

The role of the European Union's vehicle CO₂ standards in achieving the European Green Deal

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BACKGROUND

In December 2019, the European Commission put forth the European Green Deal, a sustainable growth strategy that aims to transform the economy of the European Union (EU) while tackling climate change and other environmental challenges.¹ As part of this strategy, in March 2020, the Commission proposed a European Climate Law that would create a legally binding target of climate neutrality by 2050.² To achieve this 2050 target, the Commission proposed strengthening the current 2030 greenhouse gas reduction target from at least 40% to at least 55% compared to 1990 levels. This target was endorsed by the European Council in December 2020;³ the European Parliament has yet to debate this target but had previously called for a more ambitious target of at least 60%.⁴

The transport sector is presently responsible for one-third of total CO₂ emissions and one-quarter of total greenhouse gas emissions in the EU, excluding indirect emissions from fuel production and vehicle manufacturing. The Green Deal targets a 90% reduction in transport emissions by 2050. Figure 1 shows this target in the

- 1 European Commission, "The European Green Deal," Communications from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, (December 11, 2019), https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF.
- 2 European Commission, "Proposal for a Regulation of the European Parliament and of the Council Establishing the Framework for Achieving Climate Neutrality and Amending Regulation (EU) 2018/1999 (European Climate Law)" (March 4, 2020), https://ec.europa.eu/info/sites/info/files/commission-proposal-regulation-european-climate-law-march-2020_en.pdf.
- 3 European Commission, "Amended Proposal for a Regulation of the European Parliament and of the Council on Establishing the Framework for Achieving Climate Neutrality and Amending Regulation (EU) 2018/1999 (European Climate Law)" (September 17, 2020), <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020PC0563&from=EN>; European Council, "European Council Meeting (10 and 11 December 2020)—Conclusions," (December 11, 2020), <https://www.consilium.europa.eu/media/47296/1011-12-20-euco-conclusions-en.pdf>.
- 4 "EU Climate Law: MEPs Want to Increase 2030 Emissions Reduction Target to 60%," European Parliament, August 10, 2020, <https://www.europarl.europa.eu/news/en/press-room/20201002IPR88431/eu-climate-law-meps-want-to-increase-2030-emissions-reduction-target-to-60>.

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context of the EU's historical direct CO₂ emissions from transport, as well as economy-wide greenhouse gas emissions and emissions reduction targets.⁵ While emissions from other economic sectors have generally decreased over the past few decades, transport sector emissions and their relative share of economy-wide emissions have grown: transport accounted for approximately 17% of the EU's total greenhouse gas emissions in 1990 but approximately 29% in 2018. Even under an ambitious transport decarbonization strategy, transport sector emissions are likely to account for an increasing share of the EU's total greenhouse gas emissions and remain a key challenge to achieving the EU's proposed climate targets.

