharing Regulation (ESR) target for the EU economy as a whole is a 40% reduction in emissions in 2030 compared to 2005.
In both 2030 and 2040, we assume that all sectors contribute equally to the effort to meet the climate targets.
Source: T&E EUTRM modeling of the EU27 car fleet tailpipe emissions.

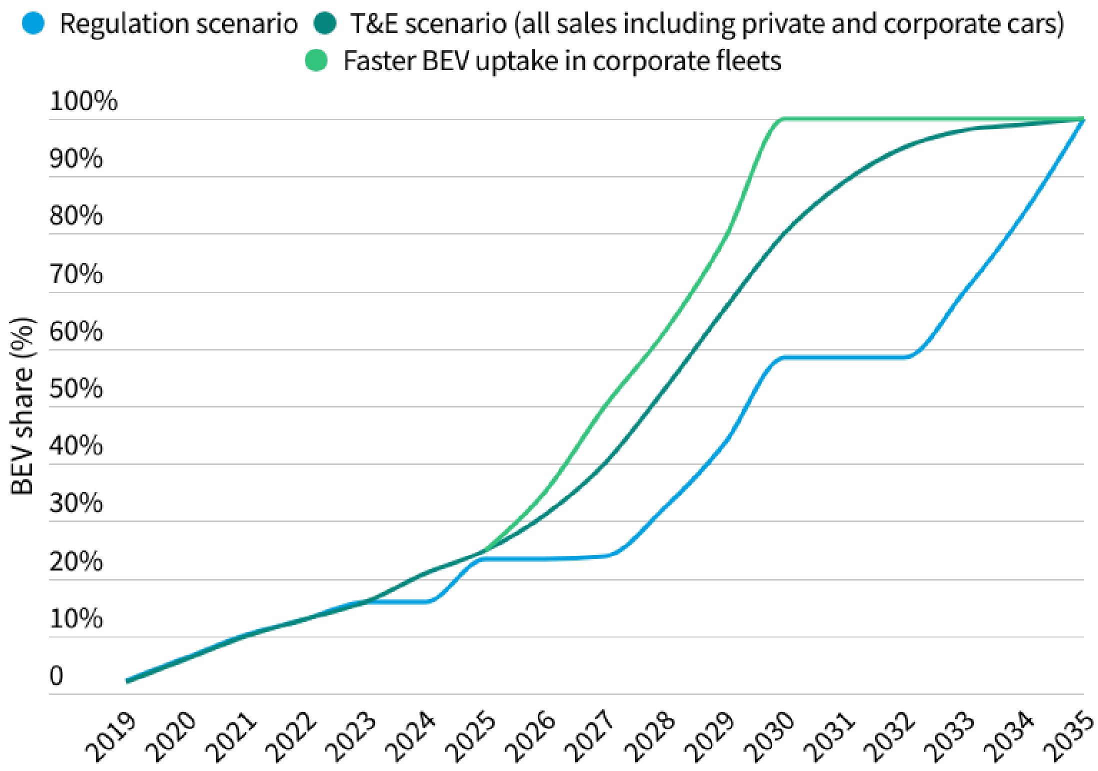
Figure 5: annual CO_2 emissions of the car fleet in the regulation scenario

3. Accelerated BEV uptake in corporate fleets

As shown in the previous section, a much faster BEV uptake is required to meet EU climate targets. One of the most effective measure to accelerate the uptake of BEVs is to electrify sales of all new corporate fleet[11] vehicles by 2030.

A new greening corporate fleets initiative is under development by the European Commission[10]. In this report, T&E modelled a maximum scenario where all sales of new corporate fleet vehicles are BEV in 2030[11] with an intermediate target of 50% in 2027. This regulation of corporate fleet sales which make up 58% of new car sales in the EU would provide a demand side push for BEVs and could increase 2030 BEV sales from 58% with the CO_2 standards alone to about 80%. Figure 6 describes the resulting sales scenario compared to the regulation scenario. These sales levels would only be achieved if carmakers do not limit the supply of BEVs by doing the minimum required by the 2023 CO_2 standards.

[11] Corporate fleets are owned or leased by a business, government agency, or other organisation. This includes cars provided by companies to their employees but also cars leased by leasing companies.



Source: T&E's modelling of the minimum BEV share of sales required to meet the EU car CO2 regulation, and the impact of faster electrification in corporate fleets (100% BEVs in corporate fleets in 2030 and 50% in 2027).

Figure 6: T&E BEV uptake scenario compared to the regulation scenario

Corporate vehicles have a higher turnover rate than private cars and would accelerate the uptake of BEVs across the EU car fleet. A binding EU fleet target would therefore bring 12.5 million additional BEVs to the used car market by 2035[11]. In addition, given the higher mileage driven by cars in corporate fleets[12], decarbonising corporate fleet sales would provide additional CO_2 savings compared to private cars. With these targets, the annual emissions from the car fleet could decrease by 8% in 2030 (-30 $MtCO_2e$) compared to the regulation scenario, 11% in 2040 (-23 $MtCO_2e$) and by 6% in 2050 (-5 $MtCO_2e$). This scenario is included in T&E's Road-to-zero pathway in Figure 11. This would lead to a 540 $MtCO_2e$ cumulative savings by 2050, which is a 7% reduction compared to the cumulative emissions in the regulation scenario. In 2030, the electrification of corporate fleets would close 36% of the gap between the regulation scenario and the ESR target. Then, in 2040, it would close 17% of the gap between the regulation scenario and the emission reduction from the EC's impact assessment (-86% reduction vs 2015). Despite these improvements, the acceleration of the BEV uptake would not be sufficient to fully decarbonise cars as about 68 million ICEs would remain in the EU fleet in 2050.

[12] On average, a car in a corporate fleet drives 27,000km annually while a private car drives 12,000km. Based on T&E analysis of data from Dataforce (2020).

In addition to the electrification of the corporate fleet, higher CO_2 savings could still be achieved with more ambitious car CO_2 standards. T&E advocates for an 80% emission reduction target in 2030 instead of 55% in the current regulation.

4. Phasing out remaining ICE cars

There are several complementary solutions to fully decarbonise the remaining ICEs in the fleet by 2050:

- **Scrappage scheme:** The first option would be to use scrappage schemes to remove old fossil cars from the fleet. In this case, the driver could choose one of three alternatives to driving an ICE: buy a new BEV; buy a second-hand BEV; or stop using a car altogether and switch to a mobility package consisting of other modes of transport such as public transport, active mobility (e.g. bike leasing) or BEV car sharing. This solution is aligned with circularity principles as the old ICEs would be recycled to feed into the production of new cars.

- **E-retrofits:** Another option is to keep the ICE but convert it to electric. This process is called "e-retrofitting" and is being developed by several companies across Europe. A separate T&E briefing presents the concept of e-retrofitting, its challenges and prospects.

It is technically possible to use CO_2 neutral e-petrol to fuel existing ICE cars. This synthetic fuel could be a co-product of e-kerosene which is required to decarbonise the aviation sector. However, synthetic fuels will be in high demand in many sectors (aviation, shipping, chemical and plastic industries, ...) and the availability of e-petrol for cars is bound to be limited and the fuel costly. Moreover, the use of e-fuel in cars would not eliminate air pollution as burning e-fuels emit as much NOx pollution as fossil fuels today[12]. The comparative analysis carried out in section 4.1 and 4.2 shows that e-petrol compares badly with the other options available and is thus not included in the decarbonisation roadmap. More information on e-petrol assumption in this study is available in Annex D.4.2.

Given the age of the ICEs vehicles remaining in the fleet after 2040 (typically more than 15 years), most ICEs are expected to be used by low- and middle-income drivers. The largest numbers will be driven in Eastern Europe even though some would remain in Western Europe. Affordable second hand EVs would be the *go to* option to replace ageing ICEs (most low and medium income drivers buy second hand cars[13]) but availability of affordable second hand EVs is expected to be lower than the demand for these vehicles. This suggests that national governments would need to provide targeted subsidies to low-income drivers to support the shift to zero-emission alternatives across all car users.

In this section T&E has evaluated the different options available and defined the most appropriate solutions to fully phase-out the remaining ICE fleet in the 2040s. First, a multi-criteria analysis compares each alternative against six key criteria. Then, the detail of the total cost of ownership (TCO) of each

[13] 100% of car owners in quintile 1 buy used cars, 96% in quintile 2, 75% in quintile 3 [13].

alternative is provided to derive the price differential that would need to be filled to incentivise the change.

4.1. Multi-criteria evaluation of each alternative

Each alternative to driving an old ICE was assessed against six criteria. Three quantitative criteria were calculated: the TCO (Section 4.2), the lifecycle emissions[14] and the air pollution costs[15]. Three qualitative criteria complete the analysis: the expected user perception, the scalability of the solution and the impact on resources. Each criterion is converted into a score between -2 and 2 and the average of these scores is used to evaluate the solution (numeric scores available in Annex D.2.3).

The scrappage scheme where the driver gives up car ownership gets the higher score thanks to the best environmental scores and few scalability and resource constraints. Fuelling the old ICE with e-petrol gets the lowest score due to high costs, low environmental scores and a scalability severely constrained by competing uses. E-retrofitting the ICE and scrapping the ICE to buy a new or used BEV receive a neutral score due to both advantages and disadvantages according to different criteria.

Table 1 - Rating matrix of alternatives to keeping an old ICE in 2040

	Quantitative criteria			Qualitative criteria			
	TCO (EUR/km)	Lifecycle emissions (gCO2/km)	Air pollution cost (EURcent per pkm)	Change in user experience	Scalability & competing uses	Resources	Average
Scrappage + mobility package		6	Negligible	Practical efforts needed to give up car ownership	Increasing the number of bus, trams, bike lanes, ...	New public transport infrastructure is needed	+
Scrappage + new BEV	0.21	32	0.05	Positive perception in 2040 due to charging infrastructure expansion	Increasing car production	Additional new BEVs put pressure on raw materials	
Scrappage + used BEV	0.16	17	0.05	Lower performance of used BEV vs new BEV	Limited by the size of the used car market	Indirect need to scale up new BEV production	
e-retrofit	0.19	26	0.05	Shorter driving range	New industry limited by industrial ramp-up speed	Smaller batteries and no need to build a new car	
e-petrol	0.26	64	0.11	No change in car use	Many competing uses of synthetic fuels, small amount expected to be available for cars	Require large amounts of hydrogen and energy	-

[14] Main assumption presented in Annex D.3 and details of T&E lifecycle assessment tool[14].
[15] Air pollution cost in urban roads from the Handbook on the external costs of transport[15].

The assessment of each alternative is detailed below:

- **Scrapping the ICE and opting for a mobility package**: This option gets the highest score on lifecycle emissions[16] and would produce negligible amounts of air pollution. However, giving up car ownership requires a significant change in travel patterns or even impractical if the infrastructure or services are not adapted. To realise the potential of this solution, policymakers will need to directly support the expansion of alternatives to cars (public transport, active mobility, car sharing). Scalability and resource constraints are not expected to be the main barriers of this solution but more buses, trams or bike lanes would still need to be scaled and resource constraints could arise in cases where new infrastructure needs to be created to expand public transport services or to facilitate active mobility solutions.

- **Scrapping the ICE and buying a new BEV**: This option is around the midpoint in terms of TCO, lifecycle emissions and air pollution in comparison to the other options. Compared to the ICE, the user perception is expected to be positive due to the expected widespread expansion of the charging infrastructure. The scalability of the solution depends on the number of additional new BEVs that need to be produced. The main disadvantage is the additional pressure on raw materials supply induced from the production of new batteries. While significant amounts of material are expected to be available in the 2040s from the recycling of old batteries, the continuous ramp-up of BEV production would still require the expansion of mining. To limit this drawback, the scrappage scheme could be designed to favour the purchase of new small and compact BEVs with right-sized batteries (e.g. 40 kWh) and chemistries optimised for resource efficiency[17].

- **Scrapping the ICE and buying a used BEV**: This option has the highest score on TCO and benefits from low lifecycle emissions and limited air pollution costs. This option may not be preferred by all users as the performance and quality of used vehicles may be lower compared to a new BEV fitted with the latest high technologies and design. The scalability is limited by the size of the used car market and any increase in demand for used BEVs is expected to indirectly increase the demand for new BEVs[18]. This indirect increase in new BEV production would have an impact on resources. As the majority of the old ICEs to be scrapped will be located in Eastern Europe, public policies would be needed to facilitate the export of second-hand BEVs to Eastern Europe.

- **E-retrofit of the ICE**: This option benefits from a relatively low TCO. The lifecycle emissions are lower than for a new BEV as production emissions only come from the conversion kits with smaller batteries compared to new BEVs[19]. The disadvantages of e-retrofits are the limited

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[16] Calculated based on package of public transport and active mobility options, see Annex

[17] In order to optimise resource efficiency, carmakers can opt for battery chemistries that cut the dependence on some critical minerals. For instance, sodium-ion batteries would reduce the need for lithium extraction.

[18] Increased demand for used BEV would increase the market price for used BEVs which would lead to more drivers selling their used BEV and buying a new one.

[19] In the case of e-retrofits, the battery size is limited by the volume available in the engine bay after removing the engine.

available driving range of the small batteries and the limited scalability of the process[20] as a new conversion industry needs to be ramped up. This option has a low resource impact, as smaller batteries[21] require less minerals compared to new BEVs, and the process avoids the production of a complete new car. This option would be best suited to use cases where the required range is shorter than for new BEVs, and where the charging infrastructure is well developed. However, it is expected that full charging infrastructure coverage across Europe would allow the development of the e-retrofits across the continent. Therefore, e-retrofit are a good solution for low-income drivers who need a car in Eastern Europe.

- **Fuelling the ICE with e-petrol**: This option scores the lowest and would therefore be the worst solution to phase out the remaining ICE. It has the highest TCO because e-fuels are expected to be expensive as the high demand for synthetic fuels will push up the price of e-petrol (in the uncertain scenario where it would be available for cars). E-petrol could still be an option in specific cases where other options are less economically relevant, such as for very old cars approaching the end of their life, but these vehicles are likely to be owned by drivers with lower incomes and the fuel would need to be heavily subsidised. The solution is unlikely to be applicable to the large parts of the lower-income fleet market where national governments do not have the capacity to subsidise an expensive e-fuel at the pump (e.g. in Eastern Europe) and where the purchasing power of drivers is low. Lifecycle emissions are also relatively high, as the fuel is not expected to be fully carbon-neutral before 2050[22]. Cars running on e-petrol have the same impact on air pollution as those running on conventional petrol. Therefore, despite some CO_2 savings, e-petrol cars will still cause health risks. This option would have the best user perception as ICE users would not have to change their habits although circulation restrictions in cities may pose a growing challenge. Scalability is the main limitation of this option as there are many factors that limit the production process of e-petrol. Synthetic fuel production requires green hydrogen production and CO_2 capture from the air and these processes need to be scaled up in a cost effective way. Then, there would be competing demands for hydrogen and synthetic fuels from other sectors that need to decarbonise as well (e.g. aviation and shipping or industry). Even if e-petrol could be one of the co-products of the e-kerosene production process, uncertainties remain. For instance, the e-fuel production process can be optimised to favour a higher proportion of other co-products such as e-diesel for the shipping industry or e-naphtha for the plastic industry. Finally, the production of e-petrol requires resources in the form of hydrogen and renewable electricity. The e-petrol production process is inefficient and the overall energy

[20] E-retrofitting requires manual operations in a garage and the process cannot be fully automated and standardised for all ICE models.
[21] For e-retrofitted cars, the battery size is limited by the space available in the engine bay and the trunk. Battery size ranges from 16 kWh for smallest cars to 50 kWh for largest vehicles.
[22] The Renewable Energy Directive (RED) requires a 70% emission reduction compared to conventional petrol. We assume that fuel producers will have enough incentives to exceed the 70% emissions reductions but that a 100% GHG savings is unlikely to be achieved voluntarily. Therefore, we assume that a midway 85% reduction could be achieved for e-petrol. As this methodology exceeds what is required by regulation, it should be considered as an optimistic scenario under current regulations.

efficiency of using e-petrol is about 16-18%[16] compared to 77-81% for directly using electricity to power a BEV.

Clean alternatives to ICEs need to be available for all

Some solutions are more relevant for certain users and markets:

- “Scrapping the ICE and opting for a mobility package” is the best option in areas where the infrastructure for public transport and active mobility is sufficiently developed.
- “Scrapping the ICE and buying a new BEV” would be best suited for Western Europe where government have more budget to allocate to alternative. This option could be combined with a social leasing scheme[17] (leasing a BEV for €100/month) which would make new entry-level BEVs accessible by removing the upfront cost barrier, even for low-income drivers in Eastern Europe.
- “Scrapping the ICE and buying used BEV” could allow Eastern European countries to attract affordable used BEV from Western Europe.
- “E-retrofit of the ICE” will be most suitable in Western Europe before 2035 due to high initial costs, but, when the e-retrofit industry is established in the second half of the 2030s, it will provide an additional solution for low-income drivers and people who absolutely need a car, including in Eastern Europe. However, the number of eligible vehicles will start to decline after 2040, so this solution will mainly need to be ramped up before 2040.
- E-petrol is the worst performing option and would not make environmental, economic and industrial sense.

4.2. TCO analysis

The TCO analysis compares the options for the baseline case of an owner of a 10 year old medium car in 2040 who will need to move to a zero-emission alternative. The TCO is presented in Figure 7 as a total cost per km to compare options with different mileage[23] and the total cost is broken down by cost item: depreciation[24], fuel cost, electricity cost, maintenance, insurance cost and the initial value owned at the start of the scenario[25]. The main assumptions of the model are detailed in Annex D.2.1. In each case, a price differential is derived so that the TCO is 10% lower than the baseline. This is assumed to be the minimum incentive for the ICE owners to switch to a zero emission alternative and make sure they are not worse off.

[23] New BEVs are assumed to have higher ownership mileage than used BEV and e-retrofitted vehicles drive even less due to smaller batteries limiting their use case.

[24] The depreciation cost represents the loss of value during the ownership period.

[25] The initial value owned at the start of each scenario is counted as a negative cost. When the car is kept, e-retrofitted or fuels with e-petrol, the residual of the 10 year old vehicle at the start of the period is accounted for. If the car is scrapped, the value of the scrapped vehicle is estimated. As a reference, two options display a scenario where the ICE is sold to buy a new vehicle, in this case, the resale value is accounted for.

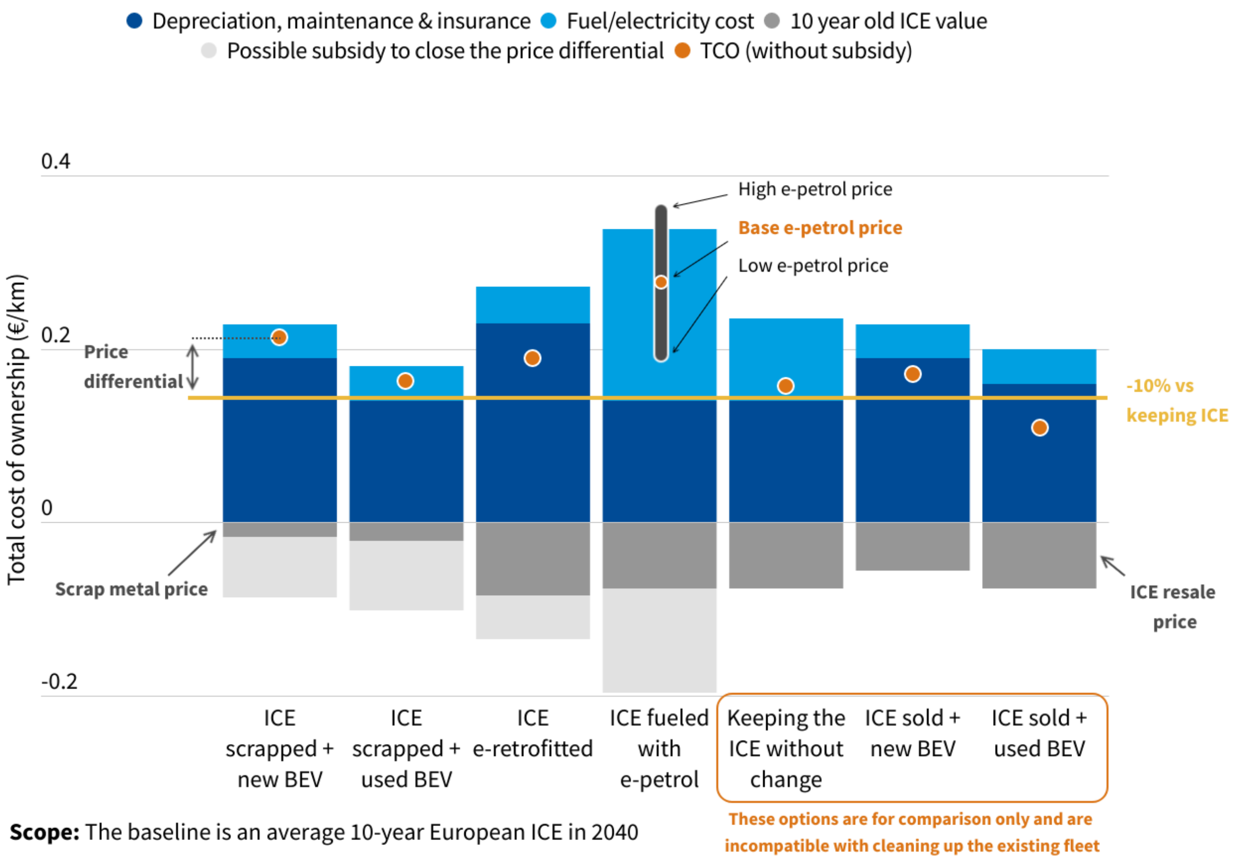


Figure 7: TCO comparison in 2040

The analysis shows that the lowest TCO (€0.11/km) would be achieved if the driver resold the old ICE to buy a used BEV (column 7). This option would not solve the climate problem of old ICEs as they would remain in the fleet. Therefore, additional policy measures would therefore be needed to limit the resale of ICE and/or to reduce their resale value (Infobox 3). In comparison, scrapping the ICE and buying a used BEV resulted in a higher TCO of €0.16/km before subsidy (column 2). In this case, a possible subsidy would need to be at least as high as the ICE resale value in order to provide sufficient incentive, otherwise the ICE owner will prefer to sell it and the ICE will not be removed from the car fleet. If the driver scraps the ICE and buys a new BEV (column 1), the TCO is €0.21/km. If the driver sells the ICE instead of scrapping it (column 6), the TCO would be lower (€0.17/km) due to the higher resale value compared to the scrapped value of the car. The possible subsidy must therefore be at least higher than the resale value of the car and close the price differential with a TCO 10% lower than keeping the ICE. In the case of the e-retrofit scheme (column 3), the TCO is €0.19/km. For the e-petrol option (column 4), a range of TCOs between €0.17/km and €0.35/km with an average at €0.26/km is possible due to the high uncertainty in the price outlook for e-petrol (more information in Annex D.2.1). The option of scrapping the ICE and opting for a mobility package is not included in the TCO calculation due to the wide range of possible options (public transport, car sharing services, ...). However, the subsidy for this option would have to be at least equal to the ICE residual value (similar to the option of scrapping the car and buying a used BEV).

