THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

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Cleaning up Germany's vehicle stock

Strategies to decarbonize the passenger car fleet

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EXECUTIVE SUMMARY

The European Union has adopted CO_2 standards requiring 100% of new passenger car registrations to be zero-emission vehicles by 2035. Under these standards, we project tank-to-wheel greenhouse gas emissions (GHG) of the total passenger car fleet will decline to 13% below 2022 levels in 2030, 66% below 2022 levels in 2040, and 92% below in 2050. However, these standards alone are insufficient to align passenger car GHG emissions with the European Union's 2030 economy-wide reduction target of 55% from 1990 levels, and with Germany's 2030 transport-wide target of 85 Mt of CO_2-equivalent (CO_2e), without requiring disproportionate reductions in other sectors.[1]

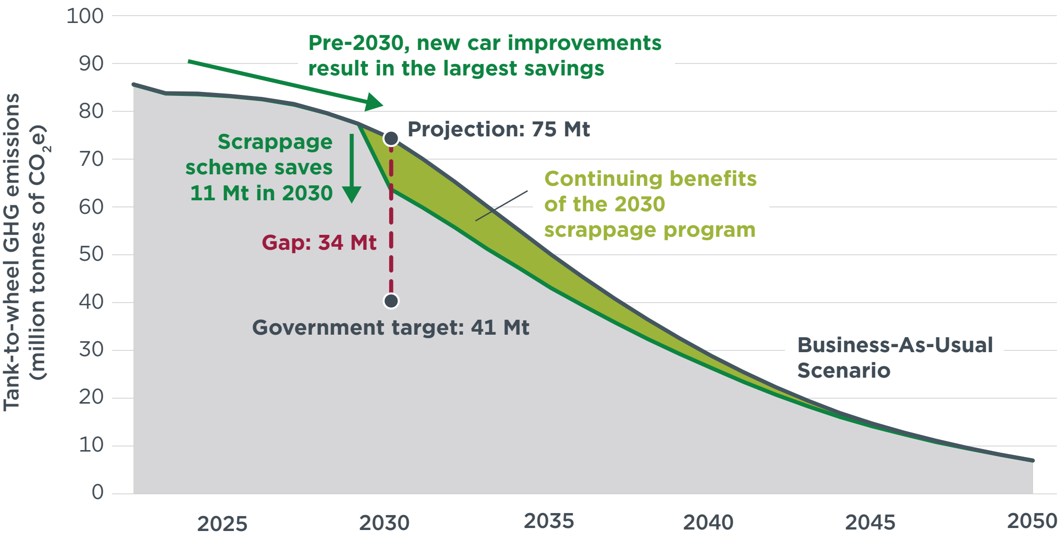
This report highlights strategies to reduce GHG emissions from the vehicle stock and is targeted toward the German federal government. The paper analyzes the extent to which a hypothetical vehicle scrappage program could accelerate GHG emission reductions from the 49 million passenger cars on the road in Germany, the largest passenger car stock in the European Union. We also briefly explore the emissions reduction potential of other strategies, such as avoid-and-shift policies and the use of synthetic fuels, or e-fuels, and discuss how these strategies could affect a scrappage scheme. We also consider the societal costs and benefits of both the vehicle scrappage program and e-fuels, and briefly discuss the feasibility of retrofitting combustion engine cars to battery electric vehicles. Vehicle scrappage strategies are assessed using the ICCT Roadmap model in combination with damage functions for air pollutants derived from a reduced-form air quality and health impact model and using the social cost of carbon values from the German Federal Environment Agency. The projected costs of producing e-fuels in Europe are assessed using the e-fuel cost model developed by ICCT.

Figure ES1 illustrates the gap between a Business-As-Usual (BAU) scenario of emissions from Germany's passenger car stock, which includes current policies, and the level of GHG emissions needed to align with Germany's 2030 climate target for the transport sector. The BAU scenario shows that new car improvements via the European Union's CO_2 standards provide the largest savings on GHG emissions up to 2030. However, we project that a further emissions reduction of 34 million tonnes (megatonnes or Mt) of CO_2e is needed in 2030 to eliminate this gap.

1 In Summer 2024, the German government revised its climate protection law to focus more strongly on economy-wide rather than sector-specific emissions reductions. For the analysis in this report, we continue to refer to emission reduction targets specific for the transport sector.

Figure ES1

Projected GHG emissions, in 100-year CO_2e global warming potential, of the German passenger car fleet, with and without a scrappage program implemented in 2030



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From the results of our analysis, we draw the following conclusions:

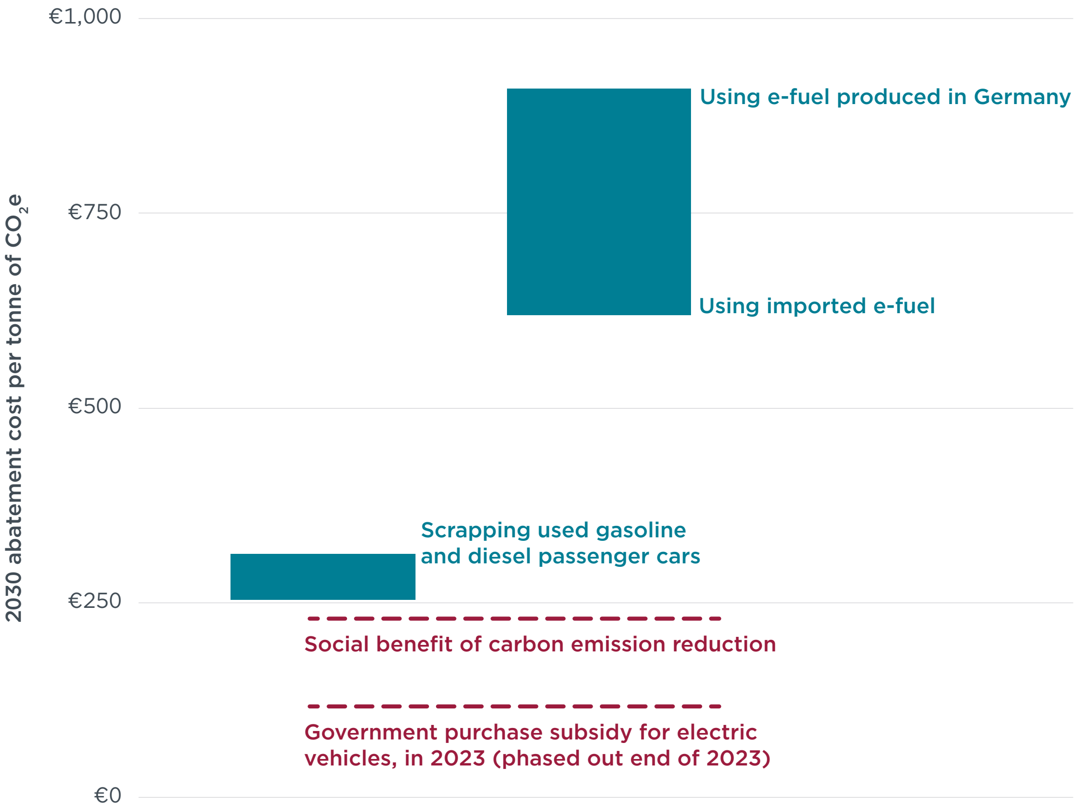
» **A vehicle scrappage program could eliminate roughly one third (11 Mt CO_2e) of the gap with Germany's climate target for 2030 but would need to be carefully designed to ensure net benefits.** Scrappage incentives that compensate vehicle owners for 80% of the residual value of their vehicles could deliver positive net benefits if the program is limited to diesel cars 15 years or older and gasoline cars 25 years or older in 2030, and if the program has full participation. Such a program would reduce the passenger car fleet emissions gap by roughly a third (11 Mt CO_2e). The expected abatement costs (excluding health benefits) would amount to about €313 for diesel and €255 for gasoline cars per tonne of CO_2e avoided in 2030. Additional health benefits, such as avoided premature deaths from cardiovascular and lung diseases, would arise from reductions in air pollutant emissions. These account for 40% of the benefits of scrapping diesel cars and 16% of the benefits of scrapping gasoline cars.

» **E-fuels could contribute to passenger car CO_2e emission reductions—although to a much lower extent than a vehicle scrappage program—but would be a very expensive option.** Tank-to-wheel (TTW) GHG emissions totaling 190,000 tonnes of CO_2e of could be avoided from passenger cars in 2030, assuming the revised recast of the Renewable Energy Directive target for renewable fuels of nonbiological origin and advanced biofuels, as well as the e-fuels target in the ReFuelEU aviation regulation, are met in Germany. This assumes all e-diesel produced is used for passenger cars only, despite the multiplier for e-fuels used in the marine sector in the revised recast of the Renewable Energy Directive. The production costs of e-fuels in Germany are projected to be €2.9 per liter in 2030, expressed in 2021 euros—roughly 4 times the 2021 spot price of gasoline in Germany of €0.7 per liter, excluding duties and taxes. This cost of producing e-fuels in 2030 translates to €910 per tonne of avoided TTW CO_2e, which is 4 times the social cost of GHG emissions estimated by the German Federal Environment Agency (€225 per tonne in 2021 prices). In comparison, the purchase subsidy for new BEVs provided by the German government in 2023 translates into an abatement cost of about €105 per tonne of CO_2e avoided. If e-fuels are imported to Germany from a renewable-rich country like Brazil, the expected abatement cost could be lower but not close to as low as the abatement cost provided by purchase subsidies. Unlike the other policy options evaluated, incentivizing e-fuels would not deliver health benefits from reduced air pollution.

» **Avoid-and-shift policies can increase the likelihood that consumers will opt into a vehicle scrappage scheme while also contributing to emission reductions.** Policy instruments such as supporting public transport, speed limits, and CO_2 pricing contribute to lowering stock emissions while simultaneously promoting a modal shift that could also broaden participation in a scrappage scheme. Other benefits from avoid-and-shift policies include health benefits such as increased physical activity and reduced air pollution exposure. We do not quantify the costs of these actions relative to their benefits nor how they contribute overall to the cost efficiency of the scrappage program. Avoid-and-shift policies could be considered as supplementary to any other stock CO_2 reduction measure.

Figure ES2

Estimated abatement costs per tonne of CO_2e emissions avoided for a scrappage program versus e-fuels to reduce emissions from the German passenger car fleet in 2030



Note: Health and economic co-benefits are not included. All costs are expressed in 2021 euros.