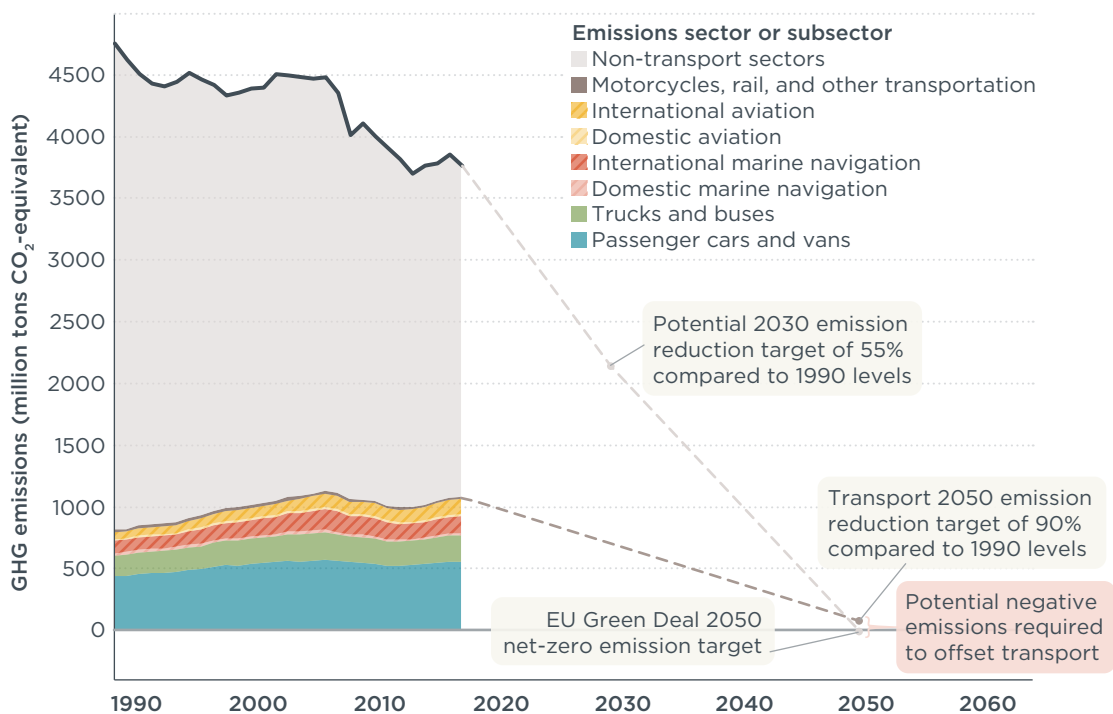


Figure 1. Historical (1990-2018) greenhouse gas emissions in the EU in the context of economy-wide 2030 and 2050 emissions reduction targets. Total greenhouse gas emissions include emissions from international transport as well as from land use, land-use change, and forestry. Emissions from international transport are hashed, as they include both intra- and extra-EU activity; we only consider intra-EU activity to fall under the scope of EU Green Deal targets. The lines that connect 2018 to 2030 and 2030 to 2050 are illustrative only and are not reflective of official targets or pathways.

Light- and heavy-duty vehicles accounted for 71% of EU transport sector CO₂ emissions in 2018. As part of the Green Deal, the Commission will review and propose revisions to the post-2021 CO₂ standards for light-duty vehicles (LDVs), including passenger cars and vans, by June 2021. These standards currently set fleet-average type-approval targets for tailpipe CO₂ emissions and sales benchmarks for zero- and low-emission vehicles (ZLEVs). A similar review of the CO₂ standards for heavy-duty vehicles (HDVs) is planned for 2022. In combination with other policies, these revisions are expected to set the EU on a clear path towards zero-emission road transport.

This briefing paper identifies several possible levels of stringency for the post-2021 CO₂ standards for LDVs and HDVs, considering the potential for improvements in internal combustion engine (ICE) technology and international examples of ambitious zero-emission vehicle (ZEV) regulations for LDVs and HDVs. We then quantify the impacts

⁵ CO₂ emissions have historically represented 98-99% of CO₂-equivalent transport sector greenhouse gas emissions in the EU and in this briefing paper we generally consider transport sector CO₂ emissions in the context of greenhouse gas targets; European Environment Agency, "EU Greenhouse Gas Inventory," (2020), https://www.eea.europa.eu/ds_resolveuid/33063c1e0e9241fb9c4fcd44ed99f55.

of these stringency choices on in-use LDV and HDV CO₂ emissions in the EU from 2020 to 2050. Finally, we compare these emissions pathways to the EU's climate and transport decarbonization goals.⁶

SCENARIO OVERVIEW

We evaluate tailpipe CO₂ emissions from LDVs and HDVs in the EU from 2020 to 2050 under four emissions reduction policy scenarios using the ICCT's Roadmap model.⁷ These scenarios include currently adopted policies and three new policy scenarios: lower ambition, moderate ambition, and higher ambition. For LDVs, we separately model passenger cars and vans; for HDVs, we model three vehicle types: medium-duty trucks, heavy-duty truck, and buses.

The adopted policies scenario considers the projected effects of the EU's current 2025 and 2030 CO₂ standards for passenger cars, vans, and regulated HDVs.⁸ For vans, we assume current ZLEV benchmarks would be met on average. For passenger cars and regulated HDVs, we assume current ZLEV benchmarks would be exceeded only so far as to achieve the maximum possible relaxation of fleet-average type-approval targets. We assume ICE efficiency would improve in alignment with these relaxed 2025 and 2030 fleet-average type-approval targets and remain constant through 2050. We assume 0% ZLEV sales shares for unregulated HDVs, excluding urban buses, which we assume would achieve the minimum ZEV sales shares set out in the Clean Vehicles Directive.⁹ We assume ICE efficiency for unregulated vehicles would improve by 0.5% per year through 2050.

The three new policy scenarios consider several options for increasing the stringency of 2025 and 2030 CO₂ standards and developing post-2030 targets that further reduce CO₂ emissions from LDVs and HDVs. For passenger cars, the new policy scenarios would strengthen both the 2025 and 2030 type-approval targets, as shown in Figure 2, which would drive both ZEV uptake and improvements in ICE efficiency. Without stronger targets, anticipated ZEV uptake would otherwise weaken the effective stringency of current targets for ICE vehicles. For vans, only the moderate and higher ambition scenarios would strengthen 2025 type-approval targets, but all new policy scenarios would increase the stringency of 2030 type-approval targets. Shown in Table 1, LDVs in each new policy scenario would achieve reductions in Worldwide Harmonized Light Vehicles Test Procedure fleet-average type-approval targets by improving ICE efficiency and increasing ZLEV uptake to 100% ZEV sales in 2030 (higher ambition), 2035 (moderate ambition), or 2040 (lower ambition).