INFOBOX 3: Reducing the residual value of old ICEs

The TCO analysis is closely linked to the residual value of ICEs. In a scrappage scheme, the higher the residual value when the car has to be scrapped, the higher the subsidy would be as the subsidy needs to at least cover the residual value. Moreover, a low residual value would encourage drivers to scrap their ICE voluntarily rather than resell it. Reducing the residual value would therefore support the transition to alternative options at a lower cost to society. Measures to reduce the residual value are not quantitatively assessed in this report, but the following measures could be considered by governments:

- Low and zero-emissions zones, high parking charges or congestion charges would discourage the use of ICE in cities and encourage urban drivers to give-up their ICE, creating a higher supply of ICE on the used car market and a lower demand.
- Sales restrictions, such as an age limit for the registration of used ICE, or age and technical limits as part of the roadworthiness test would make old ICE less desirable for drivers and would reduce the residual value in the years before the age limit.
- The attractiveness of a car is based on both the purchase price and the expected resale price at the end of the ownership. Today, drivers have the option of reselling their old ICE for export. Restricting exports after a certain age or on the basis of certain criteria (e.g. Euro class of the engine) would leave no choice but to resell the car on the domestic market (increasing the supply for a fixed demand) or to voluntarily scrap the car. This would reduce the residual value in the domestic market to a value closer to the value of the scrap value. This measure would also prevent carbon leakage to non-EU countries. However, it would need to be accompanied by strong enforcement to prevent illegal exports.

In addition to favouring scrapping over resale, these measures would also make the e-retrofit option more attractive. For instance, specialised companies would be able to buy large batches of old ICEs at low cost from the second-hand car market and convert them to electric vehicles with more automated processes than individual conversions in a garage.

Different levels of subsidy could be possible to close the price differential for each alternative

Some low income population categories would require some support to close the price differential gap and make the switch to clean alternatives. In that case, e-retrofitting an old vehicle (column 3) has a lower price differential (€5,000) compared to scrapping a 10 year old car and replacing it with a used BEV (€8,900, see column 2) and compared to scrapping the car and buying a new BEV (€11,000, see column 1). The case of running the car on e-petrol remains uncertain and strongly depends on the fuel price and, with an average price, the price differential for e-petrol would reach a total of €14,000 for fuelling a car during 10 years (equivalent to €1.7/L).

The TCO analysis depends on the age of the vehicle and the length of the period of ownership. Section D.2.2 in the Annex gives an overview of the price differential in different cases. For example, assuming a

15 year old ICE[26], the price differential is lower: €3,300 for scrapping the ICE and buying an used BEV, €3,600 for e-retrofitting, €8,800 for scrapping the ICE and buying a new BEV and a total of €7,400 for e-petrol (€1.9/L). Rules can therefore be defined to scale the subsidy depending on the age of the ICE and initial value of the vehicle (as well as the income levels). With subsidies in the upper range, the scrappage scheme would provide a greater incentive to scrap or retrofit a car sooner and save more CO_2 (Annex D.2.2 displays the relationship between subsidy and CO_2 saved), but this would be more costly for governments.

In addition, the price differential would depend on the size of the new car. The results above assume that the owner of a medium-sized car (segment C) would replace it with a BEV of the same size. However, subsidies may be targeted at smaller vehicles (segments A and B). In the case of a B-segment car, the price differential would then be limited to €8,900 (the residual value of a 10-year-old ICE) instead of the €11,000 for a C-segment BEV.

This section outlined possible subsidies that would close the price differential between alternatives and keeping an ICE. However, this is a preliminary assessment at the macro level in Europe and further work would be needed to design the exact scheme adapted to each context. Moreover, the Infobox 4 indicates that different stakeholders could be involved in providing these subsidies.

INFOBOX 4: Carmakers to support e-retrofit and scrappage scheme according to the EU's polluter pays principle

Both e-retrofits and scrappage schemes will require substantial contributions from member states, not all of which have to come from public funds. Carmakers have put the cars on the market and are responsible for their carbon pollution as part of their scope 3 emissions. Instead of (or in addition to) subsidies, governments could set strict carbon budgets (or vehicle age limits) for carmakers and require them to clean up the fleet they put on the road. It would be the responsibility of carmakers to either scrap a vehicle and provide the driver with a BEV alternative, or to convert the vehicle to electric at their own cost. Such an approach would be in line with the EU's polluter pays principle.

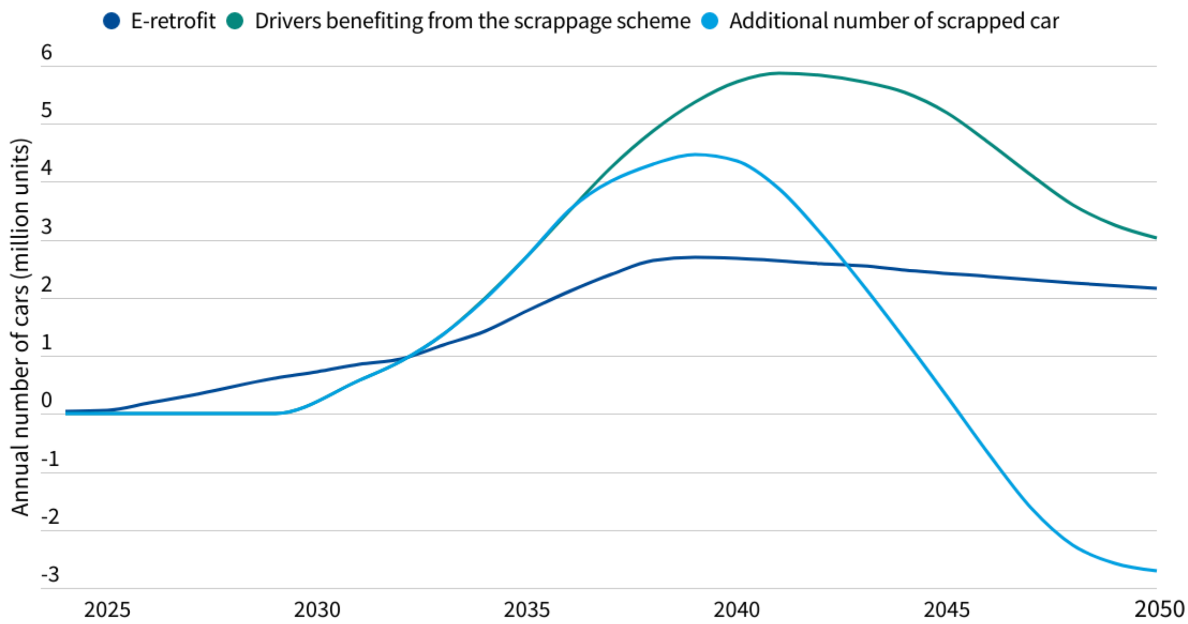
4.3. Scrappage scheme and e-retrofits scenario in T&E roadmap

In this T&E roadmap, the scrappage scheme and e-retrofits are combined with additional measures to address transport activity (presented in section 5). The number of cars to be scrapped and e-retrofitted is therefore calculated so that the combination of these measures combined with activity management leads to zero emissions in 2050.

[26] For a 15 year old ICE, the TCO is calculated over 5 years because the old ICE would have a 5 years remaining lifetime (a total lifetime of 20 years is assumed).

Ramp-up of e-retrofits will save 230 $MtCO_2e$ by 2050

With policy support, the e-retrofit industry could ramp up gradually from niche markets before 2030 to a more significant volume in 2040. Conversion numbers would then slowly decline as the number of eligible vehicles[27] becomes more limited. In a high adoption scenario detailed in a report commissioned by T&E, which we use in this roadmap, 50 million ICEs would be e-retrofitted across Europe by 2050 (45 million in the EU). As a result, e-retrofits would lead to cumulative emissions savings of 300 $MtCO_2e$ by 2050[28] in the EU. To achieve this scenario, the EU e-retrofit industry would need to convert 720,000 vehicles per year in 2030 and 2.7 million per year in 2040. This amount would require 7% of garages[29] to e-retrofit one car per week in 2040. The price differential is €5,000 per conversion, as a result, the total spending would be up to €225 billion between 2024 and 2050. The subsidy should be targeted to low income drivers that cannot make the switch to clean alternatives without additional support. In case the e-retrofit industry fails to ramp up, an equivalent number of cars would need to be scrapped instead.



Source: T&E's modelling of the scrappage scheme in the EU and e-retrofit modelling by 'Electrify' (consultancy)

Figure 8: E-retrofit and scrappage schemes scenario

[27] Assuming that cars older than 20 years would not be eligible due to safety reasons.

[28] The CO_2 savings modelled by T&E are based on the assumption that, on average, ICEs would be e-retrofitted 7 years before the end of their initial lifetime. Assuming an average lifetime of 20 years, the average age for the conversion would be 13 years, which is the midpoint of the technical eligibility age range for e-retrofitting (5 to 20 years old).

[29] According to Eurostat[18], 837,000 companies were registered in the 'wholesale and retail trade and repair of motor vehicles' category in the EU in 2020.

Ramp-up of scrappage scheme will save 550 $MtCO_2e$ by 2050

In the T&E cars roadmap, 73 million ICEs would be scrapped cumulatively between 2035 and 2050. Figure 8 shows that, at the maximum, 6 million drivers would need to benefit from the scrappage scheme in 2041 and this number would decrease to 3 million in 2050. For the car recycling industry, this will lead to a maximum of about 4.5 million additional[30] cars to be scrapped in 2039 compared to the regulation scenario. Then, as many vehicles were scrapped before the end of their life, 2.7 million less cars will need to be scrapped in 2050. As a result, scrappage schemes would lead to cumulative emissions savings of 550 $MtCO_2e$ by 2050.

Assuming that a 13 year old medium car is scrapped 7 years before the end of its life, the price differential (defined in section 4.2) would range from €5,000 if the ICE is replaced by a used BEV to €10,000 if it is replaced by a new C-segment BEV. Based on a central value of €7,500, the total price differential in the 2035-2050 period would be around €550 billion compared to a scenario where ICEs are kept in the fleet. This additional spending would be covered by multiple actors, including consumers, car industry, and public spendings. Low income groups would require dedicated support in the form of subsidies to make the switch to clean alternatives. The total price differential can be reduced if the TCO difference between keeping the ICE and the scrappage scheme option is reduced (e.g. if the difference between the fuel and electricity prices increases) and if the residual value of the ICE is reduced (Infobox 3). The budget would also be reduced if the development of the public transport infrastructure and car sharing services enables drivers to shift away from car ownership and opt for a mobility package as a lower subsidy (€5,000 to cover the ICE residual value) is required compared to scrapping the ICE and buying a new BEV. As explained in Infobox 3, further measures can support the switch away from ICEs by restricting their sales, circulation or exports and thus reduce the need for subsidies.

Compared to the CO_2 regulation scenario, the e-retrofit and scrappage schemes would reduce emissions by 1% in 2030 (4 $MtCO_2e$), 25% in 2040 (51 $MtCO_2e$) and 56% in 2050 (48 $MtCO_2e$) with 850 $MtCO_2e$ saved cumulatively over the 2024-2050 period (12% reduction compared to the baseline). In a scenario with both the scrappage and e-retrofit schemes, the total price differential could reach a maximum of €775 billion *over the whole period between 2024 and 2050* compared to a scenario where ICEs are kept in the fleet. To put this budget in context, €359 billion is allocated *per year* for fossil fuel subsidies in the EU27[19].

Additional BEV production does not increase resource demand if the battery size decreases

In the case where all scrapped cars are replaced by new BEVs, the BEV sales in the EU would have to reach a maximum of about 16 million units in 2039 (4.5 million additional BEVs compared to T&E scenario[31] without scrappage scheme) before declining to 8.7 million in 2050. The new car market would thus

[30] The analysis is based on cars scrapped on average 7 years before their end-of-life. The net additional volume to be scrapped differs from the total number of drivers benefitting from the scrappage scheme. For instance, 5.7 million drivers would benefit from the scrappage scheme in 2040. But 1.4 million cars were scrapped 7 years earlier (cars scrapped in 2033 instead of 2040). This means that the car recycling industry will have to scrap a net additional volume of 4.3 million vehicles in 2050.

[31] T&E scenario is based on measures to avoid car activity growth and increase car occupancy described in section 5. These measures decrease the number of cars sold in 2038 by 2.1 million compared to the regulation scenario.

exceed the historical peak[32] by 20%. In comparison, the regulation scenario[33] would reach 13 million BEVs in 2038. Without measures to reduce battery size, additional BEVs as well as e-retrofits would increase the battery demand compared to the regulation scenario. T&E's position is to favour compact BEVs with right-sized batteries[20]. Weight-based vehicle taxation measures and robust industrial policies have the potential to shift the focus from larger batteries to more efficient and optimised battery designs and contribute to the adoption of lower battery capacities in cars, i.e. from an average of 69 kWh in 2023 to 50 kWh by 2040. As shown in Figure 9, T&E scenario including additional BEVs and e-retrofits would lead to a maximum battery demand of 920 TWh in 2038 if the battery size tends to decrease[34]. This would be 7% lower than the demand in the regulation scenario (980 TWh) where the battery size would follow the current market trend and increase to 74 kWh by 2030.

Instead of buying a new BEV, drivers could subscribe to electric car sharing services. For example, instead of increasing BEV sales to 16 million in 2039, it would be possible to limit sales to 11.5 million, with 4.5 million BEVs being shared between two drivers on average. In this case, the battery demand would be limited to 690 TWh, a 30% reduction compared to the regulation scenario. Additional measures to decrease battery demand are summarised in recommendations (Section 7).

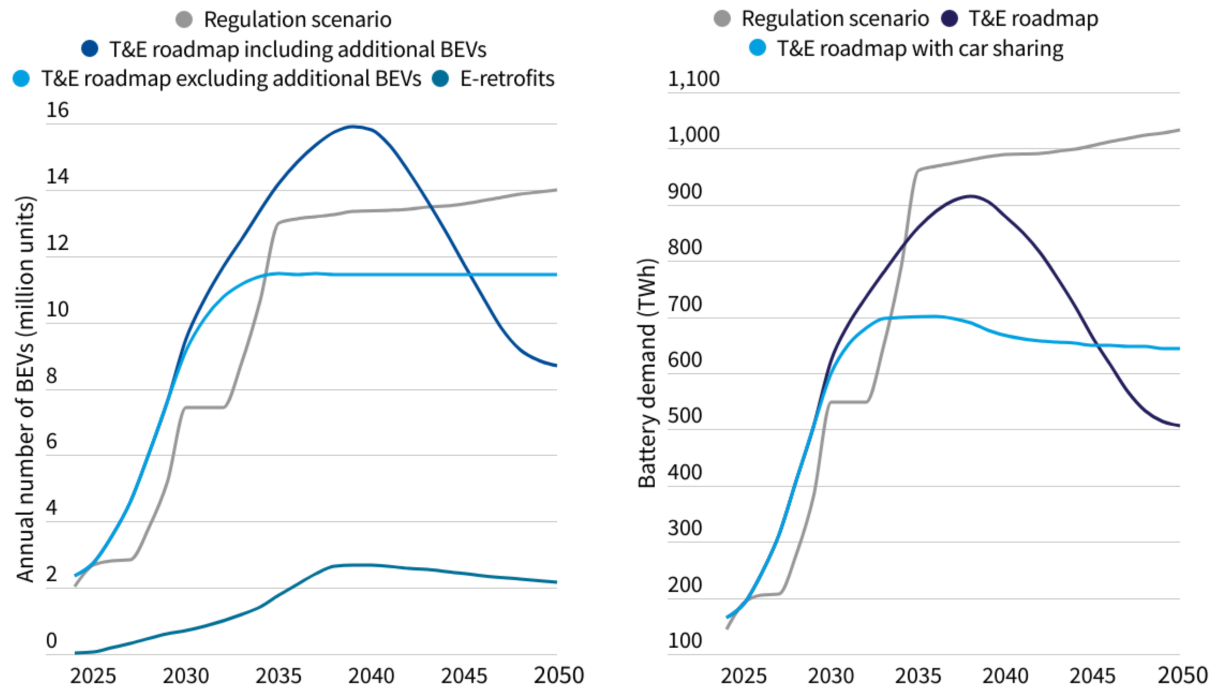
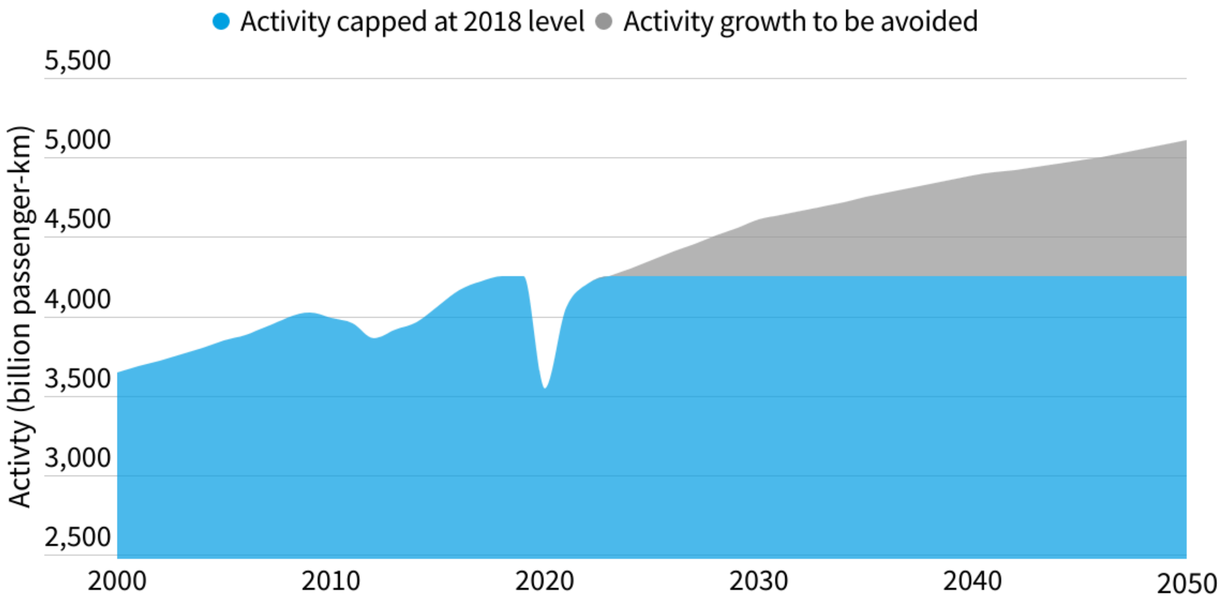


Figure 9: New BEV sales and battery demand

[32] 13.3 million cars were sold in the EU27 in 2007.
[33] The regulation scenario is based on a growing car activity.
[34] Calculated based on an average battery size of 53 kWh for BEVs in 2038 and a 33 kWh average for e-retrofitted cars (average between a minimum of 16 kWh for smallest car and 50 kWh for largest one).

5. Avoiding an increase in car traffic

According to the European Scientific Advisory Board on Climate change[21], the EU's current strategy has proven ineffective in reducing GHG emissions because incremental efficiency improvements and fuel switches have been outpaced by increased transport demand. Indeed, passenger activity has increased by about 17% between 2000 and 2018. The EC reference scenario[22] projects a growth of 20% between 2018 and 2050. This section quantifies the different levers that can be used to prevent this growth in passenger car activity and thus keep car activity constant at 2018 levels. Keeping this level would lead to a 17% decrease in activity compared to the EC baseline scenario with activity growth. The main applicable measures and their assumed contribution to activity reduction compared to the baseline of increased car activity are listed in Table 2.



Scope: Passenger cars in the EU27

Source: Activity growth from the EC reference scenario

Figure 10: Passenger car activity

Table 2 - Activity management measures and impact on 2050 car activity compared to a baseline scenario of increased car activity

Measures to reduce passenger activity	**Reduction compared to 2050 baseline activity**
Limiting activity growth by restricting the construction of new road infrastructure.	-6%
Activity reduction due to fuel price increase and voluntary behaviour change (teleworking, reduction in commuting, …).	-6%
Modal shift thanks to measures at city level (shift to active travel as well as public and shared transport, zero and low emission zones, ...) and measures promoting the shift to rail in long distance travel.	-5%
Other measures to reduce car traffic and fuel consumption[35]	**Change compared to baseline**
Car occupancy rate increase[36] (fuel price increase, development of carpooling, ...).	+10%
Fuel consumption reduction (fuel price increase, limitation of new ICE sport utility vehicle (SUV) sales, speed limit and voluntary behaviour change such as eco-driving, …).	-10%

The main policies and trends associated with each lever are summarised below:

- **Limiting activity growth by restricting the construction of new road infrastructure:** Road infrastructure availability has a significant impact on car activity. The construction of new roads is expected to induce additional transport demand as it stimulates additional car traffic[23]. For instance, T&E estimated that the planned road expansion and construction projects in Germany would induce 35 billion additional car-kilometres per year[24]. This means that restricting road building in Germany would reduce projected passenger activity by around 6%[37]. We assume that this 6% reduction can be extrapolated to the whole of Europe.

- **Impact of fuel price increases:** Increases in international oil prices and fuel taxes under the EU Emissions Trading System (ETS2) are expected to have an impact on fuel demand. This impact depends on uncertainty trends as oil price trends are speculative and the impact of the ETS2 would depend on the evolution of the CO_2 prices. Based on the European Commission

[35] Fuel consumption is not directly related to avoiding car traffic growth but it would have additional influence on CO_2 emissions and it is related to the fuel price increase and voluntary behaviour changes mentioned above.
[36] "Passenger activity (passenger-km) is the distance travelled by all passengers. If the car occupancy increases, then the car traffic (car-km) which is the distance travelled by all cars will decrease even more.
[37] Passenger activity in cars in Germany was 920 billion passenger-km per year in 2018 with an occupancy rate of 1.76.

international oil price projections[22], we estimate that petrol price would rise to €2.6/L in 2050, a 51% increase in petrol price compared to a reference of €1.75/L. Assuming an elasticity of -0.3, this would lead to a 15% reduction of petrol consumption. Modelling from Vivid Economics for T&E shows that the ETS2 CO_2 price could rise up to €440/tCO_2 by 2040. But this would lead to petrol prices up to €3.2/L which might not be politically sustainable. A €3.2/L price would lead to a 33% decrease in oil consumption. In this report, we assume that a political decision would cap the CO_2 prices at €200/tCO_2 leading to an additional €0.47/L tax on petrol. Combined with international oil price increase, this would be a 78% increase in petrol price compared to a reference of €1.75/L, leading to a 23% reduction of petrol consumption. Therefore, based on elasticity calculations, a range of reduction in petrol consumption between 15% and 33% is possible, and we assume a central scenario with a 23% reduction.

This reduction in petrol demand is expected to affect driver behaviour in three different ways. First, car activity would decrease as drivers reduce their mileage due to high fuel costs. Secondly, drivers may voluntarily reduce their speed and adopt an eco-driving style in order to reduce their fuel consumption on a given journey. Finally, car occupancy may increase as people favour carpooling and group their trip in order to share the high cost of the fuel. We assume a 23% reduction in petrol demand in 2050 could be achieved through a 6% activity reduction, a 10% reduction of the in-use fuel consumption and a 10% increase in car occupancy.