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Given the results of the study, we conclude that a mix of measures will be necessary to reduce vehicle stock emissions and that no single approach will be able to achieve Germany's established climate goals. Drastically reducing the emission levels of new passenger cars coming onto the roads by fully replacing internal combustion engine vehicles with battery electric vehicles earlier than the 2035 EU target would hasten the decarbonization of the vehicle stock. This option would significantly lower the costs and political challenges of decarbonizing the fleet later and help close the expected emissions gap for 2030.

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INTRODUCTION

The transition away from fossil fuels in road transportation is in the early stages in countries across Europe.[2] Passenger cars have been a particular focus for decarbonization, as these vehicles accounted for 60% of greenhouse gas (GHG) emissions from the road transport sector in 2020 (European Environment Agency [EEA], 2023). Passenger car emissions increased by 5.8% between 2000 and 2019, even as emissions from other sectors decreased (EEA, 2022). Policies promoting the uptake of zero-emission vehicles have led to rising levels of battery electric vehicle (BEV) registrations in Europe. In 2023, the average BEV share stood at 15% of all new passenger car registrations (Monteforte et al., 2024). CO_2 standards adopted by the European Union require a 100% tank-to-wheel (TTW) CO_2 emissions reduction for new vehicles by 2035, which will effectively phase out the registration of new internal combustion engine vehicles (ICEVs) (European Parliament, 2023). These standards include a strengthened interim target of a 55% reduction of TTW CO_2 emissions for passenger cars by 2030 compared with 2021 levels.

In Germany, which has the largest vehicle stock in the European Union, 90% of the roughly 49 million passenger cars were fueled by gasoline (61%) or diesel (29%) as of January 2024 (Kraftfahrt-Bundesamt, 2024). As the CO_2 standards only affect the registration of new vehicles, the emissions of the millions of vehicles already on the road threaten the ability of EU member states to achieve their climate goals. Additionally, the latest revision of the CO_2 standards does not strengthen fleet targets before 2030, providing little incentive for manufacturers to increase the BEV share of new registrations between 2021 and 2029.[3] The new ICEVs that will be added to the stock in the coming years, along with the long useable lifetimes of cars, pose a significant challenge to 2030 decarbonization goals. In this study, we explore complementary policy options for the German government to decarbonize the existing vehicle stock.

In the following sections, we assess the potential of a scrappage program to reduce vehicle stock emissions compared with a Business-As-Usual (BAU) scenario, as well as the potential costs, benefits, and feasibility of such a program. We also evaluate this approach in the context of other measures—including the use of e-fuels, avoid-and-shift strategies, and retrofitting ICEVs—and how these would influence emissions from the stock. The costs and feasibility of e-fuels are quantitatively assessed, while avoid-and-shift and retrofitting strategies are discussed in a qualitative manner from existing literature.

BUSINESS-AS-USUAL GERMAN PASSENGER CAR EMISSIONS IN 2030

To assess the impact of a scrappage program in Germany, we first compare the BAU GHG emissions trajectory with the reductions needed from passenger cars to align with the 2030 transport climate target set by the German Federal Climate Protection Act. To do this, we derive a 2030 GHG emission target for the passenger car stock that is consistent with meeting Germany's transport sector target (excluding maritime and international aviation) of 85 million tonnes (Mt) of CO_2-equivalent (CO_2e) in 2030 (Umweltbundesamt [UBA], 2024; Bundesministerium für Wirtschaft und Klimaschutz, 2022).[4] This 85 Mt target for the transport sector is the same amount of CO_2e we estimate was emitted by passenger cars alone in 2022. We assume passenger cars must reduce emissions slightly faster than other

2 Europe in this study refers to all 27 member states of the European Union plus Iceland, Liechtenstein, and Norway.

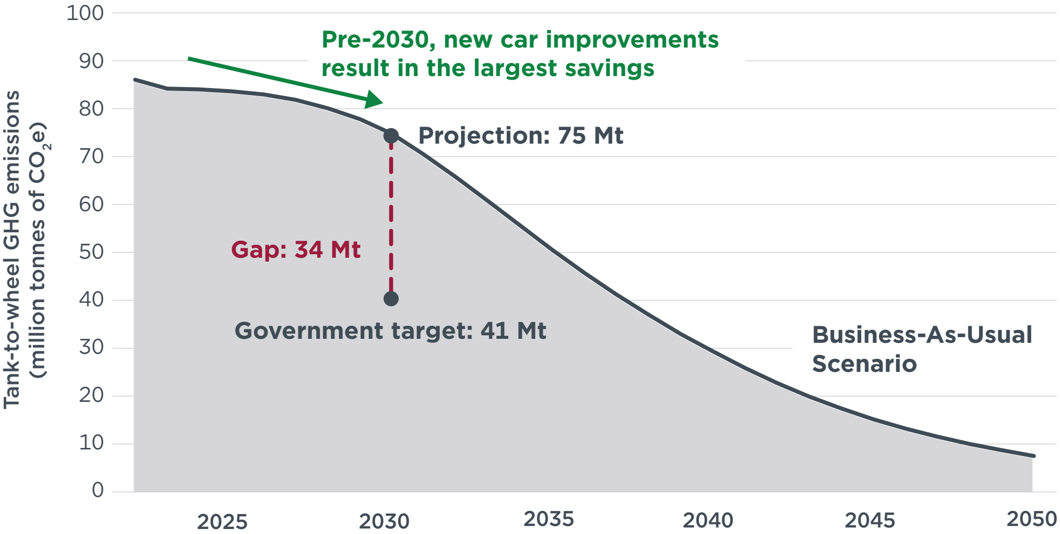
3 Vehicle stock and vehicle fleets are used interchangeably in this study to refer to vehicles in use on the road during a given time period.

4 Tonnes or grams of carbon dioxide equivalent (CO_2e) is a way to express other types of greenhouse gases in terms of the amount of CO_2 that would have the same global warming potential.

transport sources, such as heavy-duty vehicles.[5] This leads to a required 60% reduction in passenger car emissions by 2030 relative to 2022, or a target of 41 Mt.

Figure 1

Path to reduce passenger car emissions in line with Germany's 2030 climate target



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As shown in Figure 1, the projected passenger car emissions reduction targets that reflect the required 60% reduction in Germany by 2030 will be missed under the BAU scenario. The TTW GHG emissions from passenger cars are projected to decline from 85 Mt of CO_2e in 2022 to around 75 Mt in 2030 in the BAU scenario if no further action is taken from the German government. These reductions are expected to largely come from improvements to new cars adhering to the European Union's emission standards. In contrast, TTW emissions from passenger cars should fall to around 41 Mt of CO_2e in 2030 to comply with the overall transport sector-wide target of 85 Mt. This leaves a gap of 34 Mt of CO_2e between the BAU scenario and the required reductions. These projections also show that residual emissions will persist until 2050 despite the phase-out of new internal combustion engine vehicle registrations in 2035, due to the expected lifetime of these vehicles. Although the average age of passenger cars in Germany was 10.1 years in 2021 (European Automobile Manufacturers' Association, 2023), a sizeable share of vehicles will remain in the vehicle stock well beyond this average. The survival curves in our modeling account for vehicle retirement as well as used vehicle exports. In light of these projections, further policy actions are needed to close the gap with Germany's 2030 climate target for the transport sector.

SCRAPPAGE SCHEME DESIGN AND METHODOLOGY

In response to the 2007–2008 global financial crisis, Germany utilized a scrappage scheme aimed at stimulating economic growth. The program, which had a budget of €5 billion, gave a purchase subsidy of €2,500 per vehicle to buy a new car if a car of at least 9 years of age was scrapped without the option to be resold. As there were no CO_2 emission requirements for the new cars eligible for the subsidy, the replacement of an old vehicle led to an average estimated reduction in well-to-wheel (WTW) GHG emissions per kilometer driven of only about 4% (from 220 g CO_2e/km to around 211 g CO_2e/km) (Bieker & Mock, 2020). As the vehicles that were scrapped had an average age of 14 years, or one

5 For context, if we assume emissions from all other transport sectors remain constant at their 2022 value, passenger car emissions would need to fall 72% by 2030. On the other hand, if all other transport sources reduce their emissions at the same rate, passenger car emissions would need to fall 48% by 2030.

year earlier than the age at which vehicles would typically be retired, the program only brought forward the emissions reduction benefit of the program by about one year. If a proportion of the emissions from producing the replacement vehicles are also factored in, the program provided even less GHG emission reductions.

In this paper, we analyze the potential of a hypothetical scrappage program to accelerate the decarbonization of Germany's passenger car stock in the year 2030. Our 2030 scrappage scenario removes all diesel cars 15 years or older and gasoline vehicles 25 years or older from the passenger car fleet. We assume the scrapped cars are replaced with new vehicles, either directly (the vehicle owner purchases a new vehicle) or indirectly (the owner of the scrapped vehicle purchases a used vehicle and the used vehicle's previous owner purchases a new vehicle). The scrappage scenario is built off the BAU scenario highlighted in Figure 1, which considers the effects of the latest CO_2 standards for new passenger cars in 2030 and 2035, including the zero CO_2 tailpipe emissions target for new cars in 2035 (Regulation (EU) 2019/631, 2019).

We use the ICCT Roadmap model to assess emissions trajectories. We also use the ICCT Fast Assessment of Transportation Emissions (FATE) model—a reduced-form air quality and health-impact model capable of providing damage functions for air pollutants—to analyze the societal impacts of emission reductions of air pollutants. In addition to the reductions of TTW and WTW GHG emissions, we evaluate the impact on TTW nitrogen oxides (NO_x) and particulate matter (PM) emissions. To evaluate the potential net benefits of the program, we combine the emission benefits with pollutant damage functions and the social cost of GHG emissions. We then compare the resulting societal benefits with the projected costs of the program, which are based on the number of vehicles scrapped and the assumed scrappage incentive per vehicle. The scrappage program is considered cost-effective when the benefits to society through reductions of GHG emissions and pollution are higher than the total costs of the program.

The fleetwide GHG benefits are estimated assuming the activity of the scrapped vehicles is replaced by the same proportion of vehicle activity as the projected sales mix of new battery electric, diesel, and gasoline vehicles in that year. If consumers were to opt for public transportation, walking, or biking instead of buying a replacement vehicle, the GHG benefits would be even higher. However, we did not include this specific aspect in our modeling. The age thresholds for the cost-effectiveness of the program for diesel and gasoline vehicles state under which conditions (boundaries) a scrappage program would deliver only net benefits, considering pollutant and GHG emission reductions and damage functions. We assume government scrappage incentives might compensate for 80% of the residual market value for each vehicle, considering automakers have participated in past programs by covering part of the program costs and incentivizing the purchase of new vehicles.[6] We estimate the depreciated value of cars based on the average price of new cars sold in Germany from 1998 to 2021 (Deutsche Automobil Treuhand [DAT], 2021a) and market price depreciation curves, plus a scrappage fee of €100 per vehicle (ADAC, 2022).