⁶ A list of frequently-used acronyms can be found in the Appendix.

⁷ Roadmap model (technical documentation, in press).

⁸ Current CO₂ standards only regulate large trucks, which account for approximately two-thirds of CO₂ emissions from heavy-duty vehicles.

⁹ European Commission, Mobility and Transport, "Clean Vehicles Directive," October 30, 2019, https://ec.europa.eu/transport/themes/urban/clean-vehicles-directive_en.

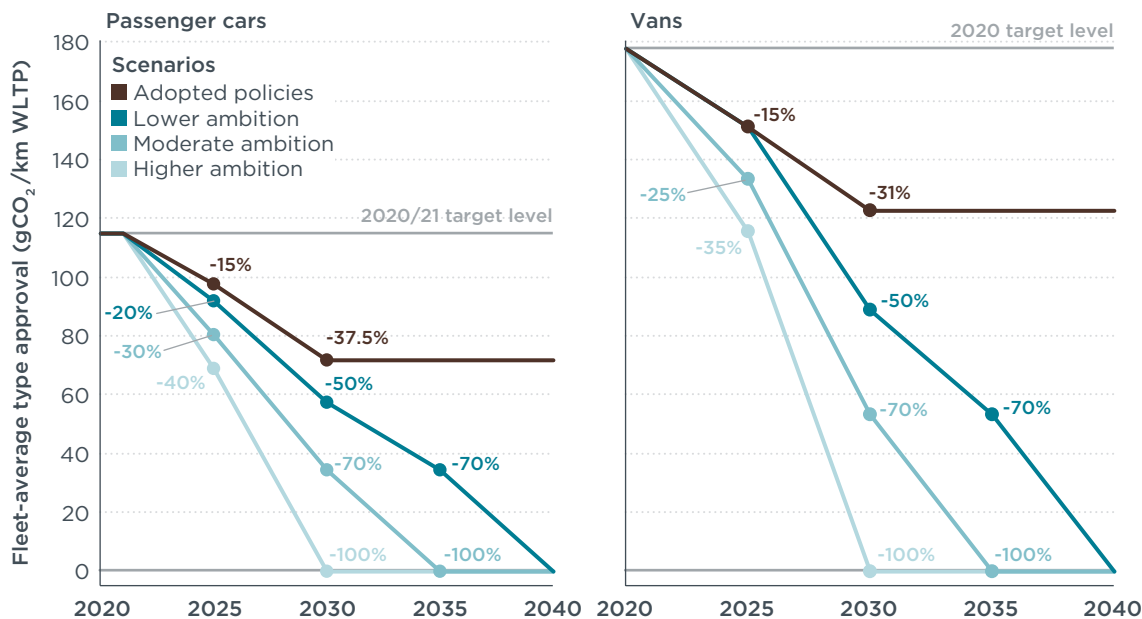


Figure 2. Fleet-average World Harmonized Light Vehicles Test Procedure (WLTP) type-approval targets for passenger cars and vans modeled under each policy scenario, shown in 5-year increments. Labels show percent reductions relative to 2020/21 targets.

Table 1. Overview of new policy scenarios for LDVs and HDVs in the EU.

Scenario	Passenger cars and vans		Trucks and buses	
	100% ZEV sales target	Annual ICE efficiency improvement ^a	100% ZEV sales target	Annual ICE efficiency improvement (post-2025)
Lower ambition	2040	Cars: 0.9% to 2025, then 2.3% to 2035 Vans: 0.4% to 2025, then 2.0% to 2035	2050	Medium-duty trucks and buses: 2.9% to 2040 Heavy-duty trucks: 1.9% to 2040
Moderate ambition	2035	Cars: 4.3% to 2025, then 1.0% to 2030 Vans: 2.9% to 2025, then 0.6% to 2030	2045	Medium-duty trucks and buses: 4.3% to 2035 Heavy-duty trucks: 3.7% to 2035
Higher ambition	2030	Cars: 5.7% to 2025 Vans: 1.2% to 2025	2040	Medium-duty trucks and buses: 8.4% to 2030 Heavy-duty trucks: 7.2% to 2030

^a For LDVs, ICE efficiency improvements are shown in reference to the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) test cycle. The gap between WLTP and real-world tailpipe CO₂ emissions is accounted for separately.

For HDVs, all new policy scenarios align with the adopted policies scenario through 2025. Starting in 2026, ZEV sales shares would increase to reach 100% in a specified year, lagging LDVs by 10 years in each new-policy scenario. We assume ICE efficiency improvements such that HDVs would achieve the full technical potential by 2030 (higher ambition), 2035 (moderate ambition) or 2040 (lower ambition). The resulting rates of ICE efficiency improvement per year, when coupled with a 100% ZEV sales target, represent some of the largest possible CO₂ emissions reductions from HDVs.