- **Measures at city level and modal shift to rail for longer distances**: Modelling by Trasporti e Territorio (TRT), commissioned by T&E's Clean Cities Campaign [25], shows that a range between 15% and 33% of passenger-kilometres in 5 major European cities could be shifted to other modes. This is based on policies that focus on promoting walking, cycling, shared and public transport. On average, we assume that a modal shift of 22% could be achieved in all European urban areas which account for 36% of the European passenger car activity [26]. For non-urban areas, the development of rail transport would be the main lever to shift passenger activity away from cars. We assume that 5% of activity could be shifted to rail outside of urban areas (64% of European passenger car activity). Overall, measures in both urban and extra-urban areas would lead to an 11% reduction in car activity. However, this modal shift could partly overlap with the 6% reduction in activity due to fuel prices increases. Therefore, we conservatively estimate that a total of 5% of car activity compared to the baseline could be shifted to other modes (public transport and active mobility) thanks to urban measures and a shift to rail for longer distances. The share of kilometres travelled by cars, buses, trains, trams and metros has remained relatively stable over the last 20 years, so there is scope to increase the share of kilometres travelled by public or active transport granted public authorities invest in the networks and their expansion. In cities, low and zero emission zones[27] would also be an important lever to limit car use and encourage modal shift.

  In addition, the EU climate Advisory Board [21] notes that spatial planning policies could be used to promote more compact urban organisation and reduce the distances people have to travel to work, education or services. The Advisory Board further notes that these measures can have positive economic and social co-benefits (see section 8.2 for more information). Outside of urban areas, a key factor in reducing car activity would be a shift to rail. This can be achieved by improving rail infrastructure, measures to reduce the cost of rail travel and make it easier to book cross-border and multi-modal journeys [28] and a strategy to facilitate the development of night trains [29].

- **Car occupancy:** The average car occupancy rate in the EU is about 1.6 persons per car. A 10% increase would raise this to 1.8. In addition to behavioural change influenced by higher fuel costs, there is potential for significant improvements through incentives and regulation (e.g. priority road access to carpooling cars or cars with high occupancy), as well as with the increased use of carpooling services [30]. Some EU countries already have higher occupancy rates, Romania has an average occupancy rate of 2.7 [31], so higher occupancy rates should also be achievable in other Member States. Priority should be given to actions in countries with the lowest occupancy rates, e.g. Denmark has an average occupancy rate of only 1.4.

- **Fuel consumption:** In addition to measures that affect car activity, the other priority should be to reduce the fuel consumption of the ICEs that would be sold between 2024 and 2035. The European Court of Auditors [32] reports that most new ICE passenger cars on EU roads still emit the same quantity of CO_2 as 12 years ago. Technological progress in terms of engine efficiency is outweighed by increased vehicle mass and more powerful engines.

  The main problem with recent trends is the rise of SUVs that have reached 54% of the car sales market in 2023[38]. In addition, the EU climate Advisory Board [21] notes that the trend towards SUVs among BEVs is also worrisome, as larger vehicles are more resource- and energy- intensive. They report that, on average, large BEVs weigh 50% more, are 20% less energy efficient and require 70% more critical raw materials than smaller BEVs. The focus on SUVs undermines the overall availability and affordability of BEVs, as they add pressure on the constrained availability of critical raw materials. Reversing the SUV trend should be a priority for policymakers in order to accelerate the reduction of fuel consumption and thus emissions of ICEs, but also to moderate demand for critical raw materials of BEVs, which is a prerequisite to enable the worldwide electrification of the transport fleet.

  Furthermore, the fuel consumption of ICE vehicles already on the road could also be addressed. For example, lower speed limits and ensuring proper enforcement, particularly on highways, can reduce fuel consumption of passenger cars. According to T&E's 2018 report[33], this would lead to a reduction of in-use CO_2 emissions per kilometre between 3% and 12%. In addition, in free-flowing traffic, eco-driving can bring a reduction of 4% to 15% depending on how many drivers drive economically[34].

Compared to the CO_2 regulation scenario, this package of measures to avoid growth in car activity would to reduce emissions by 15% in 2030 (57 $MtCO_2e$), 27% in 2040 (54 $MtCO_2e$) and 34% in 2050 (30 $MtCO_2e$)

[38] T&E analysis of Dataforce's EU27 registration data

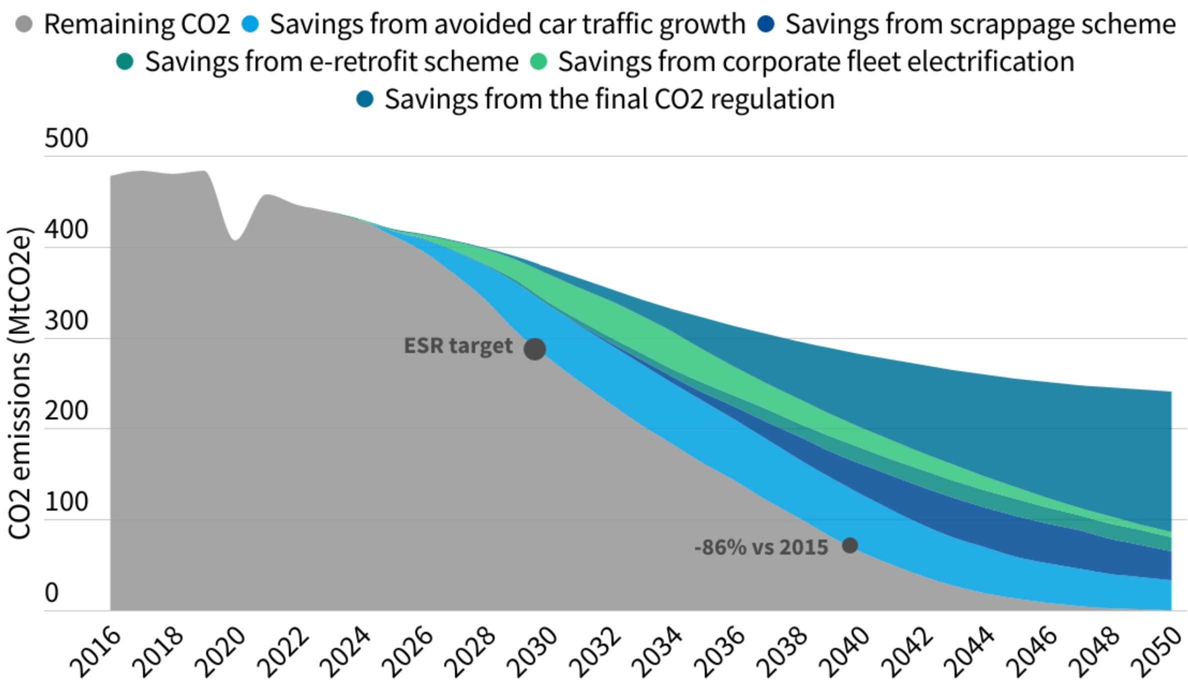
with 1,200 $MtCO_2e$ saved cumulatively over the 2024-2050 period (16% reduction compared to the baseline).

6. T&E Road to Zero car decarbonisation roadmap

T&E's car decarbonisation roadmap is based on the combination of the levers presented in the report:

- Faster BEV uptake in corporate fleets (Section 3)
- Phasing out remaining ICEs though e-retrofit and scrappage schemes (Section 4)
- Avoiding an increase in car traffic through multiple levers on infrastructure, modal split and transport demand (Section 5)

Compared to the CO_2 regulation scenario, T&E roadmap would cut emissions by 25% in 2030 (91 $MtCO_2e$), 68% in 2040 (140 $MtCO_2e$) and 100% in 2050 (86 $MtCO_2e$) with 2,700 $MtCO_2e$ saved cumulatively over the 2024-2050 period (36% reduction compared to the baseline).
This roadmap achieves zero emissions in 2050 without the need for additional measures such as the use of e-fuels which would be better used in other sectors (see Annex D.4 for more information). All these measures are sufficient for the EU to reach the EU ESR target (-40%) by 2030.

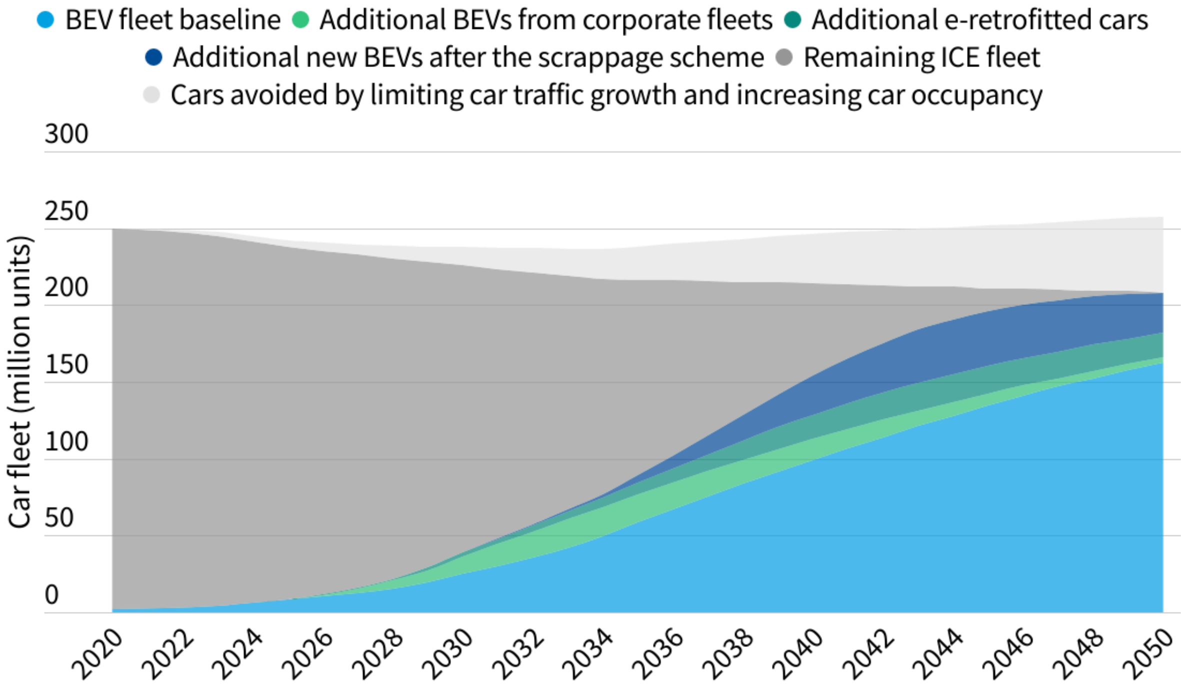


The European Commission's impact assessment for the 2040 target mentions a 86% emission reduction for road transport in 2040
Source: T&E EUTRM modeling of the EU27 car fleet tailpipe emissions.

Figure 11: T&E road to zero

With T&E measures, BEVs are projected to reach 17% of the fleet in 2030 and 59% in 2040
In the T&E roadmap, which includes all measures such as a faster uptake in corporate fleets, as well as e-retrofit and scrappage schemes, we model that the BEV fleet share would reach 17% in 2030 (39 million

BEVs) and 72% in 2040 (150 million BEVs) before reaching 100% in 2050 (210 million BEVs). By comparison, the European Commission[35] expects that at least 30 million zero-emission cars will be in operation on European roads in 2030. The faster uptake in corporate fleets allows for an increase in the BEV number compared to the EC's scenario. In 2040, the EC's Impact Assessment on the EU 2040 targets mentions that ZEVs would reach 62-63% in 2040[39].

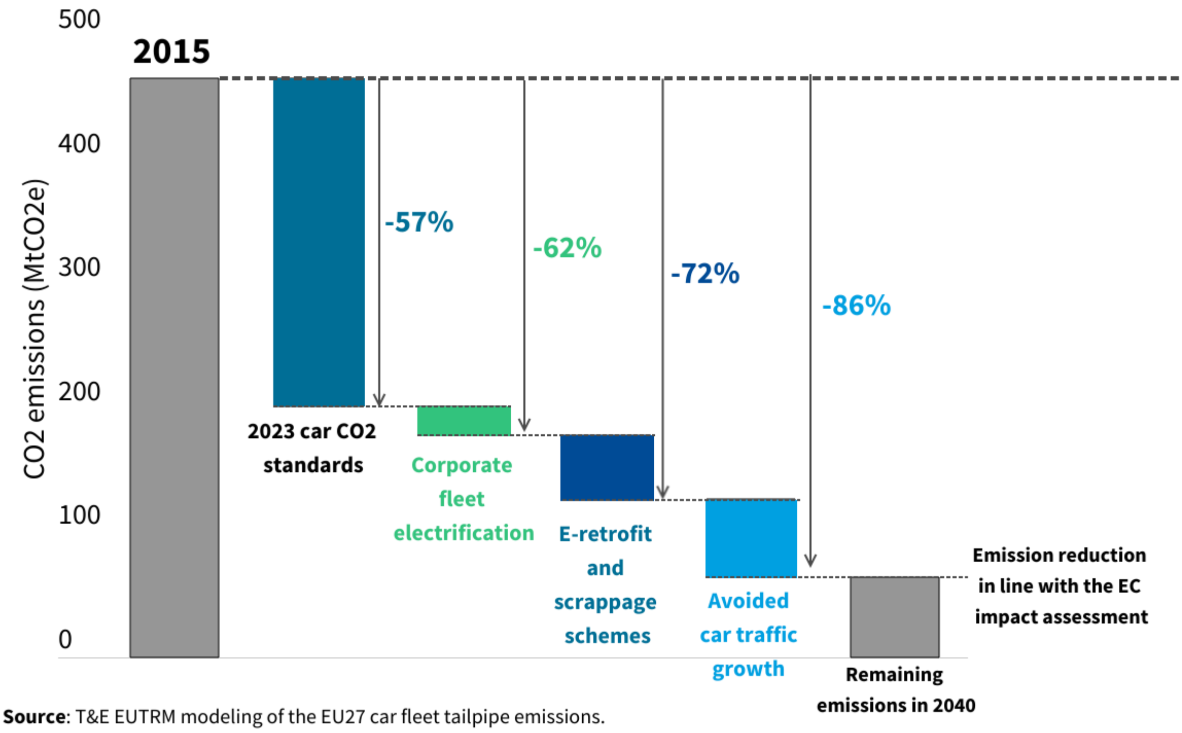


Scope: EU27
Source: EUTRM modelling based on T&E Road-to-zero scenario

Figure 12: BEV uptake in T&E road to zero

The car sector can achieve an 86% reduction in 2040 compared to 2015
Based on the CO_2 regulation, emissions would only be reduced by 57% in 2040 versus 2015. T&E roadmap shows that a significant increase in CO_2 savings reaching 86% emission reduction versus 2015 is feasible. In comparison, the EC's impact assessment for the 2040 target mentions that road transport emissions would need to fall by 86% compared to 2015 but includes the use of e-fuels. Therefore, T&E's roadmap would be in line with the European Commission's road transport scenario and avoids the use of e-fuels which can therefore be prioritised to support the decarbonisation of other sectors.

[39] 56-57% BEVs and 5% FCEVs

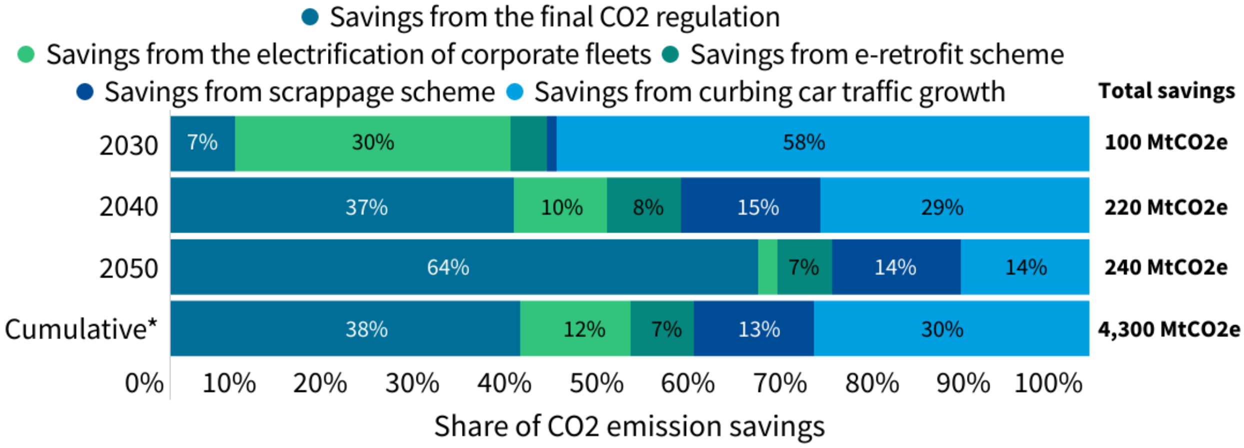


Source: T&E EUTRM modeling of the EU27 car fleet tailpipe emissions.

Figure 13: CO_2 savings in 2040 compared to 2015 level

All measures are complementary and have different impacts depending on the year

Between 2024 and 2050, both the 2023 car CO_2 regulation and the additional measures in T&E pathway will cumulatively save 4,300 $MtCO_2e$ compared to the trend of previous CO_2 standards. Of these savings, 38% come from the 2023 car CO_2 regulation alone, making it the strongest policy lever to date. This is followed by 12% from accelerating the BEV uptake in corporate fleets, 7% from the e-retrofit scheme, 13% from the scrappage scheme and 30% from the measures to reduce the growth in car use. This means that the measures aimed at accelerating the BEV uptake (2023 regulation and faster uptake in corporate fleets) are the most important levers with a combined impact of 51%. All measures are complementary as they have different impacts in different years. In 2030, as other levers would take more time to have an impact, avoiding an increase in car traffic and accelerating the uptake of BEVs in corporate fleets are the main measures needed to reduce emissions and meet the ESR target. In 2040, the e-retrofit and scrappage scheme would have their maximum impact.



Emission savings compared to a scenario based on the previous CO2 regulation (no ICE phase-out)
*Cumulative savings in the 2024-2050 period
Source: T&E EUTRM modeling of the EU27 car fleet tailpipe emissions.

Figure 14: Share of CO_2 savings per lever

7. Recommendations

The 2023 car CO_2 regulation is the single most effective measure as it will reduce emissions by 57% in 2040 compared to 2015. The 2035 ICE phase-out is therefore an essential measure to accelerate decarbonisation. However, additional measures, as outlined in this report, are needed to address the two main remaining challenges: 1) eliminating emissions from the old ICE fleet, as the regulation would leave 73 million old ICEs on the road in 2050. And 2) meet the EU's climate goals, including the new 2040 target of reducing road transport emissions by 86% compared to 2015, while providing clean solutions for all EU drivers and achieving a just transition. These challenges require more ambition in the car sector, where it is high time to move beyond new sales to decarbonise the entire car fleet. Therefore, the analysis in this report shows that phasing out ICE in 2035 is essential, but even if the planned measures are rigorously implemented, it is not enough and we need and will need many additional measures to be put in place quickly in the EU and Member States.

To ensure a pathway consistent with the EU's climate targets, the EU should focus as a priority on:

1. A faster ramp-up of BEV sales in corporate fleets, to accelerate the fleet turnover and the availability of clean used cars.
2. Technical and policy solutions specifically targeting the existing car fleet, in particular e-retrofitting of old ICE cars and scrappage schemes supporting low-income households.
3. Actions to prevent the growth of car use by limiting new road construction, shifting car use to other modes and increasing car occupancy.
4. Shifting car sales away from SUVs and towards right-sized and energy-efficient vehicles to reduce tailpipe emissions from the ICE fleet and reduce raw material demand for new BEVs.

T&E's main recommendations are detailed below:

The EU needs to maintain the 2035 ICE phase-out

Less than one year after the vote of the 2023 car CO_2 standards, some European political parties such as the European People's Party group (EPP) already hinted they would "revise" the combustion engine phase-out[36]. However, the car CO_2 regulation is the single most impactful measure and any proposition to revise would endanger 1,800 million tonnes of CO_2 savings by 2050. Without this regulation, the EU would fail to meet any of its climate targets. On the contrary, T&E recommendation is to strengthen the 2023 CO_2 regulation with more stringent emissions targets in 2030. T&E recommends a 80% emission reduction target in 2030 instead of 55% in the current regulation.

A binding electrification targets for corporate fleets of 50% in 2027 and 100% in 2030

A separate decarbonisation scheme for corporate fleets is needed to accelerate BEV sales and emissions reductions of the corporate sector. Accelerating the electrification of this segment can target millions of polluting vehicles with high mileage, as corporate cars drive twice as much as private vehicles and are responsible for 74% of CO_2 emissions from new sales in the EU. In addition, these vehicles have a higher turnover rate than private cars and would therefore accelerate the uptake of BEVs across the EU car fleet. Being the largest automotive market (58% of new sales) this sector is currently behind the private market with regards to the uptake of electric cars. This is unacceptable as companies have the financial resources to invest in e-mobility and enjoy large tax exemptions through national car taxation. This sector should be leading instead of lagging. Their slow uptake shows that the current national measures are not sufficient to reverse this trend. **Therefore, the next European Commission should by February 2025 come forward with a regulation setting binding targets for corporate fleets of 100% (new cars) in 2030 at the very latest.** The European Commission is currently launching a public consultation on the Greening Corporate Fleets. This should be the first step towards such a regulation.

Providing a clean solution for all drivers to accelerate the removal of ICEs from the fleet

Even with a faster BEV uptake, 68 million ICEs would remain in the EU fleet in 2050 and additional measures are needed to remove old ICEs from the fleet. The comparison of different alternatives shows that scrappage and e-retrofit schemes should be prioritised while the use of e-fuels in cars does not make environmental, economic and industrial sense, and these fuels need to be prioritised in other sectors. The most important measure is to provide financial support to low-income drivers so that they can benefit from a clean and affordable alternative to keeping their old ICE. Different options would need to be offered so that each driver can choose the alternative that best suits their needs. Incentivising the change through subsidies and giving each driver a choice would be the best way to avoid social unrest if solutions were forced by regulation without financial support for low-income drivers. In addition to subsidies, the EU's polluter pays principle can be applied. Governments could set strict carbon budgets or vehicle age limits for carmakers and require them to clean up the fleet they put on the road. In that case, it would be the responsibility of carmakers to either scrap a vehicle and provide the driver with an alternative, or to convert the vehicle to electric.

Removing the barriers to mass-market e-retrofitting

The European Commission should propose as soon as possible a new EU type-approval regulation for e-retrofitted vehicles. The regulation could follow the example of the series-approval introduced in

France and streamline the requirements to ensure that 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 e-retrofit type approval legislation at national level based on the French example (e.g. Belgium is currently working on this). In terms of financial support, the use of subsidies for e-retrofits is fully justified given their environmental and social benefits. Ultimately, an e-retrofit subsidy of €5,000 would be best targeted at low-income households to provide an additional affordable e-mobility option.

Incentives for scrapping of old ICEs

Scrappage schemes are an effective way of accelerating the removal of old ICE from the fleet. For a medium car, price differential would range from €3,000 to €12,000 depending on the age of the car and the alternative chosen by the driver. Scrapping a car, giving up car ownership and opting for a mobility package (public transport and shared mobility) would be the best option to incentivise, but many drivers may not be able to have practical alternatives. National governments would therefore need to expand services in areas with poor public transport connections and promote shared mobility solutions, such as BEV sharing services in local communities. The other option for the driver after scrapping the ICE would be to buy a used BEV or a new one. Used BEVs would be relatively cheap to subsidise, but the size of the used car market would be limited, so this option would be favoured in Eastern Europe in order to direct the flow of used BEVs to these countries. New BEVs would be expensive to subsidise and this solution would be preferred in Western Europe. In order to limit the resources needed to produce large numbers of new cars, subsidies would need to be limited to small and compact BEVs using right sized and resource efficient batteries. In addition, the use of a social leasing scheme would be a complementary solution to make new vehicles available to low-income drivers who don't have the financial capacity to meet the upfront costs of a new car, even with the scrappage scheme subsidy.