COSTS AND BENEFITS OF SCRAPPING DIESEL AND GASOLINE CARS

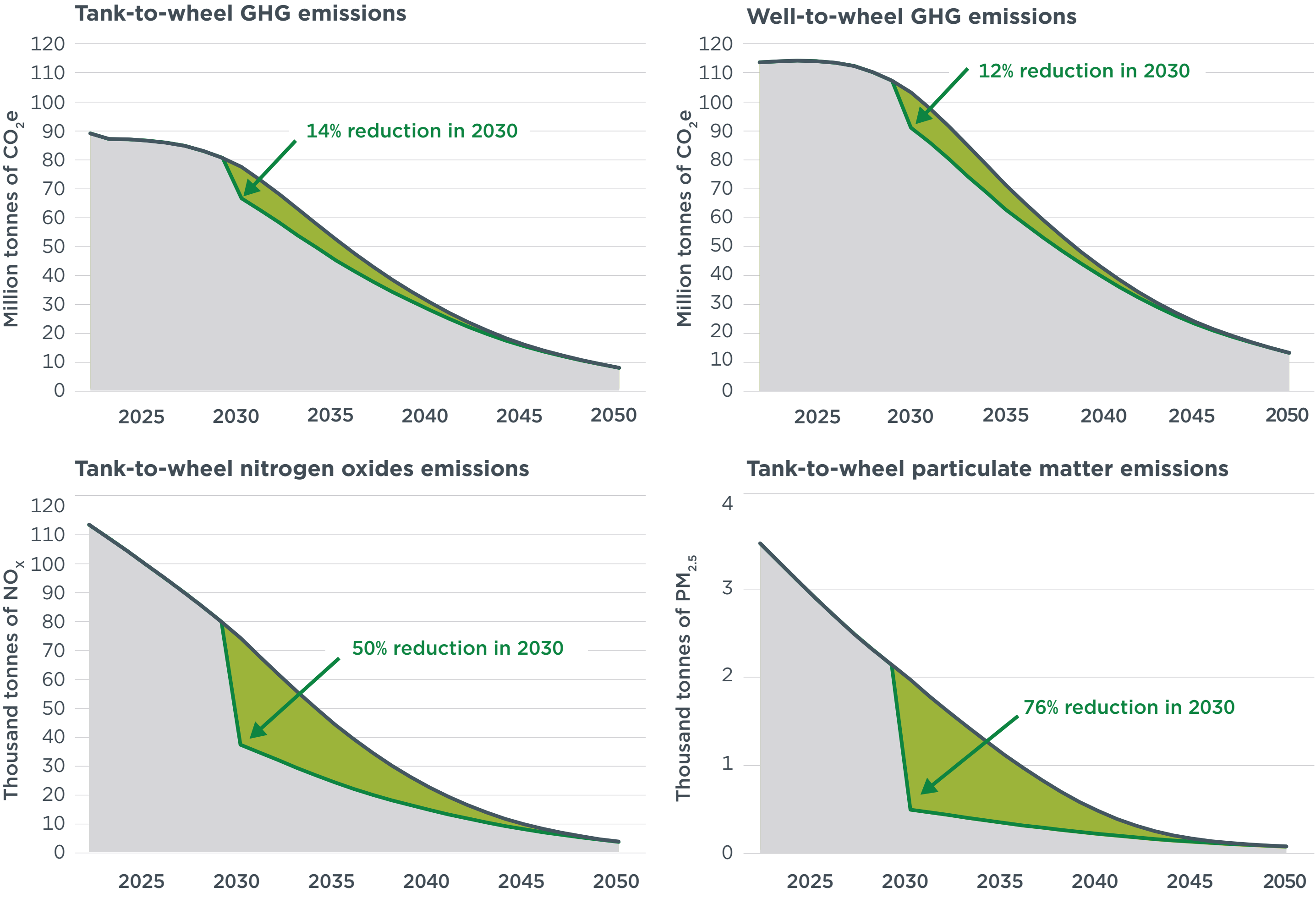
Our modeling results show that a scrappage program could cost-effectively avoid 11 Mt of TTW CO_2e emissions in 2030. Projected annual GHG emissions for passenger cars would be 75 Mt without the program (Figure 2), and 64 Mt with the program. In 2030,

6 We assume the depreciation curve for gasoline and diesel cars to be the same, as we utilized the initial average prices of all passenger cars sold in Germany for a particular year. It was not possible to confirm if there is a difference in depreciation for both vehicles in Germany. Historically, diesel cars depreciate more slowly than gasoline, but only for the most popular models. Due to environmental regulations, there is some evidence that owners of diesel cars dispose of their cars sooner than gasoline cars.

this equates to a 14% reduction in TTW GHG emissions. However, this would not be enough by itself to eliminate the gap with the 2030 climate target. In 2030, a scrappage program would reduce WTW GHG emissions by 12 Mt, or 12%. Such a scrappage program would also reduce tailpipe NO_x emissions from 74 kt to 37 kt (a 50% reduction) and tailpipe $PM_{2.5}$ emissions from 2.0 kt to 0.5 kt (a 76% reduction) in 2030. From 2030 until the end of 2050, the scrappage program is projected to avoid a cumulative total of 82 Mt of TTW GHG emissions.

Figure 2

Emission reductions from passenger cars in Germany under a hypothetical scrappage scheme



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As shown, a significant reduction in GHG and air pollutant emissions from the German vehicle stock is possible via a scrappage scheme. However, to better understand the feasibility of such a program, we explore its total costs and benefits to society. We utilize the social cost of carbon—an estimate of damages that negatively affect human health, the economy, and agricultural productivity—among other factors. The total damage is calculated based on each additional tonne of CO_2e released into the atmosphere, in €/tonne. Some uncertainty is involved in estimating these costs, as the output depends on the models and variables used in the assessment and the scope of the damage considered, leading to different estimations from various sources. In addition, the estimated social cost of carbon varies with the year in which the GHG emissions occur.

For this study, we utilize the social cost of carbon from the German Federal Environment Agency (Umweltbundesamt, or UBA), establishing that each additional tonne of CO_2e released into the atmosphere in 2030 will incur societal costs of €241 in 2022 prices. We have adjusted for 2021 prices in this study by using €225 for each extra tonne of CO_2e emitted (UBA, 2020).

For five types of pollutants—sulfur dioxide (SO_2), fine particulate matter ($PM_{2.5}$), ammonia (NH_3), nitrogen oxides (NO_X), and carbon monoxide (CO)—the marginal societal cost was determined using ICCT's FATE model (Nawaz et al., 2023). The FATE model calculates the number of premature deaths due to exposure to ambient $PM_{2.5}$ and ozone (O_3), and the effects of changes in source emissions on these exposure levels. We monetize these changes using the average of two values of statistical life (VSL): one derived from the World Bank (Narain & Sall, 2016) and another from Viscusi & Gentry (2015).[7] FATE applies the VSL for the calculation of the marginal societal cost for each type in terms of €/kg pollutant, taking into consideration the effect of income growth on increases in VSL.

TOTAL PROGRAM COSTS AND BENEFITS

The scrappage program, highlighted in Figure 2, is designed to maximize reductions in GHG and air pollutant emissions and deliver net societal benefits, while giving enough incentive for drivers to willingly scrap their vehicles. To determine under what conditions a scrappage program would deliver net societal benefits, we evaluate potential societal costs based on the scrappage incentive and the maximum number of diesel and gasoline cars of each age that could be scrapped in the 2030 fleet. We then compare this to the societal benefits of the emissions that could be avoided by scrapping all vehicles of each fuel type and age cohort. We perform this analysis for gasoline and diesel cars separately for each registration year. The societal benefits are estimated using parameters for the German fleet for each year, such as remaining lifetime VKT (vehicle kilometers travelled), emissions factors for each pollutant considered, and the damage functions for each pollutant.[8]

The FATE damage functions, based on the Global Burden of Disease methodology, include premature deaths resulting from exposure to $PM_{2.5}$ and to ozone produced in the atmosphere from transportation emissions. The methodology accounts for projected changes in population size, age distribution, and baseline disease rates. The main health outcomes assessed are stroke, ischemic heart disease, chronic obstructive pulmonary disease, lower respiratory infection, lung cancer, and type 2 diabetes mellitus. The monetized value to society of avoiding these premature deaths by reducing air pollution exposure is then evaluated using the VSL. Damage functions represent the societal value of health damages avoided per tonne of emissions reduced.

The FATE and UBA damage functions are shown in Table 1. The damage functions from UBA are lower than the FATE damage functions because the methodologies and assumptions behind the economic valuation differ.[9] However, both methodologies have been applied to studies addressing the health benefits of reducing air pollution. In this

7 When conducting a cost-benefit analysis of an environmental policy, the value of statistical life can be used to estimate the social benefits, as it represents how much a society would be willing to pay to reduce the marginal risk of dying from a certain condition, in this case by exposure to air pollution. https://www.epa.gov/environmental-economics/mortality-risk-valuation

8 To calculate the remaining lifetime VKT, we combined survival rates in ICCT's Roadmap model with a normalized mileage degradation curve extracted from the German Federal Ministry for Transport and Digital Infrastructure (infas Institute for Applied Social Science, n.d.). We did not use the absolute annual per-vehicle mileage since this varies from year to year. Instead, we calibrated based on energy consumption statistics. Our analysis of the cost-effective age threshold for diesel cars is conservative as their real-world mileage may be higher than gasoline cars.

9 UBA damage functions are based on a metric called VOLY (value of a life year). Traditionally, studies using VOLY show smaller economic benefits of reducing air pollution. https://epha.org/wp-content/uploads/2020/10/final-health-costs-of-air-pollution-in-european-cities-and-the-linkage-with-transport.pdf

paper, we utilize methodologies recommended by both the World Bank (Narain & Sall, 2016) and the Organisation for Economic Co-operation and Development (2016). In addition, FATE functions also consider the health impacts of ozone, which increases the estimated benefits of reducing air pollutant emissions. GHG emissions include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions. Methane and nitrous oxide emissions are translated into kg of CO_2 equivalents based on their 100-year global warming potential of 30 kg CO_2e per kg for methane and 273 kg CO_2e per kg for nitrous oxide (Intergovernmental Panel on Climate Change, 2021).