Measures to reduce the residual value of old ICEs

Reducing the residual value of old ICEs would support the transition to alternative options at a lower cost to society. Low and zero emission zones, differentiated parking charges or, where this is locally seen as the best solution, congestion charges would discourage the use of ICEs in cities and encourage urban drivers to give up their ICEs. Sales restrictions, such as an age limit for the registration of used ICE, or age and technical limits as part of the roadworthiness test would make old ICE less desirable for drivers. Restricting exports after a certain age or on the basis of technical criteria (e.g. Euro class of the engine) would also reduce the residual value on the domestic market. These measures would also make the e-retrofit option more attractive as e-retrofiters would have access to ICE at a lower cost.

Stop building new roads

Research shows that building additional road capacity increases traffic and therefore emissions. Moreover, transport ministries plan future infrastructure investment based on growth forecasts for traffic demand which are often unrealistic[37]. Member States should therefore adopt a moratorium on new road building.

Encouraging modal shift and additional measures to limit car traffic growth

Governments and local authorities need to promote modal shift from cars to other modes such as public transport, active mobility and shared mobility. In cities, zero- and low-emission zones would be a key measure to encourage modal shift. To be effective, this needs to be combined with the development of the offer for active and public transport as well as shared mobility services. For longer distances, shifting to rail is a key measure which can be achieved by improving rail service levels and infrastructure, measures to reduce the cost of rail travel, making it easier to book cross-border and multimodal journeys, and a strategy to facilitate the development of night trains. Other measures, such as working from home and better urban planning, can also reduce the need to travel and thus limit the demand growth.

Reversing the SUV trends and secure small, affordable EVs for the EU market at volume

The share of SUVs has been increasing over the years and has reached 54% in 2023. This is a problem in terms of fuel consumption and emissions for ICEs, but also for BEVs, as larger vehicles are more resource- and energy- intensive. The focus on SUVs is undermining the overall availability and affordability of BEVs by shifting the market towards more expensive and larger electric cars, thus slowing down EV adoption[38]. Europe needs a strategy for affordable, compact EVs to ensure that carmakers produce and sell these cars at volume:

- As suggested by the car CO_2 standards, the EU should introduce a new EV environmental standard that ends the race towards ever larger, heavier electric cars and encourages car makers to produce the compact, energy efficient, electric vehicles.
- Member State car taxation should promote rightsized, resource efficient vehicles by including weight and size metrics within the taxation framework. The French malus on car weight is a good example[39].
- The EU's Social Climate Fund should require countries to support affordable social leasing of BEVs (subsidised leasing of affordable compact BEVs for those on low incomes). This will ensure that e-mobility is accessible to the low and middle income households which require access to a private vehicle.
- Any of the funds given to car makers as part of national state aid (TCTF) or EU funding programmes to transition their factories should include a requirement to produce at least 50% of BEV models in segments A-C (non-SUV).
- Cities can apply differentiated parking charges as already is the case in several European cities including Lyon, Grenoble and Tübingen, and is planned in Paris[40].

Measures to reduce battery demand

The trend towards larger EV is also increasing the demand on critical raw materials, thus putting pressure on their limited availability. Furthermore, a scrappage scheme to replace ICEs with new BEVs would momentarily increase car production in Europe and thus could increase battery demand if the size of the battery is not managed adequately. T&E recommends the following to limit the growth in battery material demand:

- Favour compact BEVs with right-sized batteries: see above on small affordable EVs.
- Development of charging infrastructure can address range anxiety and help EV drivers choose smaller batteries.

- Improve public transport infrastructure coverage, quality and affordability and improve the accessibility of active mobility to encourage car drivers to make the shift away from car ownership.
- Improve electric car sharing services. National or local policies are needed to support the deployment of car-sharing services in all areas.
- Policies should ensure that all drivers have the choice to opt for a mobility package with comprehensive public transport and shared mobility services.

E-fuels are not needed to decarbonise the car fleet

T&E's roadmap shows that EU climate targets can be met without the use of e-fuels in cars. Moreover, e-petrol was found to have the highest cost to the owner, higher lifecycle CO_2 emissions and would not reduce urban air pollution. Crucially, e-fuels and the hydrogen needed to produce them will be in high demand in many sectors (e.g. aviation and shipping), so there is no guarantee that e-petrol would be available for cars. If any e-petrol is available for cars, it will be very expensive for the drivers and in very limited quantities. Some fuels will be co-produced as e-kerosene is mandated by regulation. Co-products have to be prioritised for other sectors where there are fewer alternatives to fossil fuels such as shipping, industrial applications, the plastic industry or special-purpose vehicles (e.g. ambulances, fire trucks).

The European Commission needs to include additional measures in its 2040 plans

The EC's 2040 impact assessment[4] relies only on existing policies such as the car CO_2 standards and the ETS2, and assumes additional e-fuels. T&E's analysis shows that the car CO_2 standards are essential but not sufficient, and that additional measures are needed to accelerate the fleet turnover. Given the difference in BEV uptake between T&E modelling of the CO_2 regulation (45% BEV in the fleet in 2040) and the EC impact assessment (62-63%), we assume that the EC relies on the ETS2 to accelerate the BEV uptake. However, this would likely rely on high fuel prices which might not be socially sustainable. In addition, the availability of e-fuels for cars is highly uncertain, and if available, e-fuels would be prohibitively expensive for cars. Policymakers therefore have to choose between high fuel prices (due to high ETS2 prices and the addition of very expensive e-fuels) with possible social consequences, or opting for moderate fuel prices with additional measures to ensure a just transition. All of the additional measures included in T&E's Road-to-Zero pathway would secure the EU's 2040 climate targets while providing clean and affordable solutions to help all drivers make the transition away from polluting fossil cars. This roadmap avoids the use of highly uncertain and inefficient e-fuels which could be prioritised in other sectors, and does not depend on high CO_2 prices. Therefore, this roadmap with additional measures is better suited to deliver a just transition with clean solutions for all without the high uncertainties and risks of the current EC's 2040 impact assessment.

8. Future prospects

8.1. The implementation of all measures in an effective and socially acceptable way requires a paradigm shift

As mentioned in Section 6, limiting the future growth of passenger car activity is the second largest lever to reduce emissions from the car fleet. For these efforts to succeed, all policy measures need to be designed in a way that ensures both their effectiveness and their acceptance among the population.

This critically depends on a paradigm shift in urban and spatial planning as well as on improvements in the availability of basic services in all areas, including rural areas. For instance, in cities, space use should be optimised to avoid further urban sprawl. This implies a more even distribution of functional areas within cities to limit urban sprawl and avoid the transformation of agricultural or natural lands. Furthermore, a redistribution of public space from motorised road transport towards people can enhance liveability, accessibility and sustainability. Priority measures include more infrastructure for pedestrians and cyclists, more green and blue space as well as more playgrounds and parks. The densification of existing urban areas should also be part of the solution.

Secondly, it is important to stress that emissions from road transport have a strong social dimension. A large, growing body of research shows that low-income households emit the least amount of air pollution and greenhouse gas emissions, while being exposed to the highest levels of air pollution and also being more vulnerable to its adverse impact[41]. Targeted support measures are therefore needed to guarantee accessibility for all parts of the population, and especially for groups that are more at risk. This is all the more important considering that certain groups (particularly among commuters) are locked into 'forced car ownership'[41]. This term refers to the fact that due to a lack of viable transport alternatives, certain citizens have no choice but to own a car. Measures that have proven successful in this regard include scrappage schemes and social leasing for electric vehicles (see chapter 7) as well as financial support for (electric) bike purchase and leasing, targeted reductions in public transport fares and shared mobility hubs in underserved areas[41].

All these principles should be guided by the objectives to build liveable and sustainable cities, but also to promote accessibility and social participation for all citizens. As many of these changes will be structural, they will require democratic participation through consultations, feedback mechanisms and information campaigns. In rural areas, most basic services and leisure opportunities would need to be available in any town to avoid long car travel.

INFOBOX 5: Better accessibility with less mobility demand

The aim of transport policy should be to improve accessibility. People want access to family and friends, to shops, recreational areas, workplaces and so on. Businesses want access to their suppliers, to the labour market, and their clients. It is crucial to grasp that accessibility can be achieved in two fundamental separate ways: by proximity and through mobility. For more than two thousand years people have clustered in cities because other destinations are close by. The proximity in urban areas made them the major engines for economic prosperity, and the hotbeds for innovation.

A major fallacy in transport policy is that its aim is to accommodate mobility demand. But it is not mobility, but accessibility that generates social and economic benefits. During the last decades Western countries have focussed on mobility, neglecting the benefits of proximity. Travel distances to schools, hospitals, jobs, leisure and so on have all grown during the last half century. This spatial dispersion and the related suburbanization, increased car dependency and even diminished accessibility.

Spatial concentration in villages, towns and cities, creates better accessibility with less mobility. A higher concentration of shops, libraries, medical services, schools, and bus stops in villages and neighbourhoods would enable inhabitants to stay nearby. In urban areas, the proximity of destinations outweighs the disadvantage of slower travel. Short distances make walking and cycling an attractive choice for many trips. Compact cities support the provision of good public transport services. Urban densification would result in a more efficient spatial structure, which is liveable, inclusive and creates lower costs for daily mobility.

Urbanisation also reduces the environmental and climate impact of mobility. Car mileage per inhabitant in major cities and metropolitan areas is only one to two thirds of that in rural areas (see table). The geographical layout is even the main determinant of mobility behaviour, both in travel distance and mode choice.

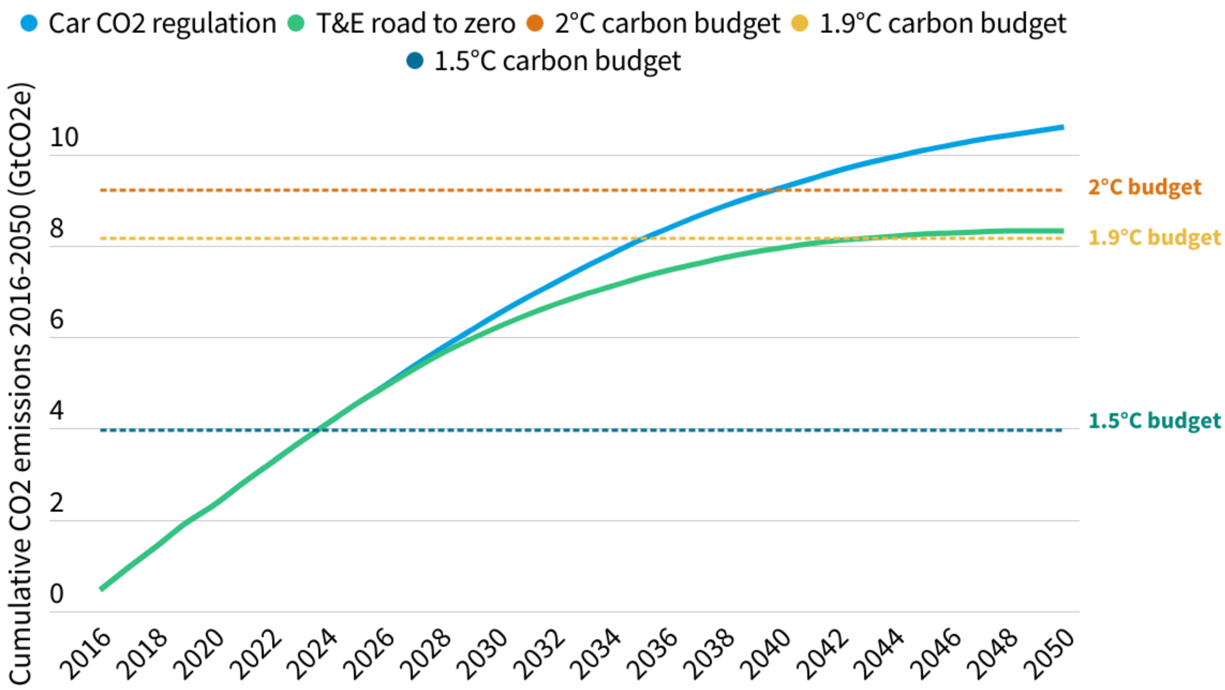
	Metropolis	**Large town**	**Rural**
Average trip distance	5 km	10 km	15 km
Average commuting distance	10 km	15 km	20 km
Average trip speed	15 km/h	25 km/h	35 km/h
Average car speed	20 km/h	35 km/h	50 km/h
Share of car trips	15%	50%	70%
Car-kilometres per capita	10 km/day	25 km/day	35 km/day

Table: In the Netherlands, mobility behaviour depends on degree of urbanisation

Author: Arie Bleijenberg
This is an abstract from the analyses of the book 'New mobility – beyond the car era' [42] and the paper 'The transport-urbanisation dialectic' [43].

8.2. T&E's roadmap would put EU cars on a 2°C compliant trajectory

As detailed in Annex C, cumulative car emissions can be compared with carbon budgets allocated to cars. As shown in figure 15, cumulative emissions from the car fleet with BEV sales driven by the 2023 car CO_2 standards only (scenario presented in section 2) are exceeding a 2°C carbon budget allocated to EU cars by 15%. The 1.5°C carbon budget is already expected to be reached in 2024 while the 2°C budget would be reached already in 2040. In section 6, T&E pathway was defined to be aligned with EU climate targets and this pathway would be 10% below a 2°C carbon budget in 2050 and 2% above a 1.9°C budget. T&E road to zero would therefore ensure that the 2°C carbon budget is not exceeded. Therefore, T&E's roadmap should be considered as a minimum and policymakers would need to set more ambitious and rapid measures for cars in order to secure a pathway "well below 2°C" as mentioned in the Paris agreement.



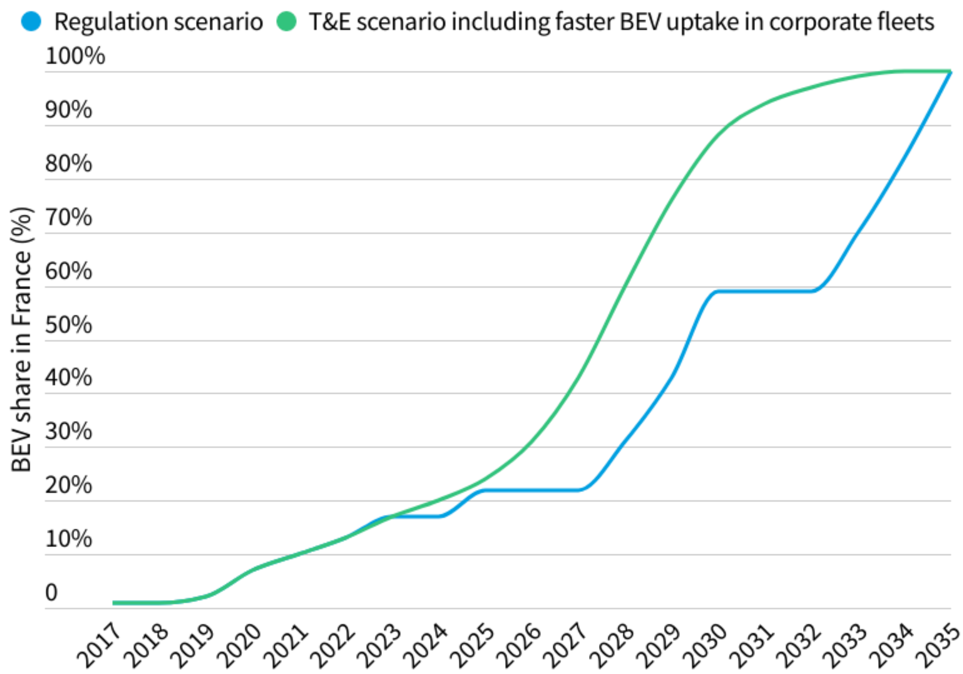
Scope: EU27
Source: T&E EUTRM modeling of the car fleet emissions

Figure 15: Comparison of the 2023 car CO_2 standards emissions with climate pathways

ANNEXES

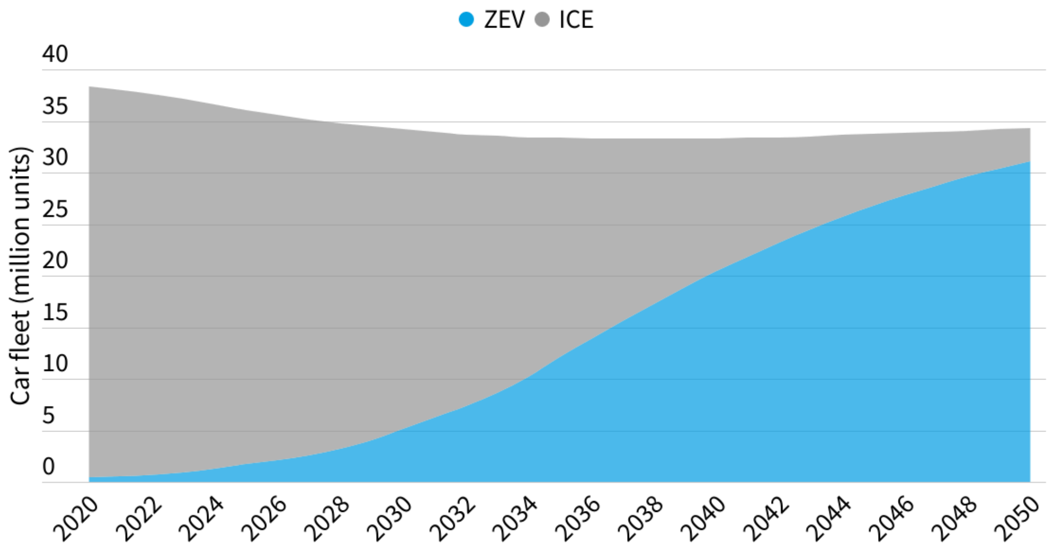
A. Results for the largest European car markets

A.1. France



Source: T&E's modelling of the minimum BEV share of sales required to meet the EU car CO2 regulation, and the impact of faster electrification in corporate fleets

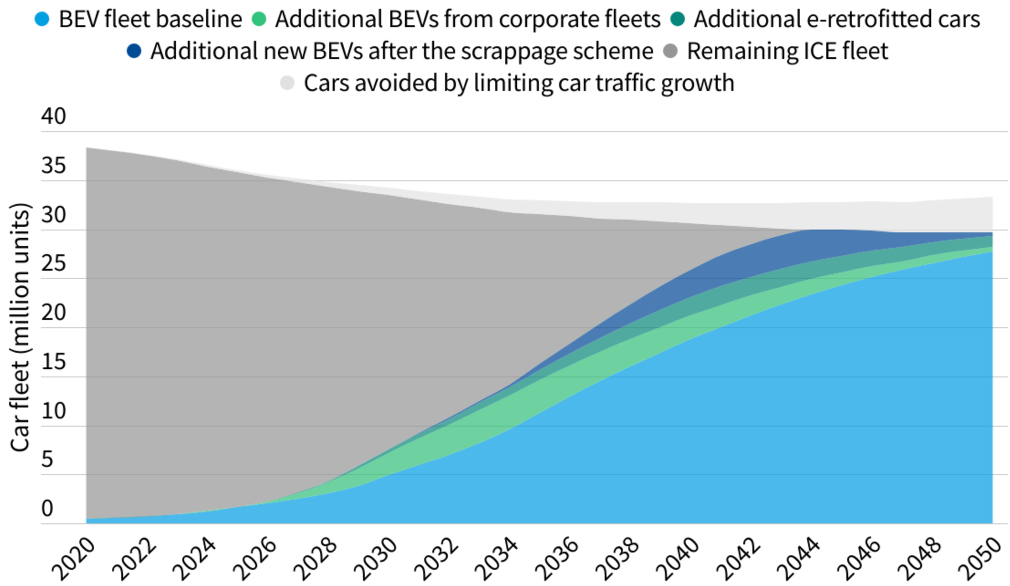
Figure 16: BEV sales in France



Scope: France
Source: T&E EUTRM modelling based on new ZEV sales required to meet the car CO2 regulation

Figure 17: Car fleet in France in the regulation scenario

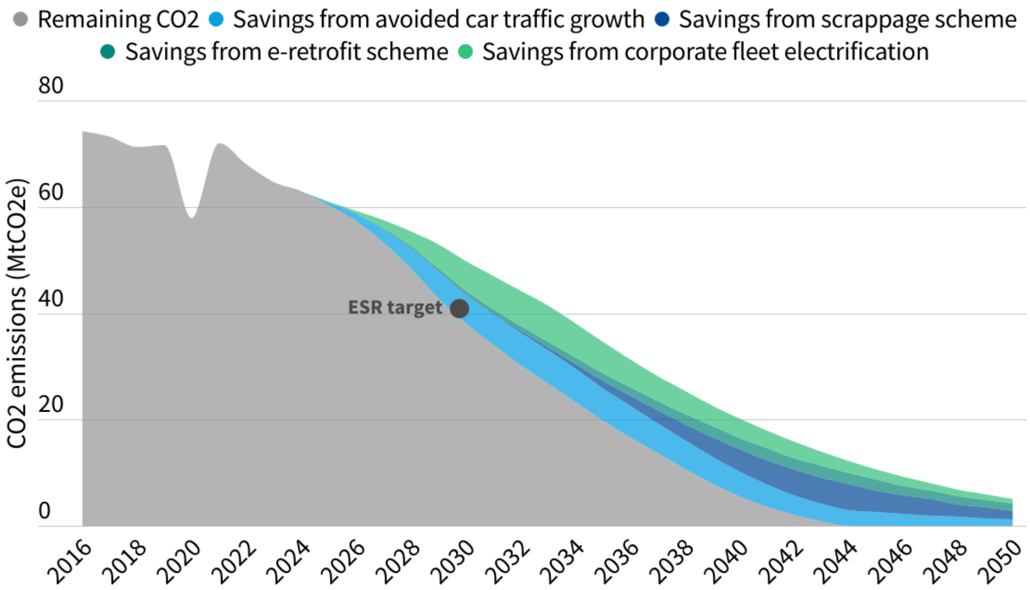
The car CO_2 regulation is expected to increase drive the BEV share of the French car fleet from 1.8% in 2022 (690,000 BEVs), to 15% in 2030 (5 million BEVs), 61% in 2040 (20 million BEVs) and 91% 2050 (31 million BEVs).



Scope: France
Source: EUTRM modelling based on T&E roadmap

Figure 18: Car fleet in France in T&E road to zero

T&E road to zero would increase the BEV share of the French car fleet from 1.8% in 2022 (690,000 BEVs), to 23% in 2030 (8 million BEVs) and 85% in 2040 (26 million BEVs) and 100% in 2044 (30 million BEVs).

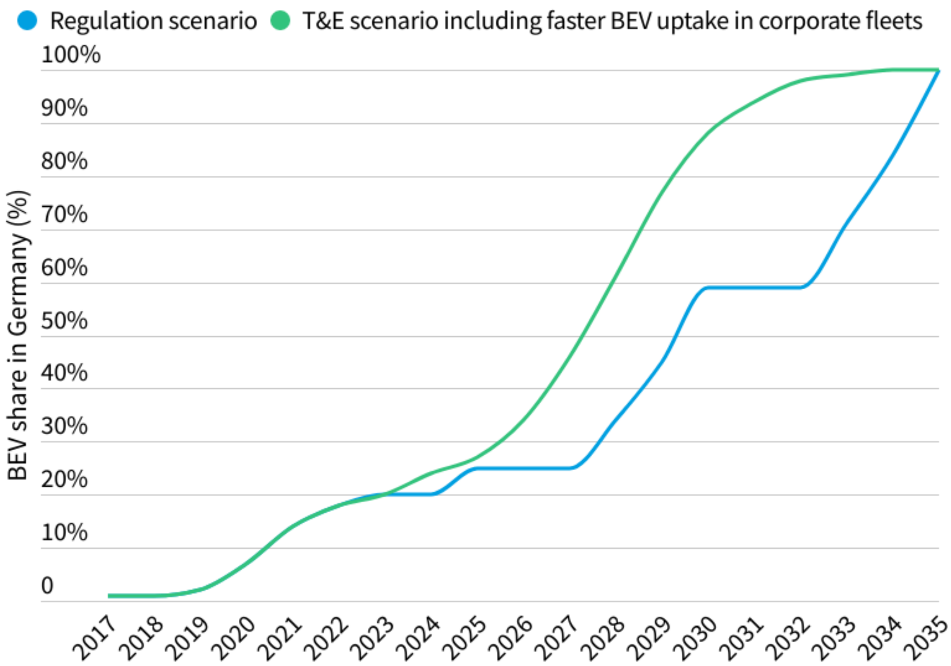


Source: T&E EUTRM modeling of the car fleet tailpipe emissions in France

Figure 19: CO_2e emissions from the car fleet in France in T&E road to zero

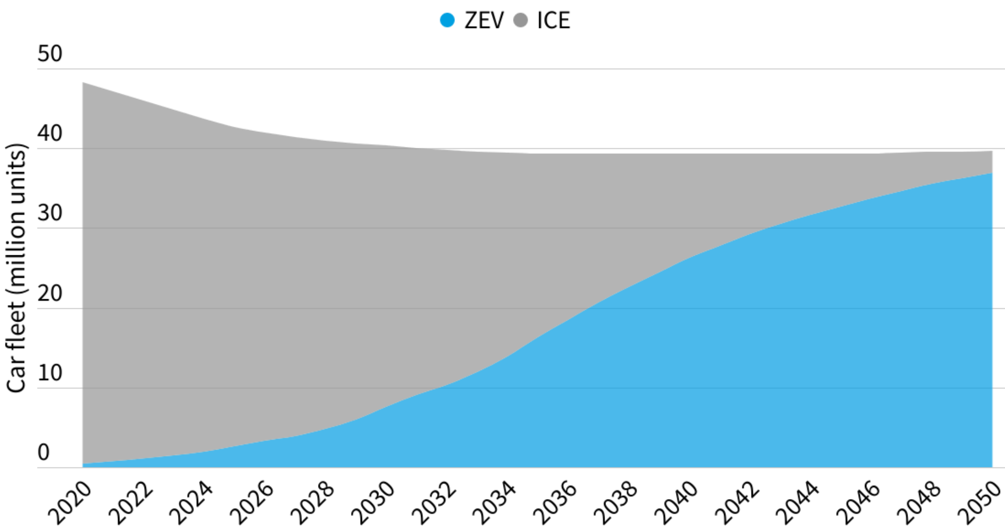
Compared to the CO_2 regulation, T&E road to zero reduce emissions by 23% in 2030 (-12 $MtCO_2e$), 72% in 2040 (-15 $MtCO_2e$) and reach zero emissions in 2044 (-12 $MtCO_2e$). This would be a cumulative 280 $MtCO_2e$ savings over the 2024-2050 period (-31% compared to the baseline). The roadmap complies with the ESR targets in 2030.

A.2. Germany



Source: T&E's modelling of the minimum BEV share of sales required to meet the EU car CO2 regulation, and the impact of faster electrification in corporate fleets

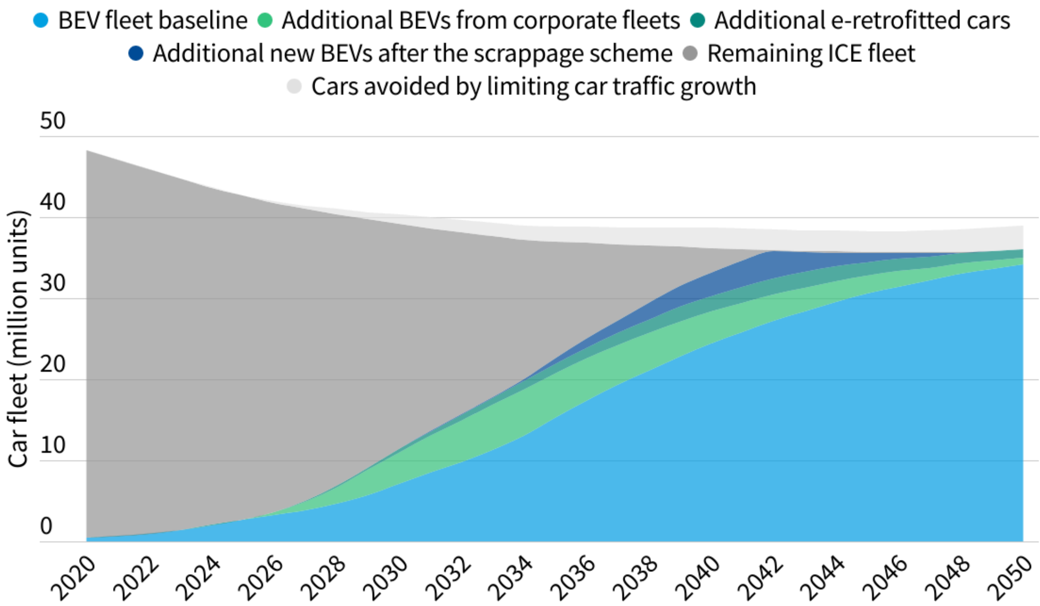
Figure 20: BEV sales in Germany



Scope: Germany
Source: T&E EUTRM modelling based on new ZEV sales required to meet the car CO2 regulation

Figure 21: Car fleet in Germany in the regulation scenario

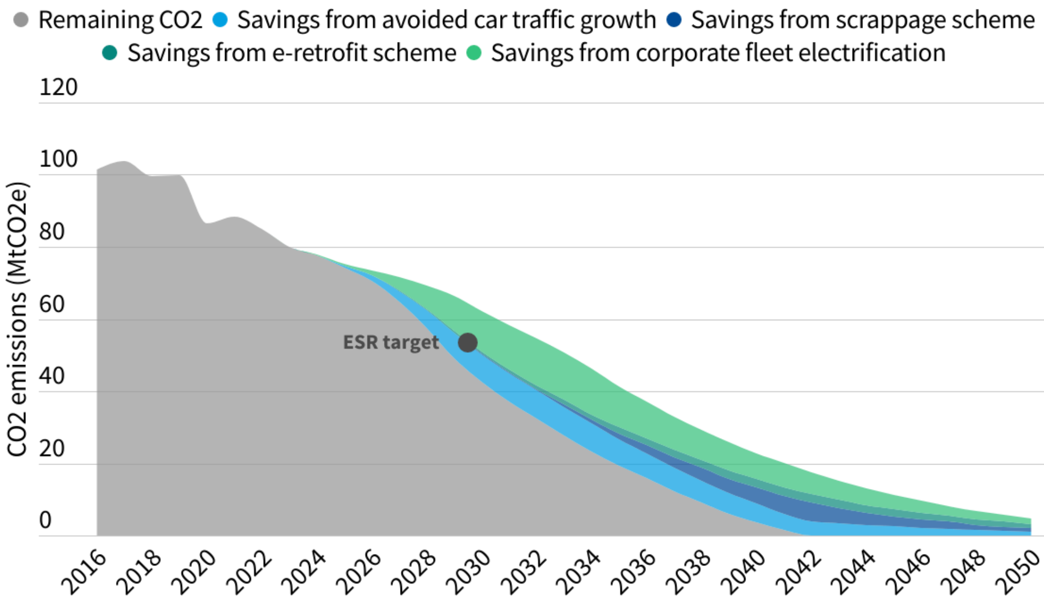
The car CO_2 regulation is expected to increase the BEV share of the German car fleet from 2% in 2022 (970,000 BEVs), to 19% in 2030 (8 million BEVs), 67% in 2040 (26 million BEVs) and 93% in 2050 (37 million BEVs).



Scope: Germany
Source: EUTRM modelling based on T&E roadmap

Figure 22: Car fleet in Germany in T&E road to zero

T&E road to zero would increase the BEV share of the German car fleet from 2% in 2022 (970,000 BEVs), to 29% in 2030 (11 million BEVs), 92% in 2040 (33 million BEVs) and 100% in 2043 (36 million BEVs).

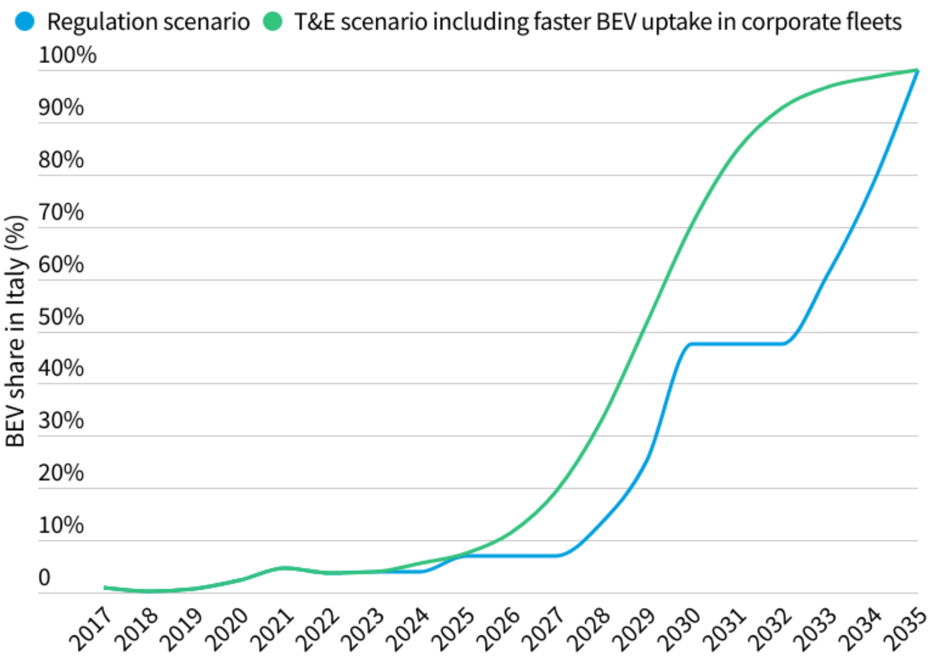


Source: T&E EUTRM modeling of the car fleet tailpipe emissions in Germany

Figure 23: CO_2e emissions from the car fleet in Germany in T&E road to zero

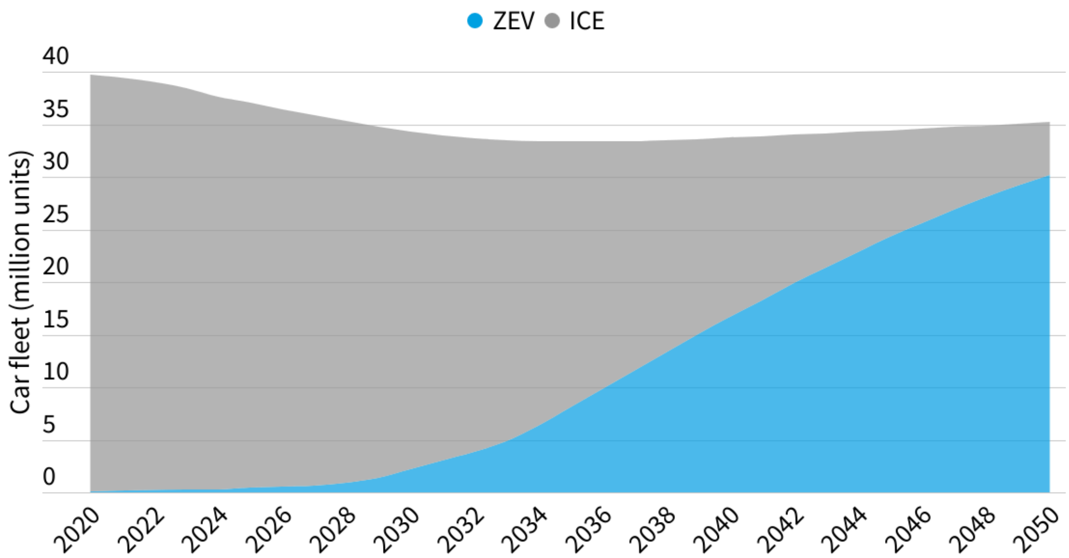
Compared to the CO_2 regulation, T&E road to zero reduce emissions by 32% in 2030 (-20 MtCO_2e), 84% in 2040 (-19 MtCO_2e) and reach zero emissions in 2043 (-15 MtCO_2e). This would be a cumulative 380 MtCO_2e savings over the 2024-2050 period (-35% compared to the baseline). The roadmap complies with the ESR targets in 2030.

A.3. Italy



Source: T&E's modelling of the minimum BEV share of sales required to meet the EU car CO2 regulation, and the impact of faster electrification in corporate fleets

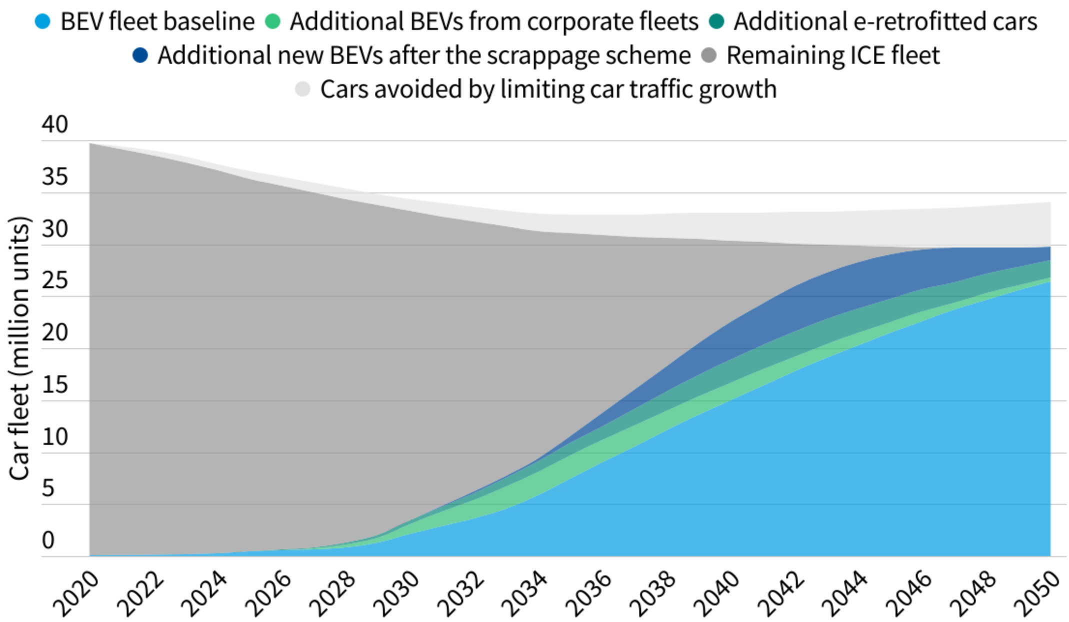
Figure 24: BEV sales in Italy



Scope: Italy
Source: T&E EUTRM modelling based on new ZEV sales required to meet the car CO2 regulation

Figure 25: Car fleet in Italy in the regulation scenario

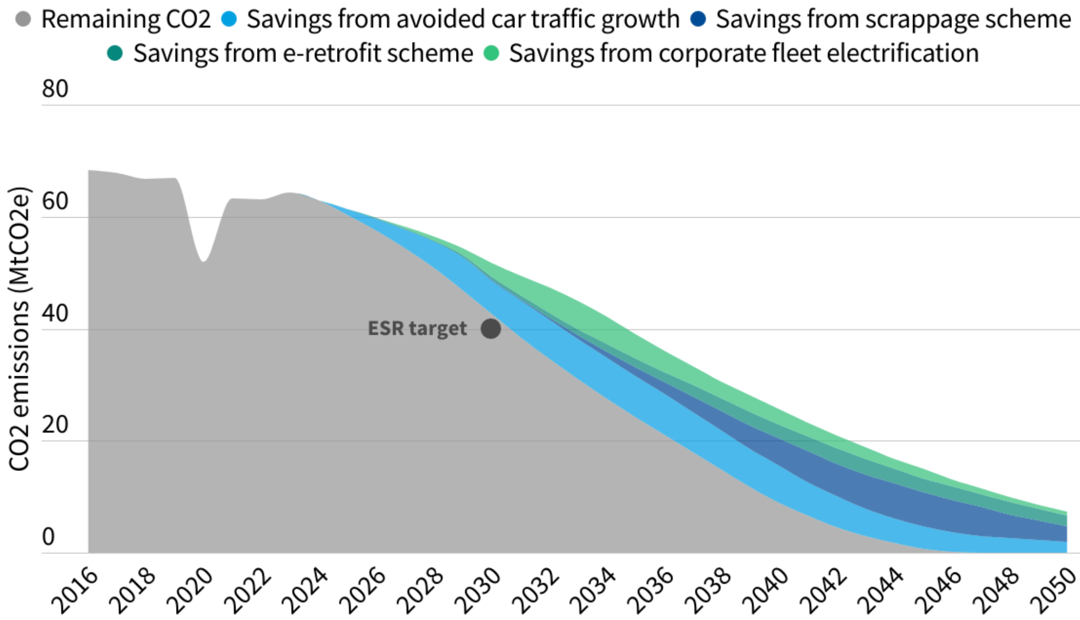
The car CO_2 regulation is expected to increase the BEV share of the Italian car fleet from 0.4% in 2022 (170,000 BEVs), to 6% in 2030 (2 million BEVs), 50% in 2040 (17 million BEVs) and 86% in 2050 (30 million BEVs).



Scope: Italy
Source: EUTRM modelling based on T&E roadmap

Figure 26: Car fleet in Italy in T&E road to zero

T&E road to zero would increase the BEV share of the Italian car fleet from 0.4% in 2022 (170,000 BEVs), to 10% in 2030 (3 million BEVs), 74% in 2040 (22 million BEVs) and 100% in 2047 (30 million BEVs).

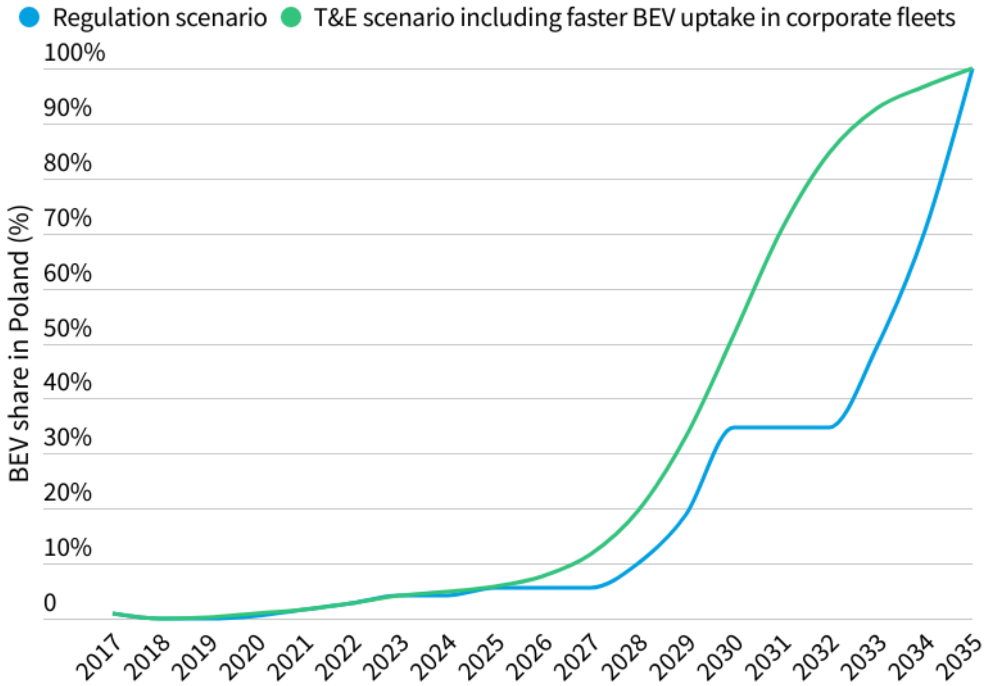


Source: T&E EUTRM modeling of the car fleet tailpipe emissions in Italy

Figure 27: CO_2e emissions from the car fleet in Italy in T&E road to zero

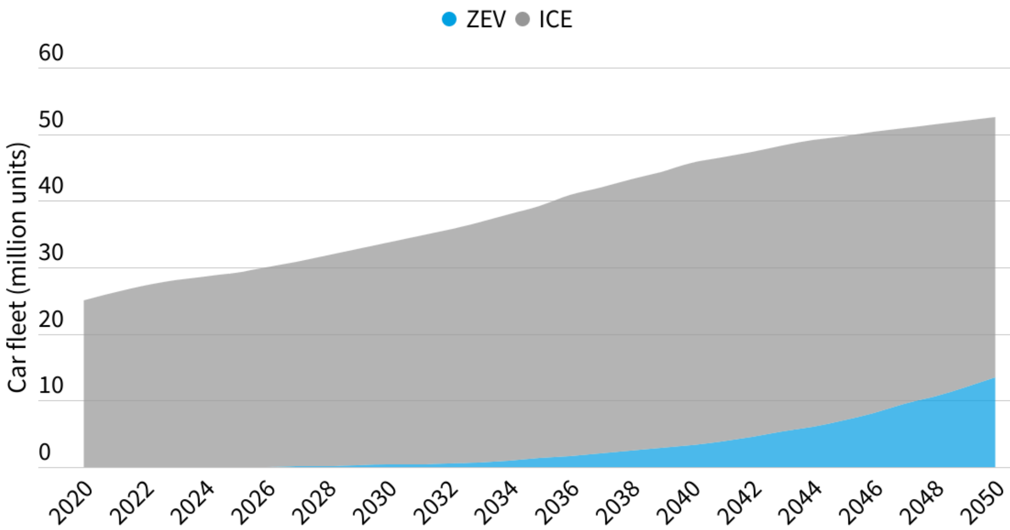
Compared to the CO_2 regulation, T&E road to zero reduce emissions by 18% in 2030 (-9 MtCO_2e), 65% in 2040 (-17 MtCO_2e) and reach zero emissions in 2047 (-11 MtCO_2e). This would be a cumulative 300 MtCO_2e savings over the 2024-2050 period (-31% compared to the baseline). The roadmap does not comply with the ESR targets in 2030 and other sectors will need to achieve higher savings than the car sector.