These functions include the value of avoided health damages in Germany, other European countries, and non-European countries, as FATE considers the transboundary dispersion of pollutants. For health damages related to ambient $PM_{2.5}$ emissions, 58% are estimated to occur in Germany, 42% occur elsewhere in Europe, and less than 1% occur in other regions. For health damages related to ozone, 68% are estimated to occur in Germany, 24% occur elsewhere in Europe, and 7% occur in other regions.

Table 1

Environmental pollutant costs from ICCT's FATE model and the Umweltbundesamt

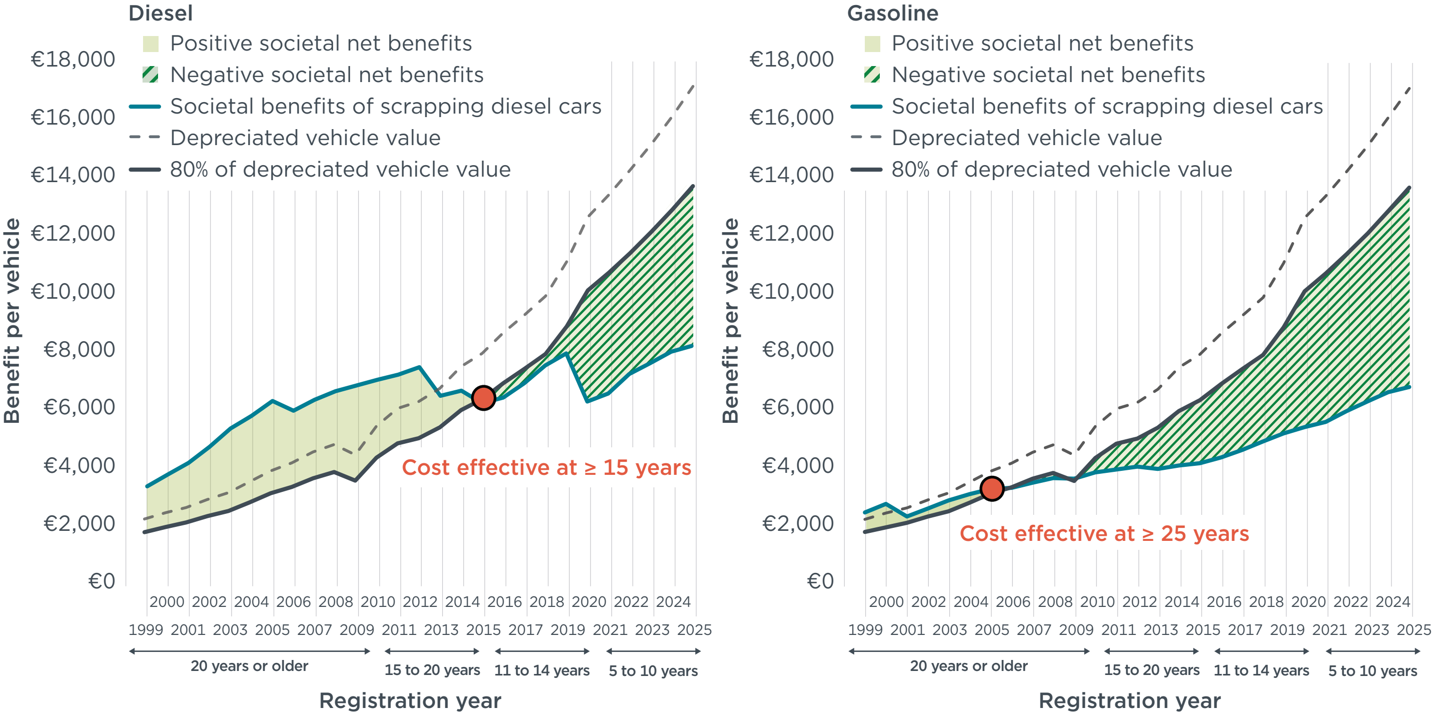
Pollutant	FATE values used for this study (2021 €/kg)	UBA values used for this study (2021 €/kg)
Sulfur dioxide (SO_2) (TTW)	39.66	14.75
Fine particulate matter ($PM_{2.5}$) (TTW)	—	63.42
Black carbon (BC) (TTW)	390.48	—
Organic carbon (OC) (TTW)	897.20	—
Ammonia (NH_3) (TTW)	83.42	23.51
Nitrogen oxides (NO_x) (TTW)	75.97	15.67
Carbon monoxide (CO) (TTW)	1.08	—
GHG (WTW)	—	0.225

Note: UBA damage functions for the pollutants and for GHG were converted from 2022 €/kg to 2021€/kg using a conversion factor of 0.93 (ratio of the consumer price index in Germany for both years). FATE damage functions were converted from 2020 US$/kg to 2021 US$/kg using an inflation factor of 1.047 and then from 2021 US$/kg to 2021 €/kg using a conversion factor of 0.8458.

Figure 3 compares the estimated benefits and costs per vehicle scrapped by fuel type and vehicle age. Areas of the chart where the societal benefit exceeds 80% of the depreciated value correspond to potential positive net benefits of a scrappage program. As depicted, the estimated benefits of a scrappage program for diesel cars 15 years and older and gasoline cars 25 years and older exceed the costs if an incentive amount equal to 80% of the depreciated vehicle value is paid. The societal benefits of scrapping diesel cars are greater than gasoline cars of the same age because diesel cars have higher pollutant emissions and, therefore, higher health impacts. Paying more than 80% of the full market price would potentially increase participation in the program but would narrow it to the scrappage of diesel vehicles 17 years and older and gasoline vehicles 30 years and older, considerably reducing the climate and health benefits. Offering a lower incentive amount for newer cars could be a cost-effective option to increase the potential benefits of the program, but owners of newer cars would be less likely to participate.

Figure 3

Comparison of per-vehicle societal benefits with estimated scrappage incentives for diesel and gasoline cars by registration year



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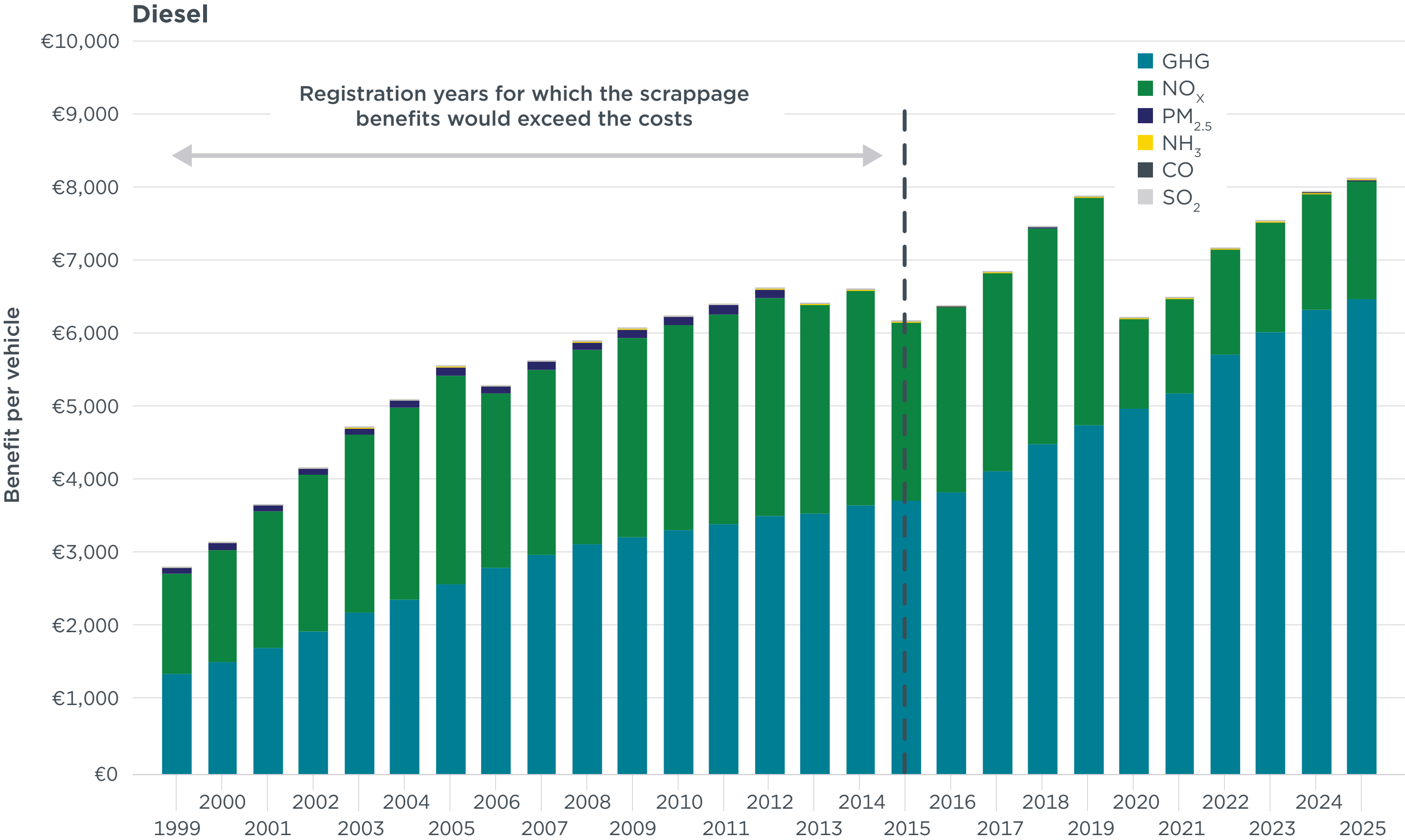
We find that the total costs of a program that targets diesel cars 15 years and older and gasoline cars 25 years and older would reach €35 billion while bringing social benefits of €50 billion and allowing the scrappage of 8 million vehicles (7 million diesel cars and 1 million gasoline cars). The costs of abatement per tonne of CO_2e would reach €313 for diesel cars and €255 for gasoline cars (excluding health co-benefits). The higher costs for diesel cars are due to the scrappage of newer vehicles 15 years and older versus scrapping gasoline vehicles 25 years or older. However, the program remains cost-effective due to the higher health benefits of scrapping diesel cars compared with gasoline cars.

This analysis does not quantify any potential economic benefits for manufacturers associated with increased car sales. As evidenced by past programs in Germany that targeted economic stimulus, it is possible that manufacturers would voluntarily offer incentives to scrappage-program participants to stimulate new car sales and enhance profitability. The presence of additional manufacturer incentives could increase the likelihood of vehicle owners participating in the program and allow newer vehicles to be scrapped, increasing the emission reductions and associated benefits.

Figure 4 shows the contribution of each pollutant to the societal benefits of scrapping diesel and gasoline cars. Reduction of NO_x is primarily responsible for the health benefits of scrapping diesel and gasoline cars. Overall, health benefits account for approximately half of the benefits of scrapping diesel cars, depending on the age, and 20% of the benefits of scrapping gasoline cars, when FATE damage functions are considered.

Figure 4

Societal benefits per scrapped gasoline and diesel vehicle by registration year



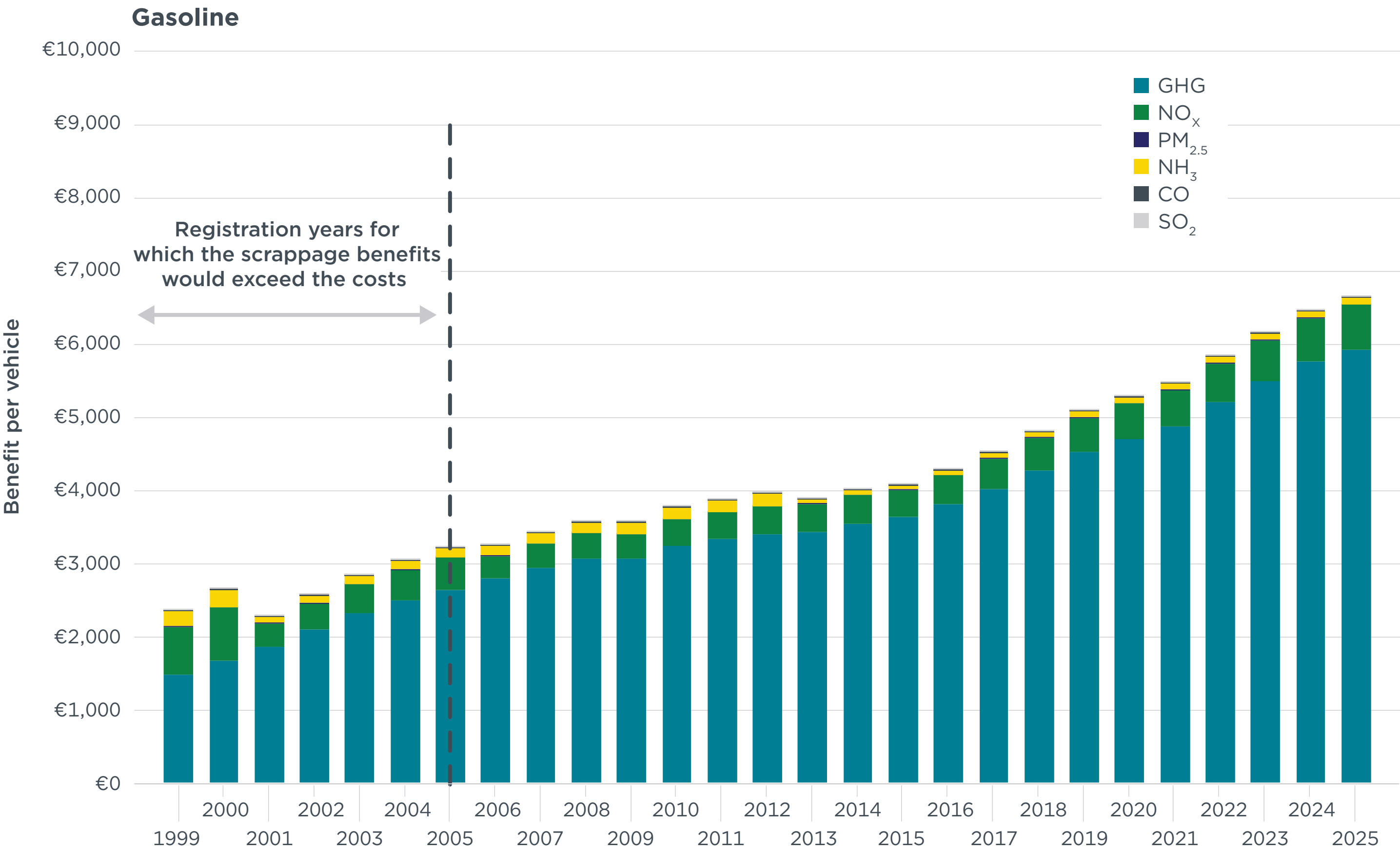


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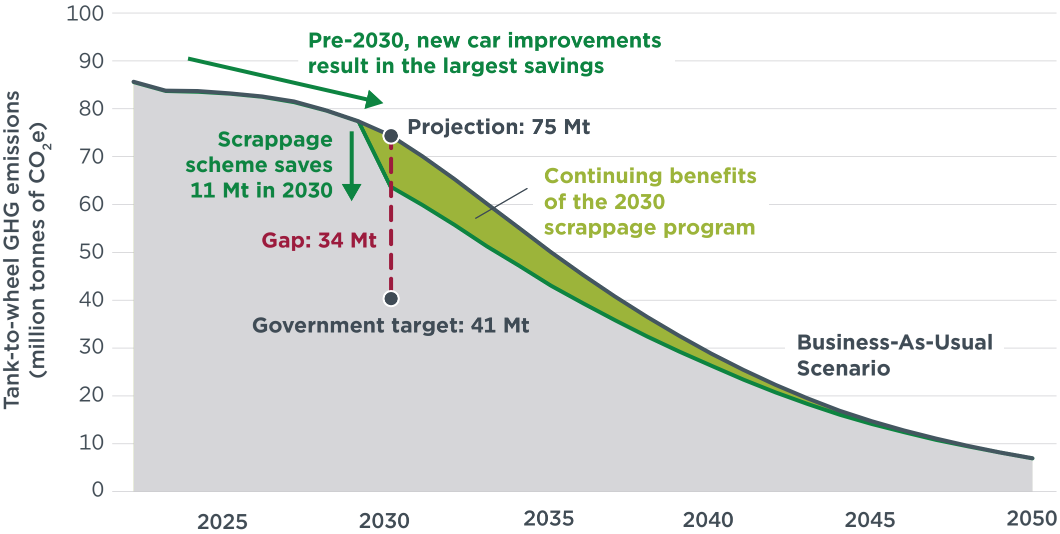
Figure 5 displays the benefit of the designed scrappage program in reducing the gap—estimated at 34 Mt of CO_2e in 2030—between the government target and the BAU emissions path. We project that the hypothetical scrappage program we evaluated could reduce annual GHG emissions by 11 Mt of CO_2e, narrowing the 2030 gap to 23 Mt of CO_2e.

Figure 5
Pathways to reduce passenger car emissions in line with Germany's 2030 climate target, including a scrappage program



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Potential roadblocks to the implementation of a scrappage scheme exist, such as the funds needed to finance such a program and the uncertainty of owners' voluntary participation. Less-than-full participation could arise from a potential lack of alternative modes of transport or the financial inability of some households to afford a replacement vehicle. Specific policy instruments could be utilized to make scrapping a vehicle more attractive, which could include a social component to help those who otherwise could not afford to participate. For example, an income-based bonus could help drivers with lower incomes take part if it is designed so that the program remains cost-effective. A congruent BEV leasing program could also help to increase participation rates. Such a program is offered in France, where groups with lower incomes receive a reduced cost of leasing a BEV of around €100 per month (Moriscot, 2023). The success of these policy alternatives rests on the ability of the German government to ensure sufficient infrastructure exists to satisfy an increased level of charging requirements.

Tightening low-emission zones (LEZs) in urban areas could also provide drivers an extra incentive to discard or replace their older ICEVs faster. If those vehicles are no longer permitted to drive through core areas in cities, drivers might be willing to dispose of their older vehicles sooner than the proposed scrappage scheme. Promoting sustainable regulations such as stronger LEZs in large and midsized cities is key, as roughly 60% of the German population resides in these areas (Federal Institute for Research on Building, Urban Affairs and Spatial Development, 2022), and this population share is projected to increase in the future. Tightened LEZs throughout Germany might increase participation rates in a scrappage program even if the incentive amount is less than the full depreciated value of the car.

Lastly, the timing of the program influences both the number of applicable ICEVs and the bonuses needed, and thereby the total program costs. Implementing a large-scale scrappage program closer to 2030—as assessed here—is preferable to implementing such a program immediately. This is due to the possibility that current BEV production levels may not be sufficient to fulfill the increased demand from a scrappage program until supply chain shortages have time to resolve. On the other hand, waiting too long to implement a scrappage program would increase the risk of missing GHG reduction targets and leave air pollutant emissions and associated health impacts from the existing vehicle fleet unchecked.

Because new BEV uptake is expected to keep increasing over time, waiting until BEVs have a higher share of the vehicle stock could affect the costs of the program. Accelerating BEV uptake for new vehicle sales is therefore critical for two reasons: it reduces the number of ICEVs that enter the vehicle fleet, reducing the scale needed for a future scrappage program, and it accelerates the timing of when a scrappage program can be implemented due to the expected reduction of BEV supply chain issues.

DISCUSSION OF OTHER MEASURES

Other options being discussed in Germany to aid in decarbonizing the vehicle stock differ in costs, political feasibility, and the potential for reducing GHG emissions. In this section we briefly explore three potential approaches—e-fuels, avoid-and-shift strategies, and retrofitting—and discuss how they compare to or could complement a scrappage program.