A.4. Poland



Source: T&E's modelling of the minimum BEV share of sales required to meet the EU car CO2 regulation, and the impact of faster electrification in corporate fleets

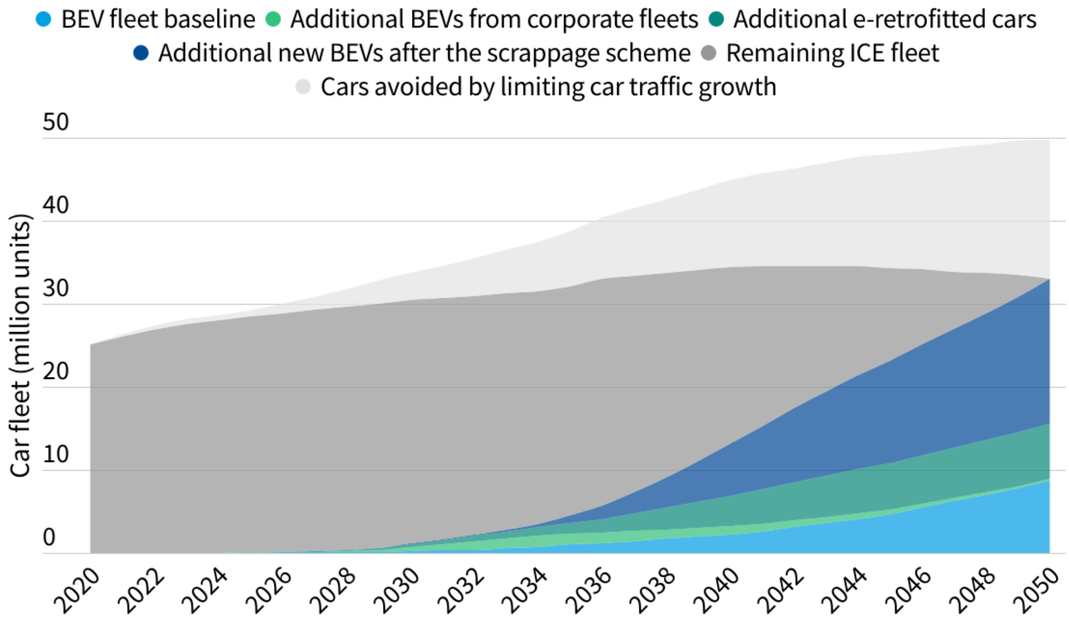
Figure 28: BEV sales in Poland



Scope: Poland
Source: T&E EUTRM modelling based on new ZEV sales required to meet the car CO2 regulation

Figure 29: Car fleet in Poland in the regulation scenario

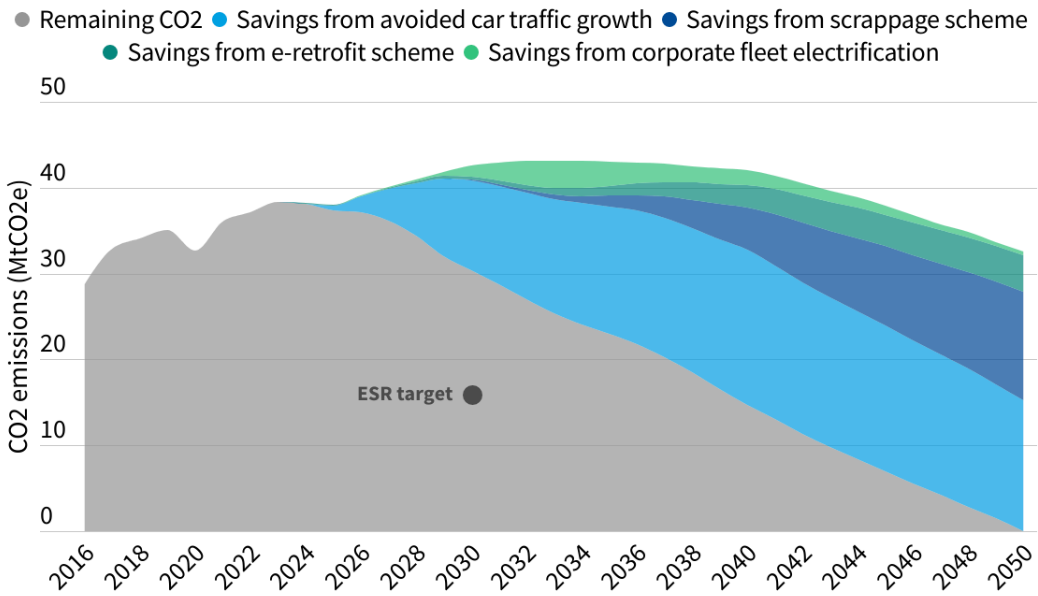
The car CO_2 regulation is expected to increase the BEV share of the Polish car fleet from 0.1% in 2022 (26,000 BEVs), to 1% in 2030 (400,000 BEVs), 7% in 2040 (3 million BEVs) and 26% in 2050 (13 million BEVs).



Scope: Poland
Source: EUTRM modelling based on T&E roadmap

Figure 30: Car fleet in Poland in T&E road to zero

T&E road to zero would increase the BEV share of the Polish car fleet from 0.1% in 2022 (26,000 BEVs), to 4% in 2030 (1 million BEVs), 38% in 2040 (13 million BEVs) and 100% in 2050 (33 million BEVs).

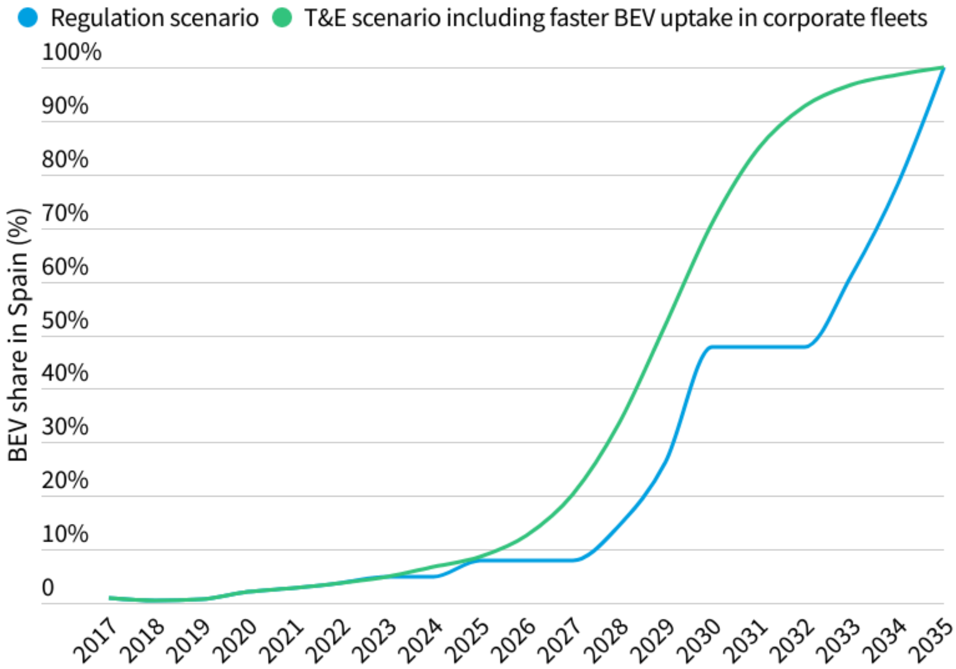


Source: T&E EUTRM modeling of the car fleet tailpipe emissions in Poland

Figure 31: CO_2e emissions from the car fleet in Poland in T&E road to zero

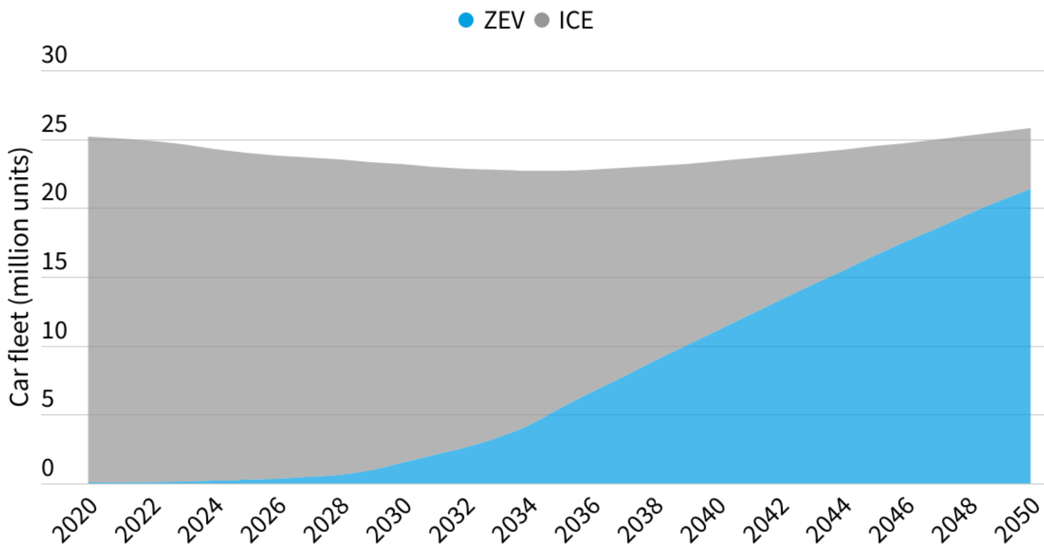
Compared to the CO_2 regulation, T&E road to zero reduce emissions by 29% in 2030 (-12 $MtCO_2$e), 65% in 2040 (-27 $MtCO_2$e) and reach zero emissions in 2050 (-33 $MtCO_2$e). This would be a cumulative 550 $MtCO_2$e savings over the 2024-2050 period (-49% compared to the baseline). The roadmap does not comply with the ESR targets in 2030 and other sectors will need to achieve higher savings than the car sector.

A.5. Spain



Source: T&E's modelling of the minimum BEV share of sales required to meet the EU car CO2 regulation, and the impact of faster electrification in corporate fleets

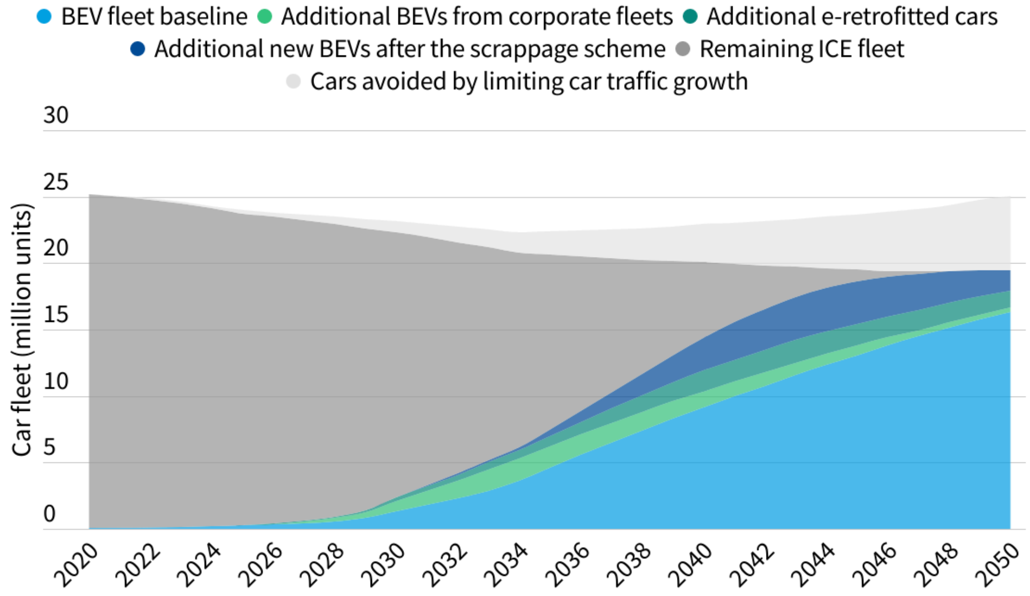
Figure 32: BEV sales in Spain



Scope: Spain
Source: T&E EUTRM modelling based on new ZEV sales required to meet the car CO2 regulation

Figure 33: Car fleet in Spain in the regulation scenario

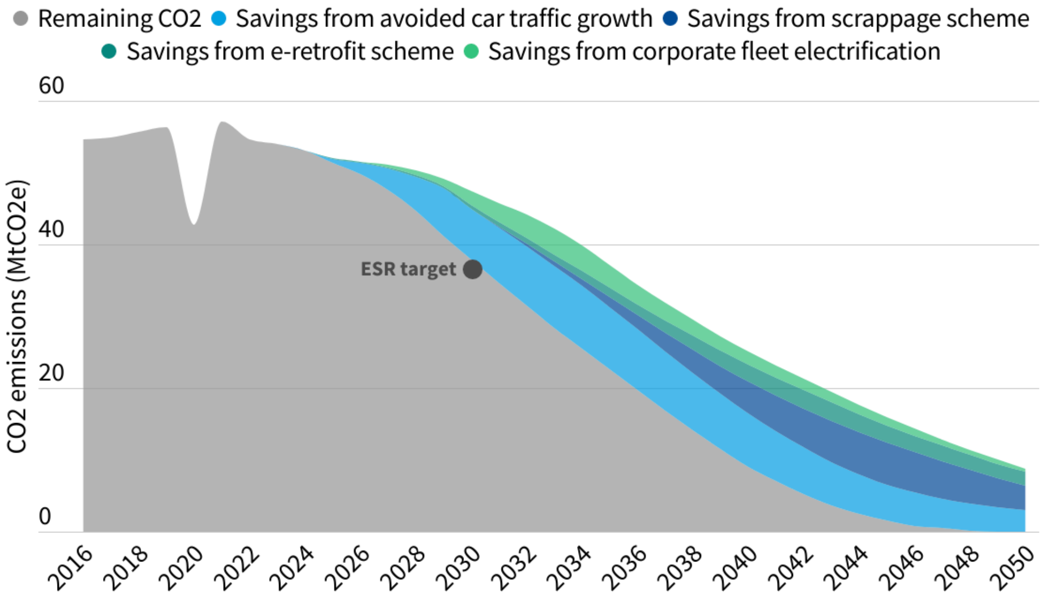
The car CO_2 regulation is expected to increase the BEV share of the Spanish car fleet from 0.4% in 2022 (100,000 BEVs), to 7% in 2030 (2 million BEVs), 47% in 2040 (11 million BEVs) and 83% in 2050 (21 million BEVs).



Scope: Spain
Source: EUTRM modelling based on T&E roadmap

Figure 34: Car fleet in Spain in T&E road to zero

T&E road to zero would increase the BEV share of the Spanish car fleet from 0.4% in 2022 (100,000 BEVs), to 11% in 2030 (2 million BEVs), 72% in 2040 (14 million BEVs) and 100% in 2048 (19 million BEVs).



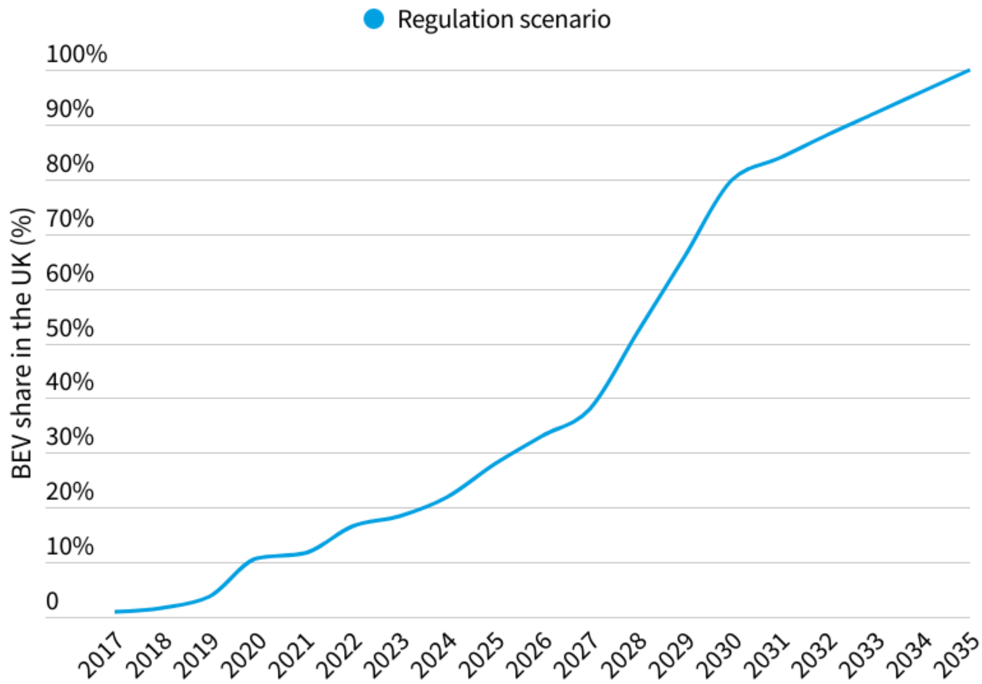
Source: T&E EUTRM modeling of the car fleet tailpipe emissions in Spain

Figure 35: CO_2e emissions from the car fleet in Spain in T&E road to zero

Compared to the CO_2 regulation, T&E road to zero reduce emissions by 20% in 2030 (-10 MtCO_2e), 64% in 2040 (-16 MtCO_2e) and reach zero emissions in 2048 (-10 MtCO_2e). This would be a cumulative 310 MtCO_2e savings over the 2024-2050 period (-33% compared to the baseline). The roadmap does not comply with the ESR targets in 2030 and other sectors will need to achieve higher savings than the car sector.

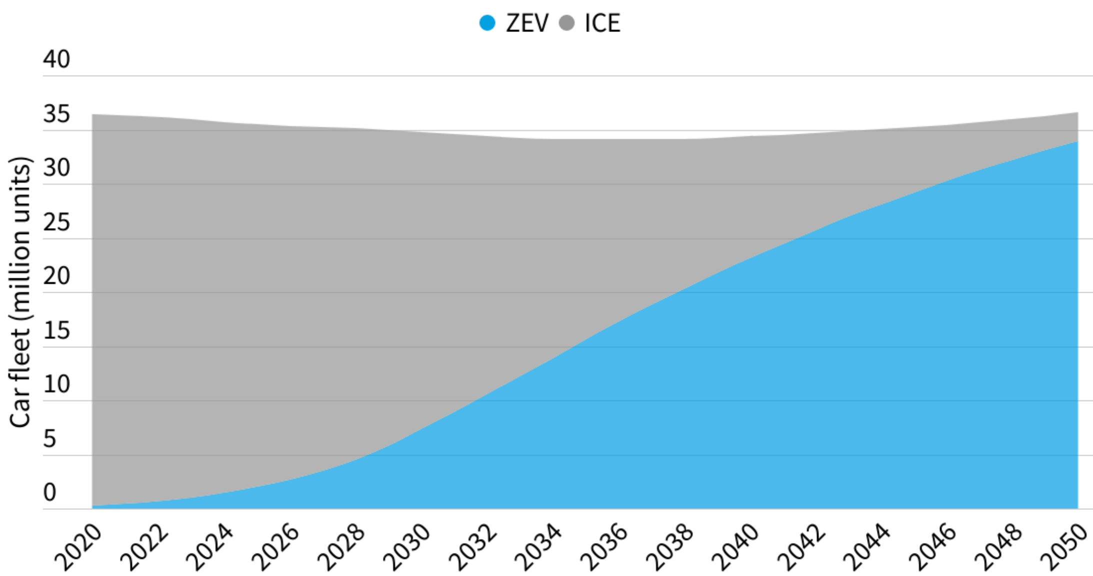
A.6. UK

Outside the EU, the UK's decarbonisation pathway for cars and vans is set largely through the Zero Emissions Vehicle (ZEV) Mandate. The mandate is a trading scheme under the UK's Climate Change Act and sets out increasing target sales of zero emission vehicles year by year. Targets have been set through regulations from 2024 to 2030 with targets beyond that to be set later to achieve 100% of sales by 2035. If car makers do not meet targets, they can buy credits from those that have exceeded the target or can face fines. Car makers can also "borrow" against future years' performance if they underperform against the targets in the early years. The 2035 phase-out date is set on the basis that most cars will be scrapped after 15 years.



Source: Minimum BEV share of sales required to meet the ZEV mandate

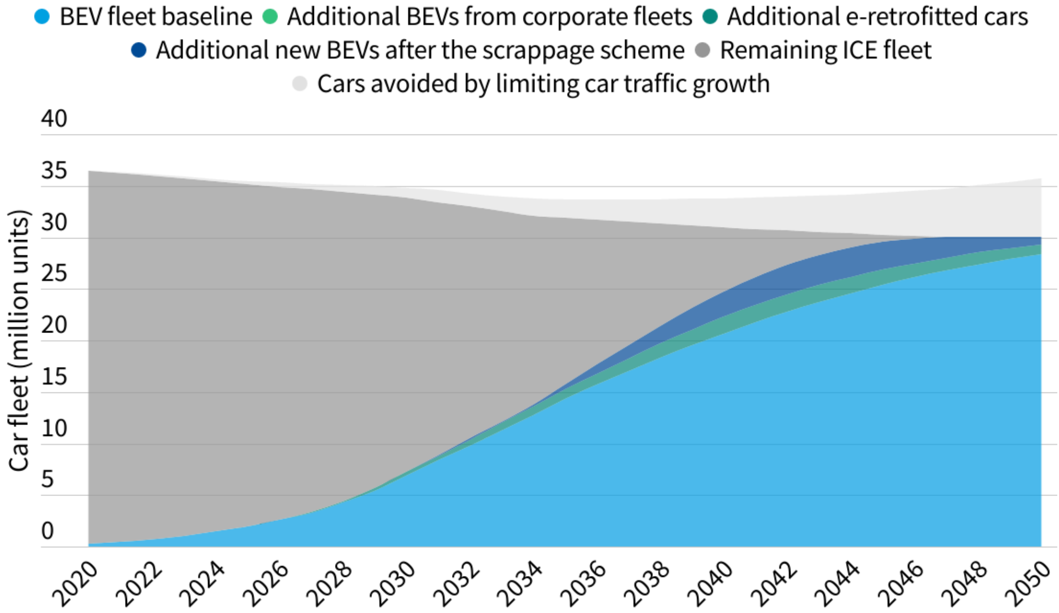
Figure 36: BEV sales in the UK



Scope: UK
Source: T&E EUTRM modelling based on new ZEV sales required by the ZEV mandate

Figure 37: Car fleet in the UK in the regulation scenario

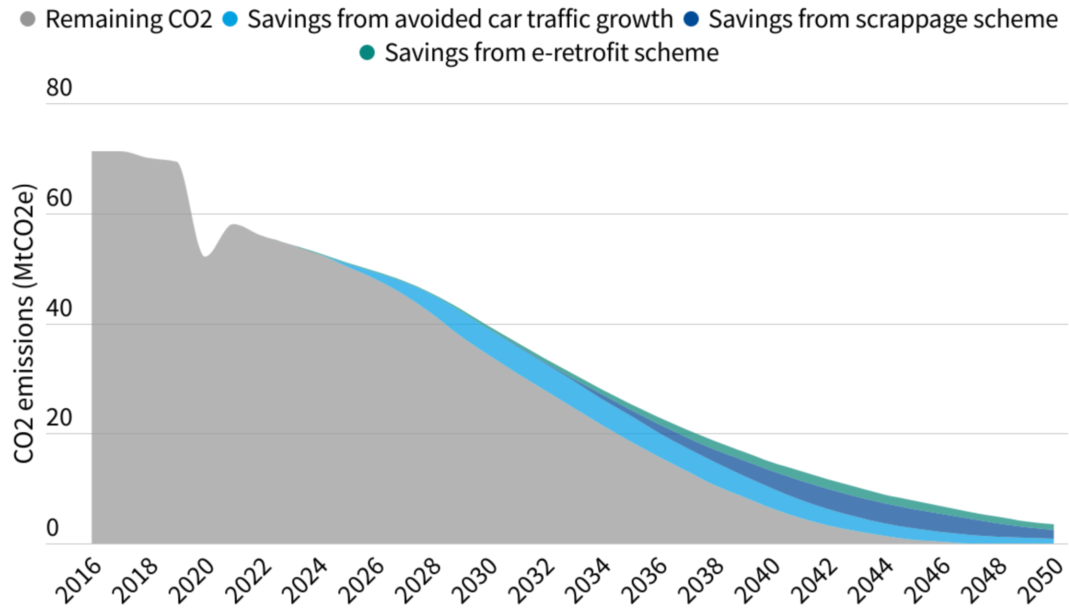
In the UK, the ZEV mandate is expected to increase the BEV share of the UK car fleet from 1.9% in 2022 (620,000 BEVs), to 21% in 2030 (7 million BEVs), 67% in 2040 (23 million BEVs) and 93% in 2050 (34 million BEVs).