E-FUELS IN GERMANY

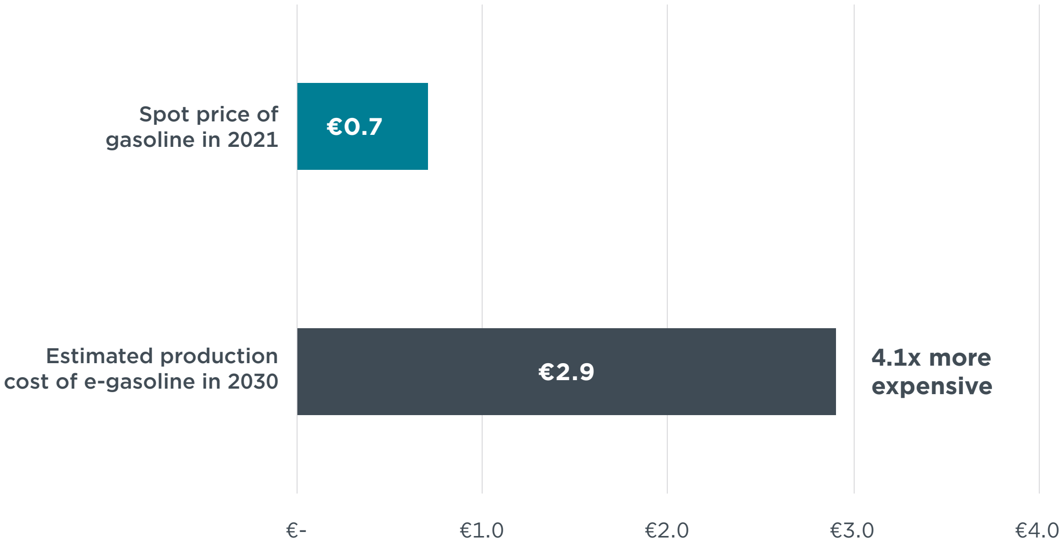
The feasibility of e-fuels to decarbonize the passenger car stock depends on availability, costs, and separate policies incentivizing e-fuels production, such as the renewable liquid and gaseous fuels of non-biological origin (RFNBO) subtargets in the EU Renewable Energy Directive (RED III) and the ReFuelEU aviation regulation.

How quickly the production capacity of e-fuels can increase and how much of these e-fuels will theoretically be available for road transport are still unclear. Production costs are a major hurdle for the viability of using e-fuels in the existing German vehicle stock. Using the e-fuel cost model developed in a previous ICCT study (Zhou et al., 2022), we estimate the levelized production cost of e-diesel in Germany to be €3.6 per liter today, decreasing to €2.9 per liter in 2030.[10] We assume the cost of e-gasoline would be about the same as e-diesel because the production process is similar although the exact quantity of e-gasoline would depend on decisions by fuel producers to optimize costs and comply with other, separate fuels policies. Therefore, we assume the cost of e-gasoline is 4.1 times more than the €0.7 per liter spot price of gasoline (i.e. excluding taxes) in Germany in 2021, as illustrated in Figure 6 (Wirtschaftsverband Fuels and Energy, 2023; Eurostat, 2023).

10 All underlying model structure and data assumptions for estimating the production cost of e-fuels can be found in Zhou, Searle, and Pavlenko (2022). A forthcoming ICCT study will estimate the cost of importing e-fuels, in 2020 euros. All e-fuel costs in this paper are in 2021 euros, using a conversion factor of 1.03 (ratio of the consumer price in Germany for both 2020 and 2021).

Figure 6

Spot price of gasoline per liter in Germany in 2021 versus the levelized production cost of e-gasoline in 2030



Note: Costs in 2021 euros

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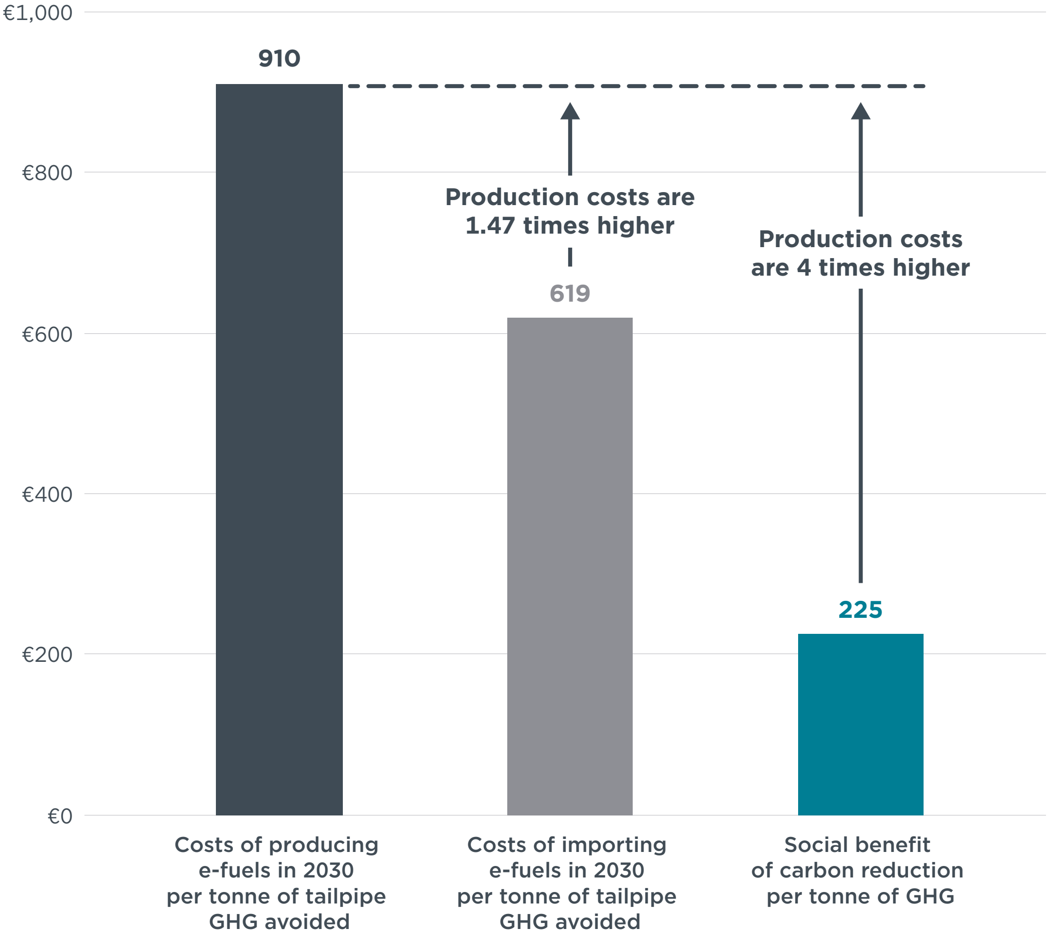
This relative cost of producing e-fuels in Germany in 2030 translates to €910 per tonne of CO_2e of TTW GHG emissions avoided, assuming the GHG intensity of e-gasoline per MJ is the same as e-diesel, and that e-gasoline replaces 100% of fossil gasoline.[11] As shown in Figure 7, this cost of carbon abatement is over 4 times the social cost of GHG emissions of €225 per tonne (2021 prices) estimated by the German Federal Environment Agency (UBA, 2020).

11 We consider the TTW GHG emissions from the combustion of fossil gasoline and diesel to be 75 g CO_2e/MJ, which we retrieve from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET). The TTW GHG emissions from the combustion of e-fuels are considered zero due to the avoided CO_2 emissions.

Figure 7

Costs of e-fuels in 2030 per tonne of CO_2e of TTW GHG emissions avoided versus the social benefit of carbon reduction per tonne of CO_2e



Note: Costs in 2021 euros

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A forthcoming ICCT study estimates the costs of importing e-fuels from Egypt and Brazil, two regions where it is commonly discussed that e-fuels could be low-cost due to their higher capacity to produce renewable energy. European countries, including Germany, have already begun partnerships with these countries. The analysis finds that e-fuels could be imported to Germany at a cost as low as €2.20 per liter in 2030 (in 2021 euros) in Brazil (in press).[12] Despite these assumptions, the cost of imported e-gasoline would still surpass the gasoline spot price by over threefold.

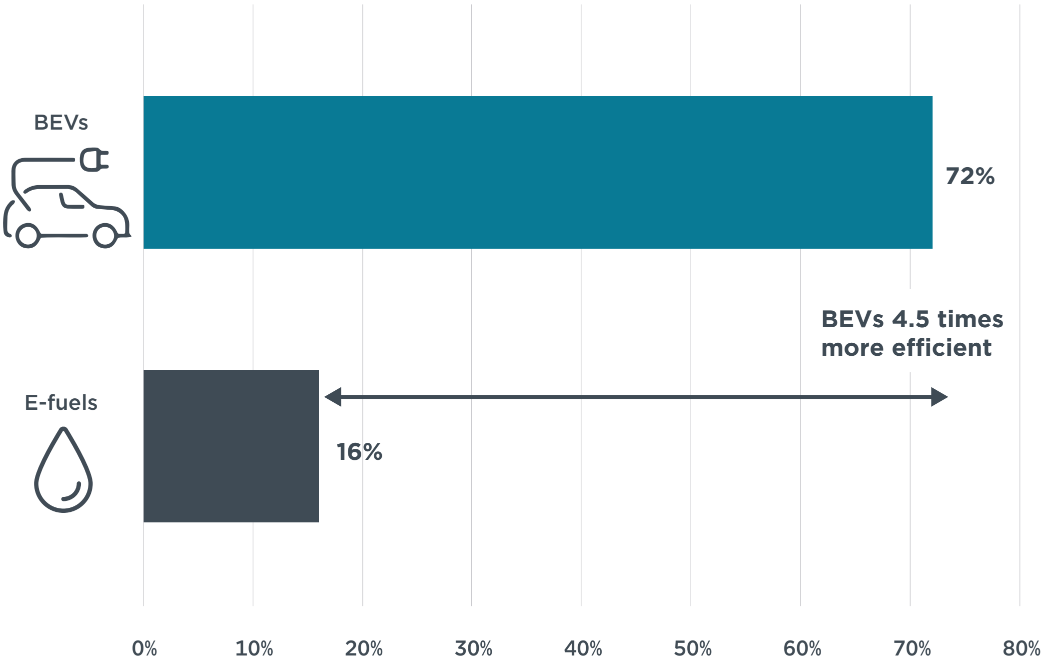
In addition to high production costs, e-fuels are prone to efficiency losses across multiple stages of their production. Specifically, about half of the electrical energy will be lost in the process of being converted into e-fuels. Splitting water into hydrogen using electricity has a present-day efficiency of about 70%, and the efficiency of combining hydrogen with CO_2 into hydrocarbons through Fischer-Tropsch is about 73% (Brynolf et al., 2018). This leads to a net energy ratio of 51% assuming the CO_2 is from a concentrated point source. The net energy ratio would decrease to about 46% if direct air capture is used (Wang et al., 2021). Battery electric motors have an energy efficiency of about 80% compared to 30% for combustion engines (California Code of Regulations, 2023). Considering charging losses of around 10%, the total

12 Not including downstream costs beyond arrival at ports in the European Union, such as e-fuel distribution, storage, and fueling.

energy efficiency from electricity would be 72% for BEVs, excluding transmission and distribution efficiency losses, compared with 16% for e-fuels (Searle, 2020), as shown in Figure 8. Given their high cost and efficiency losses, e-fuels would better suit sectors that are not practical to decarbonize through direct electrification, such as long-distance aviation and marine shipping (Ueckerdt et al., 2021).

Figure 8

Grid-to-wheel energy efficiency of battery electric vehicles versus a combustion engine vehicle running on e-fuels



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To estimate the potential GHG benefit of e-fuels for the passenger car stock in Germany, we align with the methodology in Baldino et al. (2023). In this analysis, we calculated the alternative fuel mix, including e-fuels, in EU diesel fuel in 2030. The RED III includes a 5.5% advanced biofuel subtarget with a 1% subtarget for RFNBO's as a share of energy. These fuels receive a multiplier of 2 times toward the transport target, which means the actual mandated share of e-fuels would range from 0.5% to 2.75% by energy. In addition, the ReFuelEU legislation mandates the production of e-fuels for the aviation sector, which means e-diesel will be produced as a co-product of e-kerosene. Like Baldino et al. (2023), here we assume that enough e-fuels will be produced to meet the ReFuelEU e-fuels target, and the remainder of the RED III subtarget will be met with RFNBOs used in petroleum refining and advanced biofuel.

To assess the contribution of e-fuels toward the German road transport sector, we estimate jet fuel demand in Germany in 2030 will be 9.9 million tonnes (428 PJ).[13] Thus, 5.1 PJ of e-kerosene will be needed to meet an average target of 1.2% under ReFuelEU, which corresponds to 2.6 PJ of e-diesel produced as a co-product if maximizing the product slate for kerosene (Pavlenko et al., 2019). We conservatively assume that all e-diesel is consumed in the passenger car sector. To estimate the potential GHG emission reductions

13 We retrieve 2019 jet fuel usage in Germany of 10.3 million tonnes from TheGlobalEconomy.com, https://www.theglobaleconomy.com/Germany/jet_fuel_consumption/. We assume fuel consumed in 2023 is 87% of 2019 levels based on data retrieved March 27, 2024, from the Eurocontrol website, https://www.eurocontrol.int/our-data. Assuming a growth rate of 1.5% per year based on the Airbus global market forecast, https://www.airbus.com/sites/g/files/jlcbta136/files/2023-06/GMF%202023-2042%20Presentation_0.pdf, jet fuel demand will be 9.9 million tonnes in 2030.

of using e-fuels in the German passenger car stock in 2030, we assume e-diesel has the same GHG intensity reduction potential as e-gasoline, based on Wang et al. (2021).

Based on these assumptions, we find e-diesel incentivized by the RED III and ReFuelEU could hypothetically reduce TTW GHG emissions from the passenger car vehicle stock in Germany by roughly 190,000 tonnes of CO_2e (using GWP-100) and WTW GHG emissions by 235,000 tonnes of CO_2e. This is in comparison to the Business-As-Usual scenario in which vehicles would continue to be fueled with conventional gasoline or diesel. Even in such a scenario, e-fuels would contribute little to reducing the 2030 target emissions gap for passenger vehicles of 34 Mt, shown in Figure 1. In comparison to the designed scrappage program, which would reduce the gap by about 11 Mt of CO_2e, the reduction of emissions from utilizing e-fuels—assuming all e-fuels were used for passenger cars—would be over 50 times smaller. Additionally, the utilization of e-fuels for stock decarbonization would require long-term costs and investments, whereas the designed scrappage program would incur a one-time fixed cost. As noted earlier, relying on e-fuels for reducing GHG emissions would come at high cost and impact e-fuel availability for sectors such as marine and long-distance aviation.

COMPARISON OF ABATEMENT COSTS

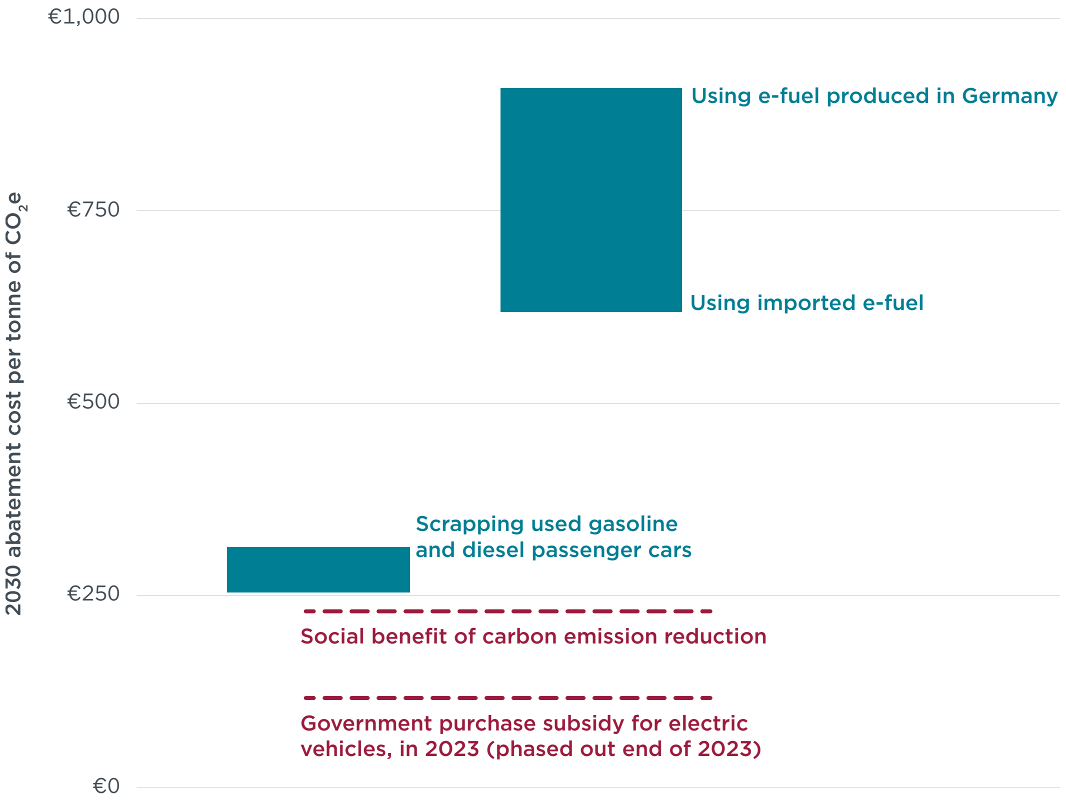
For a scrappage program implemented in 2030, the costs of abatement per tonne of CO_2e emissions would reach €313 for diesel cars and €255 for gasoline cars (excluding health co-benefits), as derived in previous sections of this report (Figure 9). In comparison, the social benefit of carbon reductions is estimated by the German Federal Environment Agency to be €225 per tonne of CO_2e in 2030. However, in the hypothetical scrappage program that we evaluated, health co-benefits are responsible for the program's positive net societal benefits. Depending on the design of the scrappage program, part of the cost for the government could be offset by economic benefits for the automotive industry as well as increased tax revenue.

The costs of using e-fuels to bring down CO_2 emission levels of new or used cars is much higher. The relative cost of producing e-fuels in Germany in 2030 translates to €910 per tonne of TTW GHG avoided. For e-fuel imported from Brazil, the estimated abatement cost could be as high as €619 per tonne of CO_2e avoided. To allow e-fuels to compete in the market and become an attractive option for consumers, high subsidies would be required.

In comparison, the purchase subsidy for BEVs provided by the German government until the end of 2023 amounted to €4,500 per vehicle with a net list price of up to €40,000. Considering that each BEV replaces an ICEV with 155 g/km of CO_2 (based on the average for a new gasoline or diesel car in 2023), and assuming that a new car will drive, on average, about 243,000 km throughout its lifetime (Bieker, 2021), plus the average discrepancy between type approval and real-world driving CO_2 emission levels (Dornoff et al., 2021), this equates to abatement costs of about €105 per tonne of CO_2e. This value does not account for health co-benefits or economic benefits for the automotive industry. Furthermore, it is important to note that the current government subsidy for BEVs has been phased out and buying a new BEV is expected to be cheaper than buying a new ICEV by 2030 (Mock & Diaz, 2021).

Figure 9

Estimated abatement costs in terms of governmental spending in 2030 per tonne of CO_2e GHG emissions avoided for scrapping passenger cars or using e-fuels



Note: The 2030 social benefit of reducing carbon emissions, as well as the abolished 2023 government purchase subsidy for electric vehicles in Germany, are shown for comparison. All costs are expressed in 2021 euros. Health and economic co-benefits, as well as fuel cost savings, are not taken into account.

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AVOID-AND-SHIFT POLICIES

Strategies to reduce the demand for driving cars can be an effective means for reducing vehicle stock emissions and could complement a scrappage program. Significant research has been conducted on these strategies, which involve reducing passenger car activity and shifting it to more sustainable forms of mobility, such as biking, walking, public transportation, or shared mobility options. These measures are categorized as either avoid policies or shift policies, with instruments further categorized within the shift approach as push (restrictive) or pull (promotive). Avoid implies reducing the need to travel at all, such as a walkable city design, while shift reduces the environmental impact of travel by prioritizing more sustainable means, such as shifting from ICEVs to public transportation.[14] In this section, we discuss some of the policies that could be utilized by the German government to aid in reaching emissions reduction goals in congruence with a targeted scrappage scheme. The instruments described below are only some of the many within the reviewed literature which can contribute to broader strategies for reducing stock emissions. These can have a stronger emissions reduction potential when implemented together, and the full mitigation potential of all considered instruments are shown at the end of the section.

14 These instruments are analyzed by their carbon mitigation effect when applied together and therefore assumed to be utilized in congruency, as their effectiveness on reducing emissions can enhance one another. As a consequence, many of the instruments are evaluated in the literature in terms of their combined efficacy as scenarios, rather than as stand-alone instruments.

Sustainable land use planning. The design and layout of infrastructure and buildings influences the decision to use passenger cars in day-to-day life and can make the choice to scrap one's vehicle easier if residents can live without needing to drive. Germany's National Platform Future of Mobility highlights the importance of transport and housing development, where cities plan to prioritize urban density and avoid ongoing city expansion that increases the need to travel. The NPM estimates that city-specific design, coupled with other related instruments such as public transportation funding, could reduce passenger car emissions by 4.3–7 million tonnes of CO_2e in 2030 (Nationale Platform Zukunft der Mobilität, 2021).