Scope: UK
Source: EUTRM modelling based on T&E roadmap

Figure 38: Car fleet in the UK in T&E road to zero

In the UK, T&E road to zero would increase the BEV share of the car fleet from 1.9% in 2022 (620,000 BEVs), to 21% in 2030 (7 million BEVs), 80% in 2040 (25 million BEVs) and 100% in 2047 (30 million BEVs).



Source: T&E EUTRM modeling of the car fleet tailpipe emissions in the UK

Figure 39: CO_2e emissions from the car fleet in the UK in T&E road to zero

Compared to the ZEV mandate alone, T&E road to zero reduce emissions by 13% in 2030 (-5 $MtCO_2$e), 56% in 2040 (-8 $MtCO_2$e) and reach zero emissions in 2050 (-6 $MtCO_2$e). This would be a cumulative 150 $MtCO_2$e savings over the 2024-2050 period (-21% compared to the baseline).

B. Glossary of policy measures

This section highlights the main policy levers available to decarbonise the EU27 car fleet. Based on T&E pathway (Section 6), measures are defined to provide a comprehensive toolkit to meet EU climate targets.

The table below includes a non-exhaustive list of policy instruments aimed at decreasing either the number, or the activity or the emissions per km of ICE vehicles, classified according to their nature (regulatory, economic, innovation and information) and the level of governance (EU, national, urban/local and company level).

B.1. Regulatory measures

Level	Measure	Description	Policy target
EU	CO_2 performance standards for new vehicles[44]	Fleet based targets to reduce CO_2 emissions per km and decrease the number of ICE vehicles sold through a phase-out (100% reduction	Decreasing the number of ICE vehicles by accelerating BEV uptake

		target by 2035, which could be brought forward to 2032).	
	Type-approval for e-retrofitted vehicles	Simplified procedure for introducing into the market used ICE vehicles e-retrofitted.	
	Binding electrification targets for corporate fleets	Binding electrification targets for corporate fleets to be 100% zero-emission by 2030.	
	Green public procurement for public fleets (Clean Vehicles Directive)	The directive sets national minimum targets for the public procurement of clean vehicles (defined as vehicles with emissions up to 50g/km until 2025 and zero-emission from 2026).	
	Public & private charging infrastructure targets (AFIR[40] & EPBD[41])	Ensure the timely roll-out of charging infrastructure to enable the electrification of the fleet.	
	Road worthiness requirements[42]	Introduce requirements to remove from road or retrofit the most polluting vehicles (i.e. vehicles emitting much more than their EURO class limit).	
National	ICE phase-out/BEV mandate	While introducing an ICE ban in EU countries is technically in breach of EU law, some Member States[47] (e.g. Denmark, The Netherlands, Sweden) announced ICE phase-out dates earlier than 2035, foreseen by the EU CO_2 standards. The UK is introducing a ZEV mandate[48].	Accelerating BEV uptake
	Series approval for e-retrofitted vehicles	In the absence of a common EU framework, implement a national simplified procedure for introducing into the market used ICE vehicles e-retrofitted (e.g. France).	
	Obligation for cities to implement Low- and Zero-Emission Zones	Countries could introduce a national framework requiring cities to establish Low- and	Accelerating BEV uptake, modal shift

40 Alternative Fuel Infrastructure Regulation[45]
41 Energy Performance of Buildings Directive[46]
42 The EU roadworthiness package is currently under revision and the Commission is due to propose new measures in Q3 2023.

		Zero-Emission Zones (e.g. France[49]).	
	Speed limits on motorways/national roads	Speed limits on motorways and national roads not only improve road safety but also reduce fuel consumption, and hence emissions per km driven[43]. Effective enforcement is crucial.	Reducing in-use fuel consumption (hence emissions per km)
	Infrastructure planning	E.g. park and ride facilities, enhanced cycling infrastructure and public transport network.	Reducing activity (modal shift)
	Moratorium on expansion of road network	Several studies show that building new roads at first reduces congestion but in the longer-run causes an increase in traffic, and hence in emissions[44].	
Urban/local	Access restriction zones	Low- and Zero-emission zones[52].	Accelerating BEV uptake, modal shift
	Speed limit	A speed limit of 30 km/h not only improves safety and air quality in cities, it also reduces fuel consumption and hence CO_2 emissions (e.g. Brussels[53] and Paris[54]). Effective enforcement is crucial.	Reducing in-use fuel consumption (hence emissions per km)
	Urban planning	Improving accessibility and reducing (parking) space for individual car use, while increasing space for active mobility.	Reducing activity (modal shift)
Company	Mobility plans privileging zero-emissions	E.g. in France Employer Mobility Plans (PDME) are a legal requirement within certain conditions[55].	Reducing activity (modal shift)
	Flexible working conditions	Work conditions that favour the reduction of overall emissions from commuting (e.g. flexible working time avoiding peak hours commuting; tele-working with conditions avoiding rebound in emissions).	

[43] As an example, see calculations by Deutsche Umwelthilfe[50] (with data from the Umwelt Bundesamt) of the potential CO_2 emission savings from introducing a 100km/h on the German Autobahn and of 80 km/h outside of cities.
[44] As an example, see the potential CO_2 savings linked to the suspension of the expansion of the federal road network in Germany calculated by the Wuppertal Institute[51].

B.2. Economic/pricing measures

Level	Measure	Description	Policy target
EU	Financial (instruments to) support investments in zero-emission vehicles/infrastructure	E.g. premiums for the acquisition of zero-emission vehicles using resources from the Recovery and Resilience Facility (RRF), or support for the roll-out of charging infrastructure from the Connected Europe Facility (CEF) Transport calls.	Accelerating BEV uptake
National	Subsidies for e-retrofitting	E.g. France provides a premium for e-retrofitting[56].	Accelerating BEV uptake
	Targeted subsidies for buying or leasing a BEV	Premiums linked to income, e.g. 'bonus écologique' in France[57].	
	Feebates (or bonus-malus programs)	Charging a fee for the purchase of ICE vehicles while providing a rebate for the purchase of BEVs, e.g. bonus-malus scheme in France[58].	
	Low-cost leasing for electric cars	Ensure equitable access to BEVs for low-income households, e.g. announced social leasing scheme in France[59].	
	Scrappage schemes	Well-designed scheme to incentivise giving up old ICE vehicles for alternative transport modes (bicycle, car sharing, public transport) or for an electric vehicle.	Modal shift, accelerating BEV uptake
	Road charges	Distance-based charges as well as external-cost charges for CO_2 emissions applied to passenger cars on all roads. Currently not mandatory under EU law[60].	Modal shift, accelerating BEV uptake
	CO_2-based car taxation	Registration and annual circulation taxes based on the CO_2 emissions of the car. The taxes could also take into account the width, weight and height of the vehicle.	
	CO_2-based fuel taxation	Excise duties levied based on the carbon content of the fuel.	

		Currently not harmonised at EU level[45].	
	Remove tax exemptions for ICE company cars	Reform benefit-in-kind taxation, VAT returns and depreciation write-offs, to stop subsidising ICE company cars.	
	Subsidies for individual and company bikes	Tax-incentive and purchase-premium schemes for cycling[46].	Modal shift
Urban/local	Congestion charging	Imposing a cost for driving on certain urban roads/zones (e.g. London, Milan) with clear communication and alternative routes, reinvesting the charge in public transport or other sustainable transport infrastructure.	Modal shift
	Parking pricing	Effective parking pricing to dissuade from using a private car (e.g. Paris[63]).	
	Public transport pricing	Fair public transport fees, depending on resources and public transport network, to favour poorer passengers (e.g. Dunkirk[64]).	
Company	Public transport/bike/active mobility incentives	Benefits-in-kind or other forms of incentives for employees to use sustainable modes of transport for their commuting.	Modal shift

B.3. Information measures

Level	Measure	Description	Policy target
EU	Vehicle fuel consumption labelling	Car labelling directive[65] requiring a label showing a car's fuel efficiency and real world CO_2 emissions.	Reducing in-use fuel consumption (hence emissions per km)
	Sustainable mobility week	Promoting behavioural change in favour of active mobility, public transport, and other intelligent clean transport options.	Modal shift
National	Awareness raising campaigns for zero-emission/active mobility		

[45] A proposed revision of the Energy Taxation Directive is currently under EU co-decision process[61].
[46] See examples across Europe collected by the European Cyclists' Federation[62].

	Promotion of tele-working	Favouring working from home policies to reduce (public administration) employees' commuting needs, while raising awareness about the rebound effect.	Reducing activity
Urban	Car free days	Promoting behavioural change in favour of active mobility, public transport.	Modal shift
	Public transport (real-time) info	Allowing travellers to plan better their trip, making public transport more attractive.	
	Multimodal transport plans	Enabling the use of one or more modes (including cycling) to increase accessibility and provide an alternative to the use of the private car.	

B.4. Innovation measures

Level	Measure	Description	Policy target
National/Urban	Mobility as a Service	Integrating various forms of transport services into a single, comprehensive, on-demand mobility service (i.e. a single application and a single payment channel).	Modal shift
	On-demand public transport	Bookable public transport, replacing the need to run a traditional fixed route and timetable.	
	Bike sharing	Service to improve availability of active alternative transport mode.	
	Zero-emission car sharing as an alternative to private car use	Regulated car sharing schemes (i.e. zero-emission vehicles only) to make sure they lead to effective emission reductions.	
	Ride sharing/car pooling	Sharing a journey with people travelling towards the same destination as a way to increase car occupancy and reduce car activity.	Increase car occupancy rate
	Priority road access to carpooling cars or cars with high occupancy	High occupancy vehicles lanes reserved for the exclusive use of	

		vehicles with a driver and one or more passengers.	
	Smooth driving	I.e. eco-driving systems, Adaptive Cruise control, Eco Cruise Control, Intelligent Speed Adaptation.	Reducing in-use fuel consumption (hence emissions per km)
Company	Automated electric shuttle service	Service could be offered for employees in case company premises are located far from public transport options.	Modal shift
	Car pooling	See above.	
	Bike sharing		

C. Definition of carbon budgets for cars

A carbon budget is a tool used to define climate targets and evaluate emission reduction pathways. It is the maximum amount of CO_2 that can be emitted to limit global warming to a specific level. For instance, the Intergovernmental Panel on Climate Change[66] (IPCC) defined that a maximum of 400 $GtCO_2$ can be emitted globally after 2020 to keep the temperature below 1.5°C[47]. This would be equivalent to 10 years of 2019 CO_2 emissions[48]. Carbon budgets are used in this report to compare the order of magnitude of CO_2 emissions from the car fleet up to 2050.

In previous reports, T&E has previously looked at a grandfathering approach to allocate a carbon budget. However, the Secretariat of the German Advisory Council on the Environment (SRU)[68] highlights that grandfathering disadvantages economically and technologically less developed countries in terms of their available budget share and it also contradicts the intention of Article 2.2 of the Paris Agreement, which binds the signatories to the principle of common but differentiated responsibilities.

We therefore use a methodology described by the SRU to define what the IPCC's carbon budget for each temperature threshold would imply:

1. Starting from IPCC's global carbon budgets[49], the methodology implies a per-capita distribution of emissions based on the year 2016 when the Paris Agreement formally entered into force. Based on these assumptions, we estimated that the EU economy has in total a 56 $GtCO_2e$ carbon budget for 2016 to 2050.

2. Then, based on the EU27 overall budget, the part allocated to cars was derived from the sectoral emission split in 2016 from the United Nations Framework Convention on Climate Change

[47] With a 67% likelihood
[48] In 2019, Copernicus reports that total anthropogenic CO_2 emissions were 42,000 $MtCO_2$[67].
[49] In this report we use IPCC's carbon budgets defined to have a 67% likelihood of keeping temperature below a certain temperature threshold.

(UNFCCC)[3]. We derived that 12% of EU emissions are from cars[50]. Therefore, we assume that 12% of the EU 2016 carbon budget would be allocated to cars[51].

3. Using this methodology, we can define the carbon allocated to EU cars for all 0.1°C temperature step as shown in Table 1 below:

Table 3 - Allocation of IPCC's carbon budget to EU cars

Temperature threshold (67% likelihood)	Carbon budget allocated to EU cars in the 2016-2050 period ($GtCO_2e$)
1.5°C	4.0
1.6°C	5.0
1.7°C	6.1
1.8°C	7.1
1.9°C	8.2
2°C	9.2
2.1°C	9.9
2.2°C	11.0

D. Technical Annexes

D.1. EUTRM modelling

The modelling of car fleet emissions is based on T&E's Internal European Transportation Roadmap Model (EUTRM). In input of the model, EUTRM makes use of the following data:

- Historical car emission trends from UNFCCC,
- The historical composition of the fleet from the European Automobile Manufacturers' Association's vehicle in use report[69],
- Historical data on the emissions of cars sold by powertrain from the European Environment Agency[70],
- Activity forecast from the European Commission 2020 reference scenario[22],
- T&E forecast of powertrain share of new car sales to meet the car CO_2 regulation.

The model's outputs include the fleet composition and the associated CO_2 emissions until 2050.

Methodology

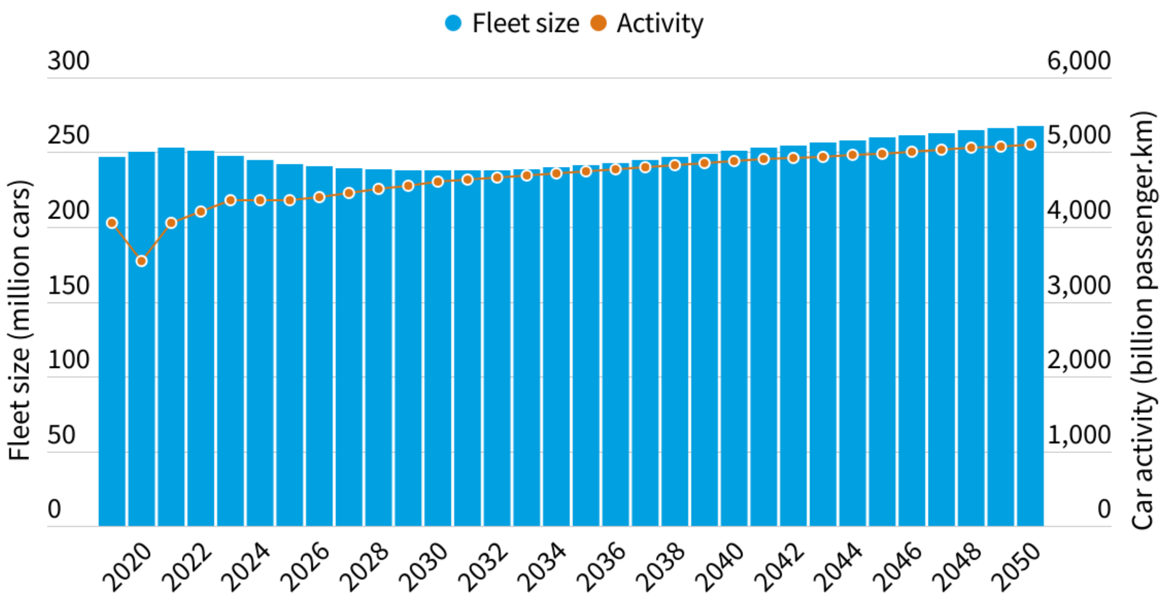
For each forecast year, the model enables the calculation of emissions from the fleet taking into account the age and powertrain of vehicles in the fleet. The annual mileage is based on an internal model and

[50] Based on total positive emissions without land use, land-use change, and forestry (LULUCF) and including international travel and bunkers.
[51] This methodology indirectly assumes the same speed of emission reduction for all sectors. If sectors have different speeds, the carbon budget needs to be consistently defined at EU level.

takes into account that old cars drive less kilometres. In each European country, a survival curve enables cars to define the lifespan of cars. Import flows of used cars are included in the model. Based on the passenger activity forecasted, the number of cars that are removed in the fleet of each country and the number of used cars imported in the country, the model forecasts the number of new cars sold in each country and the evolution of the fleet size.

Fleet size modelling

Under the baseline scenario it is expected that car activity will grow in line with the European Commission's expectation that transport activity for passengers will continue growing in the future. The decline of activity in 2020 due to the COVID-19 pandemic is projected to be followed by a rebound in activity for 2025-2030. Based on the EUTRM model and assuming a constant car occupancy rate in the baseline scenario, this activity increase would lead to a growth in the size of the EU car fleet.



Scope: Passenger car fleet in the EU27

Source: EU reference scenario 2020 for the car activity and T&E EUTRM for the car fleet size

Figure 40: Car activity and fleet size

Parameters influencing CO_2 emissions

- **Transport demand** (number of kilometres travelled in passenger-km): The overall transport demand impacts the number of kilometres driven by car. The higher the demand the higher the car fleet kilometres driven.
- **Modal split** (split in distance travelled between car and other transport modes): Car activity can be reduced by shifting transport demand from car to active mobility and public transport.
- **Car occupancy rate** (number of passengers per car): Measures can promote car sharing to increase low occupancy rates and to meet travel demand from multiple passengers. The occupancy rate was about 1.6 passenger per car for the EU27 average in 2020[26]. If there is no

associated rebound in travel demand[52], the increase in the car occupancy rate leads to reduced traffic and emissions.

- **Zero emission vehicles (BEVs) uptake** (percentage of BEV in the fleet): Resulting from the sales of new BEVs, the uptake of BEV in the overall car fleet defines the percentage of car activity with zero tailpipe emissions[53].
- **Energy consumption** (energy consumed per km): Energy consumption depends both on the specific characteristics of cars (e.g. size, weight, engine power) and their use in real world conditions such as driver behaviour and speed.
- **ICE lifespan**: The shorter the lifetime of ICE cars, the faster the transition toward cleaner, lower emission solutions. Scrappage schemes can be used to accelerate the removal of old ICE from the fleet.
- **E-retrofits:** Cars can be converted from ICE powertrains to electric in order to reduce their emissions. A report on the e-retrofit outlook is published alongside this report.
- **Fuels**: In theory, the use of sustainable and carbon neutral fuels could reduce emissions. This option is not included in the analysis as it is not expected that sustainable fuels will be available for the car fleet. The use of these fuels in cars would compete with sectors that have no other solution to reach zero emission. More information on biofuels and e-petrol can be found in Annex D.4.

D.2. TCO modelling

D.2.1. Assumptions

The main assumptions of the TCO model are summarised below:

- The TCO modelling is based on an average European medium car in 2040. The car is assumed to have a 20 year lifetime.
- The TCO compares multiple alternatives to a baseline where the ICE is kept without change until the end of its life.
- The calculations are carried out for different car age and therefore different ownership time. The ownership time is the difference between the car's total lifetime (20 years) and the car age at the start of the scenario. The mileage depends on the car age based on T&E internal modelling.
- The fuel and electricity consumption depends on the vehicle age as younger cars in 2040 will benefit from more efficiency improvements. As a reference, T&E expects that a medium ICE bought in 2025 would have a fuel consumption of 7.2L/km, and a medium BEV would have an electricity consumption of 17.2kWh/km. For cars bought in 2030, the ICE would consume 6.9L/km and the BEV would consume 16.8kWh/km.

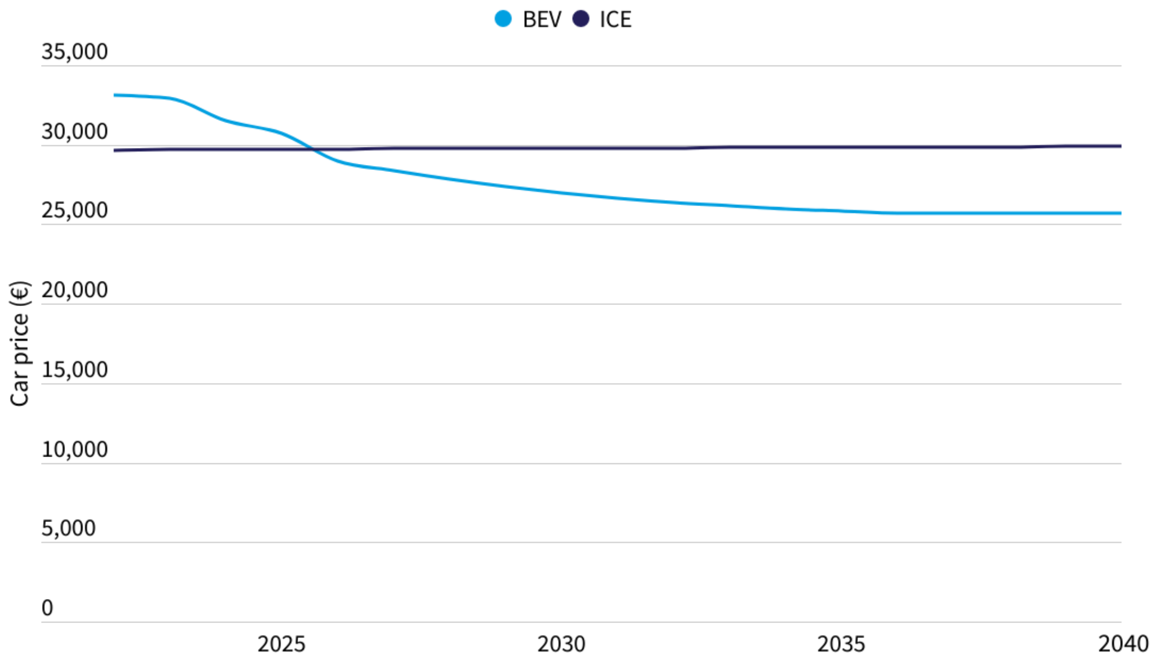
[52] The higher availability of carpooling can cause a rebound effect: passengers would take the ridesharing opportunity to travel more or to replace the use of public transport. For instance, a study on ridesharing in the Paris area shows that the overall rebound effect can cancel out from 68 to 77% of CO_2 emission reductions[71].

[53] In this report, the focus is placed on direct tailpipe emissions. To understand the overall life cycle emissions of electric cars, please refers to T&E's lifecycle assessment report[14].

- The petrol and electricity prices are based on the average prices in the EU in 2023 (€1.7/L for petrol and €0.3/kWh for electricity).
- The insurance cost is estimated to be 3.5% of the car price for ICE.
- The maintenance cost is estimated to be €0.02/km with a 50% for BEV due the less mechanical parts compared to the ICE.
- An e-retrofitted car is expected to have a 10% lower annual mileage compared to a BEV of the same age due to a smaller battery which limits the use case. The e-retrofitted vehicle is expected to be 5% less efficient than a BEV. And, it is expected to have the same maintenance cost as an ICE due to the less robust conception of the conversion kit compared to a new car. The conversion of a segment C car with a 38 kWh battery is expected to cost €13,000 (including VAT).

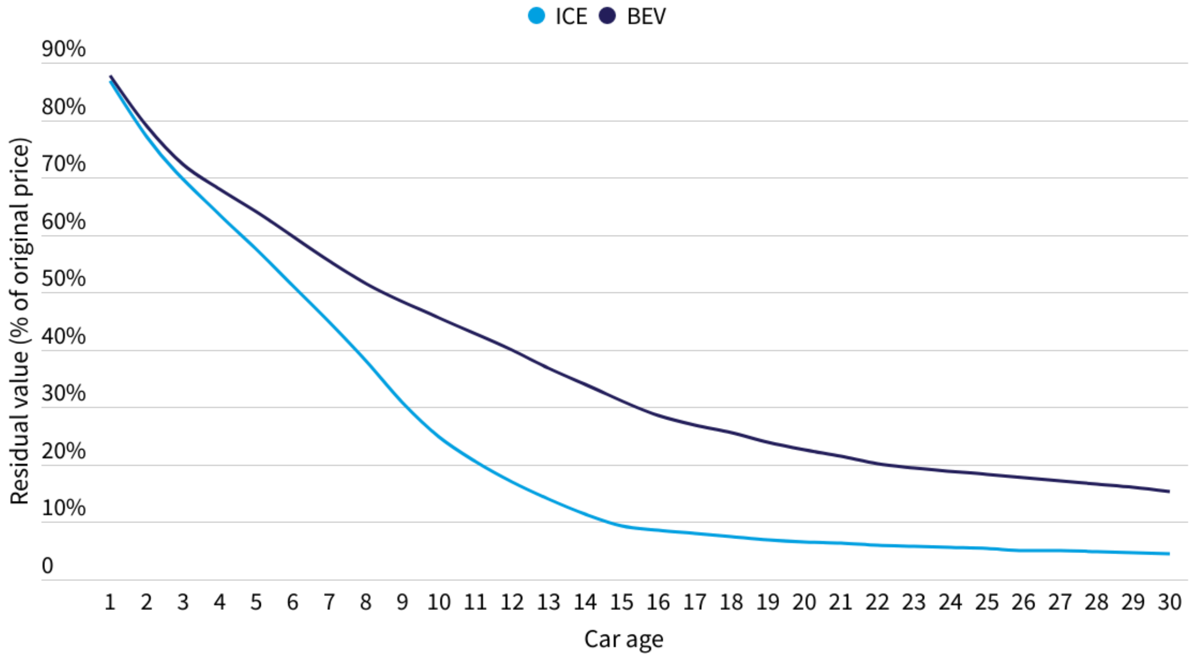
Vehicle's value

The vehicle's price at the start of each scenario is based on the initial car price (depending on the year it was bought, Figure 41 below) and its depreciation depending on the age (Figure 42 below). The price of new medium cars in Europe are based on BloombergNEF forecast[72] until 2030 which T&E extrapolated until 2040. The depreciation curves are based on the Annex of Electrify's e-retrofit report assuming a shortage of second-hand BEV (slower depreciation) with a faster depreciation of ICEs due to regulations making the ownership of ICE less attractive (low and zero emissions zones, taxes, …).



Source: BloombergNEF's pre-tax price forecast for a medium BEV and ICE in Europe up to 2030 and T&E's extrapolation from 2031

Figure 41: Price trends



ICE price collapse scenario due to regulatory constraints and high fuel prices
BEV scenario based on a used BEV shortage scenario leading to higher residual value
Source: From the report: *Ending the ICE age – Can e-retrofit help Europe phase out fossil fuel cars?* (Electrify 2023)

Figure 42: Residual value trends expected in 2040

E-petrol price
The market price of e-fuels would depend on the demand and therefore differs from the production costs of these fuels: a high demand for e-fuels with limited production capacity leads to a high market price, even if solutions are found to reduce production costs. In the low price scenario, we assume that the e-petrol market price could not be lower than the price of bioethanol. Based on a bioethanol price forecast from Stratas[73], we estimate that the bioethanol price would reach €1.9/L at the pump in 2040. On the other hand, the maximum e-petrol price would be reached if the hydrogen price remains high (high production costs and high demand). Assuming a hydrogen price of $8/kg[54] and a 20% margin due to high demand for e-fuel, we estimate that the upper range of the e-petrol[55] price would reach €5.2/L at the pump. Therefore, we expect a range of e-petrol prices at the pump in 2040 from €1.9/L to €5.2/L, with a central price of €3.6/L.

[54] Upper range of IEA projection in 2050[74].
[55] We conservatively assume that the price of e-diesel would be similar to the price of e-diesel, even though more processing steps would be required to produce e-petrol.

D.2.2. Price differential depending on car age and ownership time

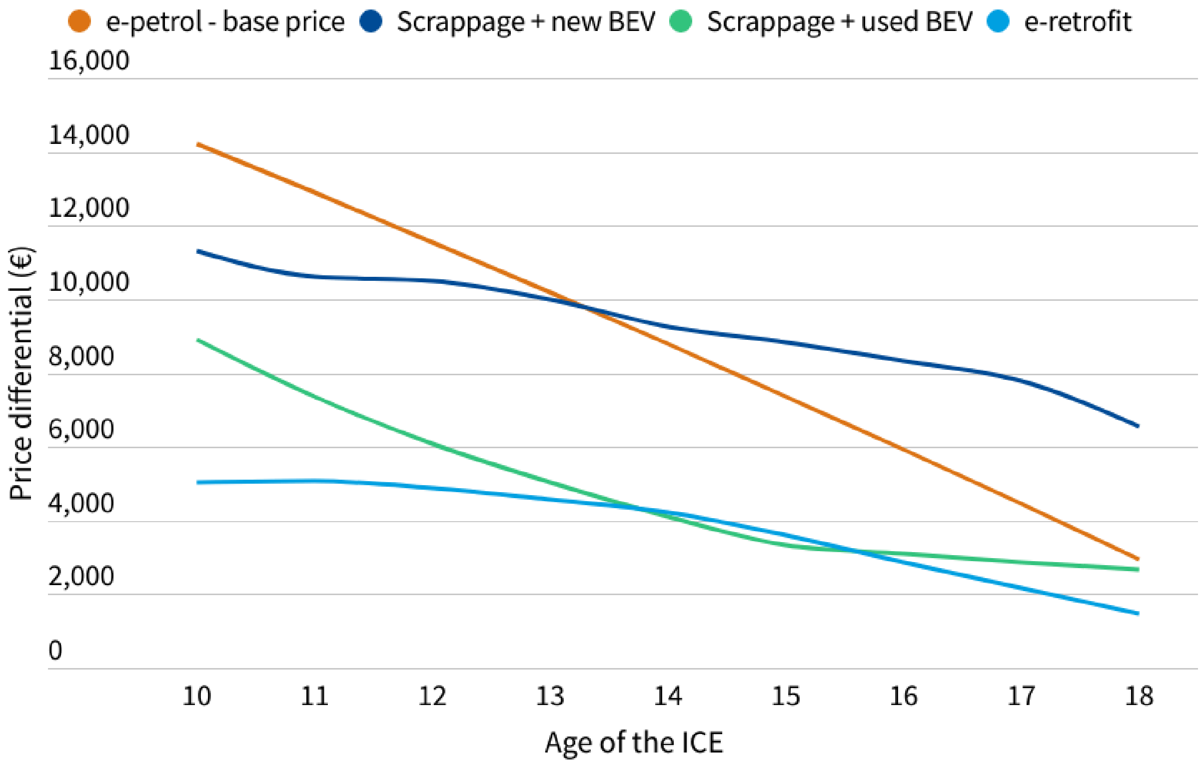


Figure 43: Price differential depending on car age and ownership time

The earlier an ICE is scrapped or retrofitted, the more CO_2 will be saved

Figure 8 shows that the best use of scrapping and e-retrofitting subsidies to avoid CO_2 emissions (low ratio of subsidy per tCO_2 saved) is in the earliest year of the ICE's lifetime. The scrappage scheme to buy a new BEV is the most expensive solution for very old cars. In that case, the subsidy value would be high relative to the small amount of CO_2 saved before the end of the ICE's lifetime, and the scrappage scheme with used BEVs would be more efficient.

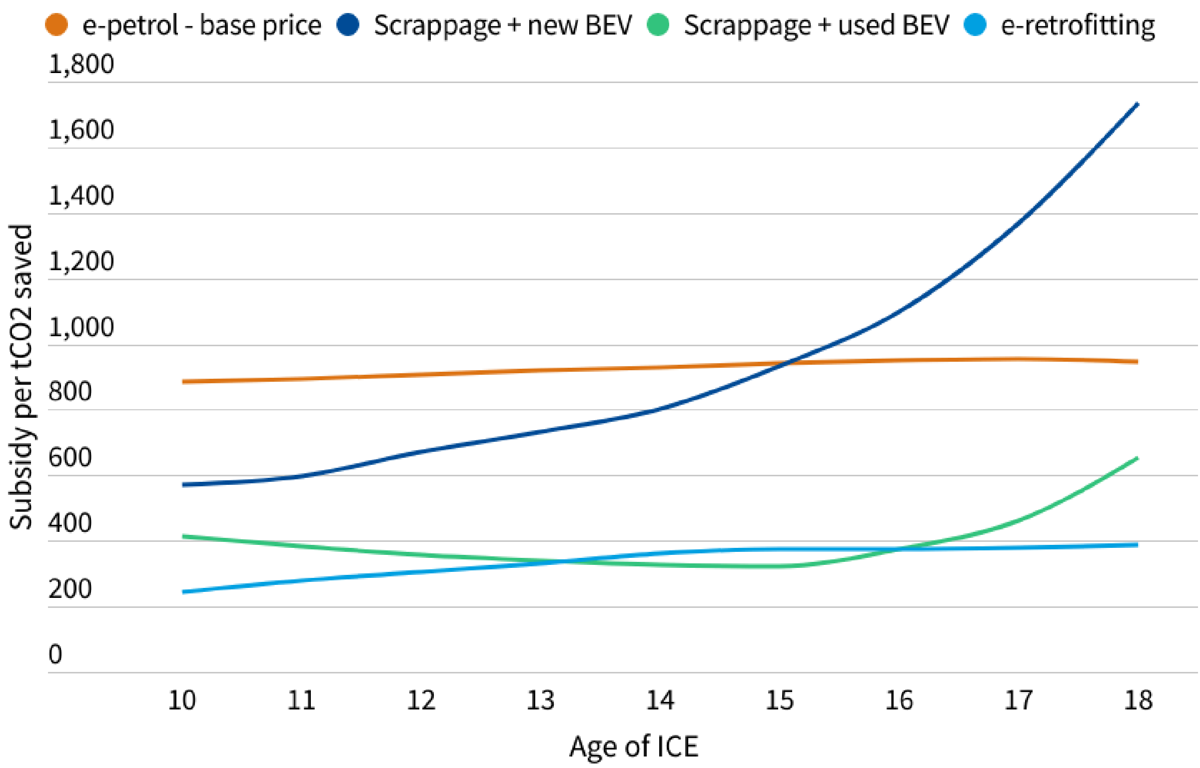


Figure 44: Subsidy per tCO_2 saved for each alternative

D.2.3. Rating matrix

Scores (-2/+2)	TCO score	Lifecycle emissions score	Air pollution cost score	Change in user experience	Scalability & competing uses score	Resources score	Average score
e-petrol	-2.0	-2.0	-2.0	2.0	-2.0	-1.0	-1.2
Scrappage + new BEV	0.0	0.2	0.2	2.0	1.0	-2.0	0.2
Scrappage + used BEV	2.0	1.2	0.2	0.0	-1.0	-1.0	0.2
Scrappage + no car		2.0	2.0	-2.0	1.0	1.0	0.8
e-retrofit	0.9	0.6	0.2	-1.0	-1.0	0.0	-0.1

D.3. LCA modelling assumptions

LCA calculations are done for an average European medium car in 2040. BEV and ICE lifecycle emissions are based on T&E's LCA tool[14]. The e-retrofitted car lifecycle emissions are derived from Electrify's report. In the case of the used, the production emissions of the vehicle are allocated based on the residual value of the vehicle when it is bought. For instance, if the vehicle value is 20% of the initial vehicle price, then we assume that the production emissions are 20% of the total vehicle production emissions. In the case of the mobility package, we considered the average of light rail, e-bike, e-bus, metro, bus, high speed train, regional train from TNMT's study[75] and this value is scaled to take into account the reduction of the electricity grid emissions in 2040. In all cases, the electricity grid emissions are based on the EU27 grid from T&E LCA tool. The LCA results are expressed in gCO_2/km and the following mileage were considered: the 10 year old ICE, the 10 year old BEV and the e-retrofitted vehicles are kept during 10 years for 120,000km; the new BEV is used during 15 years and 225,000km.

D.4. Fuels

D.4.1. Biofuels

In this report, it is assumed that no additional biofuels enter the car market for sustainability and availability reasons. While the oil industry[76] forecasts that part of road transport energy demand in 2035 could be met by food and feed-based biofuels, when the impacts of indirect land use change are taken into account, many crop-based biofuels are even more harmful to the climate than fossil fuels[56]. Aside from the negative impact on climate and the environment, burning food in cars (equivalent to 15 million loaves of bread a day[78] for 'bioethanol' in Europe) poses a risk to global food security as prices of food commodities such as wheat, corn or cooking oils - all extensively used to make biofuels - have skyrocketed since 2021 and have been further exacerbated by Russia's invasion of Ukraine. While Hydrotreated Vegetable Oils (HVO) are often presented as a new pathway for biofuels, they come with similar negative impacts when relying on crop feedstocks.

Finally, advanced biofuels - manufactured from various types of waste and non-food biomass - are often promoted as more sustainable in the long run. However, there are only very limited quantities of advanced feedstocks and many already have existing uses[57]. Adding pressure on already used feedstocks could have significant impacts on existing markets and lead to indirect impacts on the environment and the climate. As such very limited quantities of truly sustainable biofuels would be better used in hard to abate sectors such as planes and we do not consider biofuels as a viable option for decarbonising road transport. Therefore, additional biofuels are not included in our baseline scenario or additional modelled scenarios for decarbonisation of the EU27 car fleet.

[56] The direct or indirect conversion of natural ecosystems into agriculture lands leads to significant emissions of greenhouse gases, negating the emissions saved from replacing fossil fuels and it also impacts negatively on biodiversity[77].

[57] Many of the waste & residues feedstock used for this type of biofuels already have existing markets such as pet food, livestock feed, chemicals, straw for insulation or paper making.

D.4.2. E-fuels

E-fuels are not included in T&E car roadmap as they are unlikely to play a role in cars
E-fuels[58], synthetic hydrocarbons refined from a process that combines hydrogen and carbon in the context of road transport, are not considered as their availability for cars cannot be guaranteed. In the European market, e-fuel production is expected to be driven by regulations such as the renewable energy directive (RED) that will mandate 1%[59] e-fuel use in the transport sector in 2030, or the ReFuelEU regulation for aviation that could mandate up to 2% e-kerosene use in aviation by 2032[80] while RefuelEU Maritime set a 2% target for 2034 if renewable fuel usage remains below 1% in the fuel mix in 2031[81]. It is expected that the majority of the RED requirement for e-fuels will be used for shipping and aviation given the regulatory requirements to use e-fuels in those sectors.

The Fischer-Tropsch process creates an e-crude, which requires further refining to extract useful products such as e-kerosene. Given that aviation has an e-kerosene mandate, refineries are expected to prioritise e-kerosene production. Studies[82] as well as pilot projects[83] show that when e-fuel production is optimised for producing e-kerosene for aviation (a sector where no other decarbonisation pathways are available) 75% jet fuel can be produced along with just 12.5% petrol and 12.5% diesel.

The e-diesel produced could be used in shipping and industry applications that are hard-to-decarbonise sectors with less alternatives compared to road transport. In 2021, 68 Mtoe of diesel were used in non-road sectors[84] such as international maritime bunkers or energy use in industry sectors. This is nearly 11 times more than the 6.4 Mtoe of e-diesel expected to be produced as a by-product of e-kerosene production in 2050. On the other hand, petrol has similar hydrocarbon chains as naphtha, and e-naphtha could also be co-produced instead of e-petrol. E-naphtha may also be used as a fossil fuel substitute for the petrochemicals industry. The e-fuel industry may decide to further optimise e-fuel production for e-kerosene and other by-products required for hard-to-decarbonise non-road transport applications. In addition, the high demand for hydrogen and e-fuels in many sectors (e.g. aviation, shipping or petrochemicals) will lead to high market prices. Even in a potential scenario where the production costs decrease, the actual market price of e-fuels will depend on the demand. The use of e-petrol in cars would then lead to a high demand which would maintain high prices and high TCO (Section 4.2). High prices are of concern because the remaining ICEs after 2040 will be fourth and fifth hand cars owned by low income drivers, often in Eastern Europe. Drivers of these old cars are unlikely to be able to afford to fill up with very expensive fuels, and section 4 shows why it would not make economic sense for governments to subsidise this fuel. For these reasons, neither e-petrol nor e-diesel are included in the baseline scenario as there is no guarantee that these fuels would be available for cars, and, even if available, these fuels would be too expensive.

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58 T&E discussed the e-fuel topic in previous reports[79].
59 Based on energy content and including some incentives to prioritise e-fuels in aviation and shipping, making the actual energy target smaller.

Sensitivity analysis: even if limited volumes of e-petrol were supplied to the existing car fleet, the impact would be very limited

What if some e-petrol co-produced from e-kerosene is available for cars?

In the case of any e-fuel being available, we modelled the potential impact of e-fuels on reducing fleet emissions. We estimated the maximum amount of e-petrol that could be available as a by-product of e-kerosene production. This scenario is defined by Concawe's jet-optimised pathway and assumes that a refinery would produce 75% e-kerosene, 12.5% e-petrol and 12.5% e-diesel. The e-kerosene demand is based on the T&E aviation roadmap, which includes measures to reduce aviation activity. E-diesel is assumed to be fully allocated to other sectors (shipping and industry). Based on Eurostat, we assumed that 93% of petrol is used in road transport and estimated the share allocated to cars based on the petrol demand split between cars and vans in T&E's EUTRM model (97-98% of road petrol is used by cars depending on the year). The maximum amount available for cars is detailed below.

Optimistic scenario on e-petrol availability for cars as a by-product of e-kerosene production between 2030 and 2050

	2030	2035	2040	2045	2050
E-petrol allocated to cars (PJ)	7	20	45	74	123

The combustion of these quantities of e-petrol in cars emits the same amount of CO_2 as fossil fuels but the difference in CO_2 impact between fossil fuels and e-fuels lies in the upstream CO_2 emissions used for the production of e-fuels.

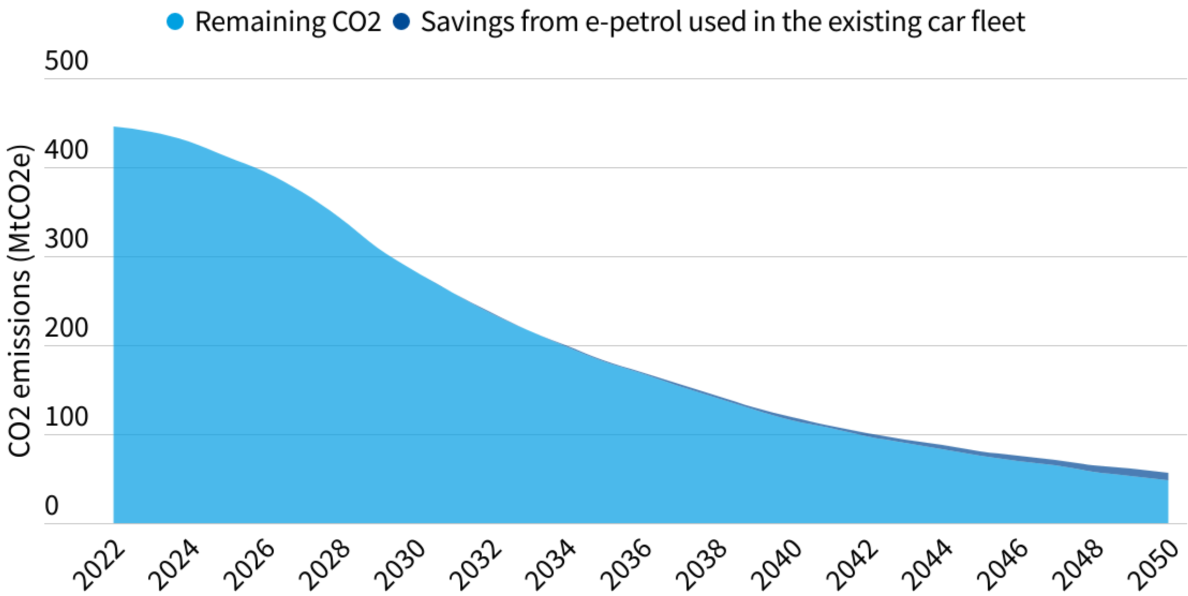
In theory, if additional renewable electricity is used for electrolysis and production while the source of carbon is captured directly from the air, then e-fuels could be considered as CO_2 neutral. The only remaining GHG emissions are from methane and nitrous oxide when the fuel is burned in an ICE or from urea in the exhaust aftertreatment system. In practice, the EU RED[85] only requires e-fuels used in Europe to achieve a 70% reduction in GHG emissions over their entire lifecycle and CO_2 can be extracted from industrial sources until 2041. The only application where a 100% CO_2 reduction could be considered is in new cars. The European Commission has made a proposal to allow only 100% carbon neutral e-fuels in new cars after 2035[86]. However, this proposal does not apply to the existing car fleet which is studied in this report.

Therefore, in a scenario where e-petrol is used in the existing car fleet, this fuel cannot be considered to be strictly carbon neutral. We assume that fuel producers will have sufficient incentives to exceed the 70% emission reductions required by the RED, but that a 100% GHG reduction is unlikely to be achieved voluntarily. We therefore assume that a mid-range reduction of 85% could be achieved for e-petrol. From 2040, we assume that the emissions reduction increases progressively to a 100% reduction by 2050, which is likely to be required by future regulation to achieve a net zero emission pathway. As this methodology goes beyond what is required by regulation, it should be considered as an optimistic scenario that may overestimate the emission reduction impact of e-petrol.

To calculate CO_2 emissions for the purposes of this study, we directly allocate the emissions savings from using e-fuels to tailpipe emissions[60] i.e. it is assumed that cars running on e-fuels have 85% lower CO_2 emissions than fossil fuel cars. We assume that other GHG emissions resulting from methane and nitrogen oxide would be similar to those from conventional petrol.

If available for the existing fleet, e-petrol would play a minor role

If e-petrol were to be used in cars to power the existing fleet, a maximum of 9 $MtCO_2e$ would be saved by 2050 (Figure 19 below). Assuming that e-petrol is used after measures presented in sections 3 and 5, e-petrol would reduce emissions by 19% in 2050 (39 $MtCO_2e$) and cover 19% of the remaining total fuel consumption of the existing fleet (equivalent to about 10 million cars, or 4% of the total car fleet). E-fuels for new cars are not considered as these fuels would only displace electric car sales without providing any additional CO_2 savings. If e-petrol was used only by new cars and not used in the existing fleet, then emissions would be 23% higher (48 $MtCO_2e$). In that case, about 10 million new ICEs would use e-petrol in 2050, 10 million ICEs in the fleet would not use e-petrol, and 10 million BEVs would be absent from the fleet.



Scope: EU27

Source: T&E EUTRM modeling of the car fleet tailpipe emissions. E-petrol produced as a by-product from e-kerosene.

Figure 45: Additional CO_2 savings if e-petrol is used in the existing fleet

[60] Strictly speaking, as e-fuels do not provide tank-to-wheels (TTW) CO_2 emissions savings, these savings should be allocated in upstream sectors to be consistent with the carbon budget allocation. Therefore, this allocation would imply that upstream sectors do not benefit from CO_2 savings from CO_2 captured from the air.

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