Funding, expansion, and affordability of public transportation. Making public transportation more affordable and reliable is one of the most highlighted ways to reduce passenger car emissions, especially for those with lower incomes. Increasing the affordability of public transport could also encourage participation in a national scrappage scheme by providing mobility options for those who give up their cars. To maximize participation by lower income groups, a country-wide, income-based price plan for the 49-euro Deutschland Ticket (Deutschlandticket.de)—which allows access to all local public transportation and regional trains—could be offered. It is especially important to connect public transit to the roughly 16 million people living within German rural regions to reduce car dependency (ADAC, 2020). The UBA found that an increase of existing local public transportation funds and other environmentally friendly modes of transport (walking and bicycling infrastructure) will lead to an annual additional savings of 2–3 million tonnes of CO_2e in 2030 (UBA, 2024).

Speed limits. Implementing speed limits on the German motorways and requiring vehicles to drive at more fuel-efficient speeds could further reduce vehicle emissions. Such a policy comes at very little cost to the government and could be implemented prior to the 2030 scrappage program scheme, as the programs would not compete for financial resources. At present, most German highways (about 70% of highway kilometers) do not have established speed limits (Bauernschuster & Traxler, 2021). Speed limits of up to 100 km/h exist for passenger cars on nonurban or "country" roads, and urban roads have limits of 50 km/h or 30 km/h, depending on the surroundings (UBA, 2023). The UBA approximates that, in 2030, a general limit of 100 km/h could avoid 4.5 million tonnes of CO_2e, a 120 km/h highway speed limit could avoid 3 million tonnes of CO_2e, and a 130 km/h highway limit could avoid 2 million tonnes of CO_2e.

Financial incentives. Pricing and tax instruments could also contribute to reductions in vehicle emissions by internalizing the external costs of this pollution. For example, the Ecological-Social Market Economy Forum (FÖS) estimates a CO_2-based registration tax on new passenger cars could avoid 2.8 Mt of CO_2 in 2030 (Forum Ökologisch-Soziale Marktwirtschaft [FÖS], 2022). The tax revenues from financial incentives such as this could be used to fund further emissions reduction programs, such as a scrappage scheme or a bonus-malus system for new vehicles.

One important financial instrument is carbon pricing, or the quantification of the external costs of carbon emissions. Germany implemented carbon pricing for transportation via the national emissions trading system in 2021. The price of carbon was set at €30 per tonne of CO_2 for 2022 and 2023. The price will gradually increase to €55–€65 per tonne in 2026 (Bundesregierung, 2020). Studies have found the GHG benefits of raising the price of carbon depend on other policy instruments that are simultaneously implemented, such as a ban on the new registration of ICEVs. Nonetheless, FÖS estimates that a higher CO_2 price could avoid 3.6 Mt of CO_2 from transport in 2030. Other studies have found that a carbon price of €82–€300 per tonne could lead to significant additional carbon savings, especially if combined with a ban on new ICEV registrations in 2035 (Seibert et al., 2022). Despite high mitigation potential, adopting a high carbon price could be politically challenging; energy and fuel prices have already placed a high burden on those with lower incomes, leading to a freeze on the German carbon price increase for 2023 (Wehrmann, 2022). A delay of subsequent price increases by one year will also follow suit.

Financial instruments can produce other co-benefits, such as increased physical activity and reduced exposure to traffic-related air pollutants. The biggest potential for mitigation lies with using pricing and tax instruments to internalize the cost of passenger car emissions. However, establishing a reliable public transportation system to satisfy mobility needs is key.

A summary of the highlighted avoid-and-shift strategies and the corresponding studies is provided in Table 2.

Table 2
Overview of avoid-and-shift strategies and mitigation potential in 2030

Avoid-and-shift strategies	GHG/CO_2 mitigation potential in 2030
Forum Ökologisch-Soziale Marktwirtschaft (Forum Ökologisch-Soziale Marktwirtschaft, 2022; Beerman et al., 2022)	**Total:** up to 36 million tonnes of CO_2
Correct existing misaligned incentives (Close the diesel tax gap, reform the private use of company car taxation, reform the commuter allowance, etc.)	16.8 million tonnes of CO_2
Strengthen the central instrument of market-based climate protection: Higher CO_2 price for transport (BEHG)	3.6 million tonnes of CO_2
New tools for the start of the transformation (CO_2 based registration tax, introduction of a passenger car tax starting in 2030)	15.6 million tonnes of CO_2
Umweltbundesamt (Umweltbundesamt, 2024)	**Total:** up to 23.5 million tonnes of CO_2e
End fossil fuel subsidies (energy tax for diesel, company car subsidy, etc.)	5–6 million tonnes of CO_2e
Polluter pays-based pricing (carbon price and car-based toll)	3–5 million tonnes of CO_2e
Speed limits (100-130 km/h)	2–4.5 million tonnes of CO_2e
Strengthening the railways (Increased funding for rail passenger and freight transport)	3–5 million tonnes of CO_2e
Increased funding of public transport, bicycling, walking, car sharing	2–3 million tonnes of CO_2e
Nationale Plattform Zukunft der Mobilität (Nationale Plattform Zukunft der Mobilität, 2021)	**Total:** up to 7.0 million tonnes of CO_2e
Promotion of alternative transport, traffic flow optimization, raising awareness, etc.	4.3–7.0 million tonnes of CO_2e

RETROFITTING ICEVS TO BEVS

Another option for reducing vehicle stock GHG emissions is retrofitting passenger cars by converting ICEVs to BEVs. Retrofitting could help reduce emissions, as well as the raw materials needed to produce an entirely new electric vehicle; however, costs and the practicality of large-scale implementation remain a concern. One study found that these costs could be €13,000–€15,000 per vehicle for mid-sized passenger cars in Germany (Hoeft, 2022). Retrofitting is therefore comparable to the average cost of a used vehicle in Germany in 2020 of around €14,730 (DAT, 2021b). Other reports find that in similar markets, such as the United Kingdom, the costs of retrofitting could be significantly higher, with estimates ranging from £18,000 to £100,000 (€20,000 to €116,400) (Watts et al., 2021).

Despite additional concerns regarding the legality, safety, and scalability of this technology, several companies across Europe offer retrofitting services (Decarbone, n.d.). Retrofitting could potentially complement a scrappage program by focusing on newer or specialized vehicles that are more cost-effective to retrofit than to scrap and replace. However, further research is needed regarding the ability of retrofitting to serve as a viable, cost-efficient, and large-scale decarbonization strategy

CONCLUSION

Under a Business-As-Usual scenario, emissions from the German passenger car stock in 2030 will exceed the transportation CO_2 reduction target by 34 Mt of CO_2e. We assessed the feasibility and carbon-reduction potential of various measures to close this gap, including a targeted vehicle scrappage program, the utilization of e-fuels, and the implementation of select avoid-and-shift strategies. Retrofitting ICEVs to BEVs was qualitatively discussed from a feasibility and costs perspective without assessing GHG mitigation potential. From this analysis, we draw the following conclusions:

» **Introducing a targeted scrappage program with incentives that vary by vehicle age and fuel type could cost-effectively cut one third of the emissions gap in 2030 (11 Mt of CO_2e).** We identified cost-effective thresholds for vehicle ages above which the benefits of scrapping a vehicle—based on the social cost of carbon dioxide and other air pollutants—would outweigh the costs of compensating owners for the residual vehicle values. We find that a scrappage program in Germany would be cost-effective if it targets diesel vehicles 15 years and older and gasoline vehicles 25 years and older in the year 2030 and provides scrappage incentives that are 80% of the full depreciated vehicle price. The estimated net benefits of scrapping older diesel cars are several thousand euros per vehicle when older than 15 years. It is uncertain whether a voluntary scrappage program targeting those vehicles would have an appreciable rate of voluntary participation, as these vehicles may have an additional nonmonetary value (i.e., classic cars). Nevertheless, for owners who voluntary participate in such a program, our analysis indicates that the societal benefits of scrapping these cars could outweigh the costs of the scrappage incentives.

  The expected abatement costs would amount to about €255 per tonne of CO_2e for gasoline and €313 for diesel cars in 2030 (excluding health co-benefits). The vehicle age thresholds for a cost-effective scrappage program also include the health co-benefits calculated using damage functions from ICCT's FATE model. Using lower values, such as the 2016 damage functions published by the German environment agency UBA, would increase the age thresholds needed for a scrappage program to be considered cost-effective. This highlights the influence damage function methodologies have on cost-benefit analyses and on future policy decisions. Additionally, the potential economic benefits to manufacturers from a scrappage program were not considered in this paper but would be high given the modeled replacement of ICEVs with new BEVs. Manufacturers offering additional voluntary incentives might lower the costs of the program for the German government or increase rates of participation, depending on their design.

» **E-fuels could contribute marginally to stock decarbonization (190,000 tonnes of TTW GHG emissions), but high costs limit their feasibility.** We estimate that 235,000 tonnes of well-to-wheel CO_2e greenhouse gases emissions and 190,000 tonnes of tank-to-wheel greenhouse gases could be avoided from the German passenger car stock in 2030 with the use of e-fuels. However, this assumes that all produced e-diesel only goes to the passenger car stock and not to the difficult-to-decarbonize maritime and aviation sectors. Additionally, the costs of e-fuels in Germany in 2030 are projected to remain high, at €2.2 per liter in 2021 prices, roughly 3 times the spot price of gasoline in Germany in 2021 of €0.7 per liter. This puts the cost of e-fuel production in 2030 at €910 per tonne of TTW CO_2e avoided—4 times the social cost of GHG emissions estimated by the German Federal Environment Agency (€225 per tonne of CO_2e). Importing e-fuels from other regions would also likely be cost prohibitive.

» **Avoid-and-shift measures can contribute to the success of a vehicle scrappage program while simultaneously lowering road transport emissions.** Implementing avoid-and-shift policies can enhance the likelihood that consumers will choose to participate in a tailored vehicle scrappage program while also aiding in the reduction of emissions from the existing vehicle stock. Measures such as investing in public transportation, implementing speed limits, and increasing user costs for passenger cars all play a role in reducing emissions from the current vehicle stock. Additionally, these policies offer supplementary advantages, such as improved public health through increased physical activity and decreased exposure to air pollution.

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