In each scenario, we account for factors such as the market share and energy efficiency of ZEVs and plug-in hybrid electric vehicles (PHEVs), the effects of ZLEV super-credits and benchmarks, and the evolving gap between type approval and real-world CO₂ emissions performance. We consider ZEV uptake to be the primary mode of CO₂ emissions reductions, with additional reductions achieved from ICE efficiency improvement. Another strategy to reduce emissions could be to produce synthetic fuels, or electrofuels,¹⁰ using renewable electricity. However, because of their high cost and relatively limited potential to meet road transport demand, we do not consider the deployment of electrofuels in our policy scenarios.

¹⁰ As referenced here, electrofuels do not include hydrogen produced via renewable electrolysis.

A detailed description of our modeling approach, the underlying assumptions for each policy scenario, and an electrofuels cost analysis can be found in the Appendix.

RESULTS

Tailpipe CO₂ emissions projections for LDVs and HDVs in the EU are shown in Figure 3. Under the adopted policies scenario, reductions in LDV CO₂ emissions are driven by current ZLEV benchmarks through 2030; continued fleet turnover further decreases emissions out to 2050. Passenger cars are responsible for the majority of LDV CO₂ emissions, accounting for 80% in 2020 but gradually falling to 73% as vans account for an increasing share of the LDV stock. With increasing freight activity and low ZEV uptake, HDV CO₂ emissions remain relatively flat in the adopted policies scenario, decreasing only 19% by 2050 relative to 2020.

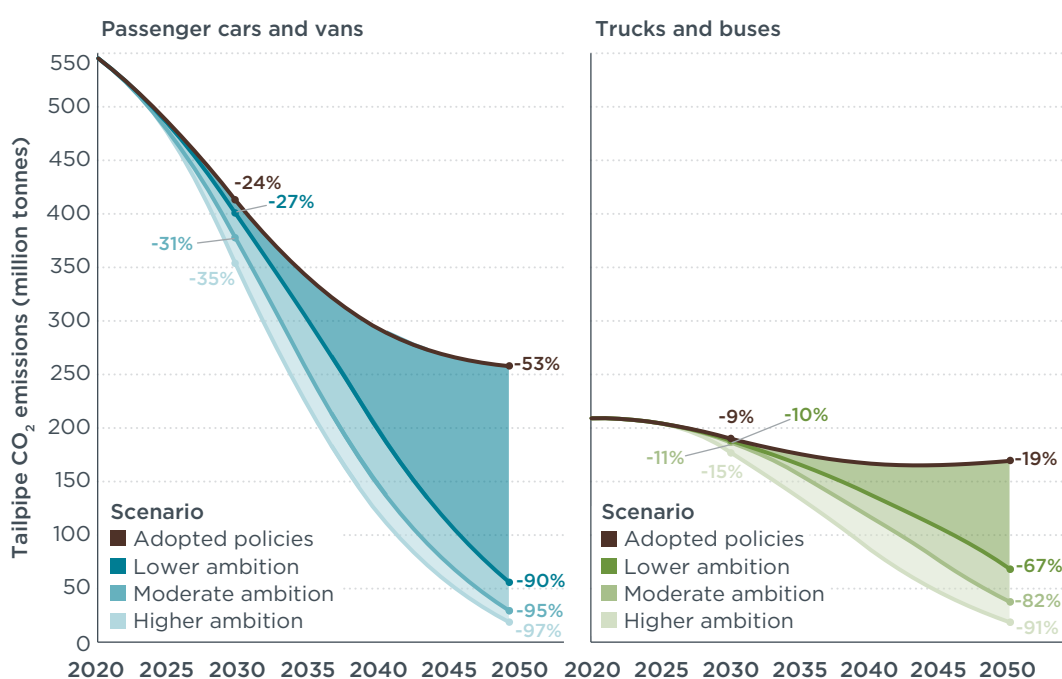


Figure 3. Light- and heavy-duty vehicle tailpipe CO₂ emissions under each policy scenario. Data labels show percent reductions in annual CO₂ emissions in each policy scenario in 2030 and 2050 relative to 2020.

In the lower ambition scenario, LDV and HDV tailpipe CO₂ emissions are nearly the same as in the adopted policies scenario through 2030, after which ZLEV sales shares and fleet-average type-approval targets outpace currently adopted policies. In the moderate and higher ambition scenarios, which considerably strengthen 2025 CO₂ standards, emissions reductions begin earlier and are more substantial. While LDVs in the lower ambition scenario would only save 12 million tonnes (Mt) of CO₂ in 2030 compared to the adopted policies scenario, LDVs in the higher ambition scenario would save 59 Mt CO₂, or 4.8 times as much (Figure 4). This difference in emission savings decreases to 3.1 times in 2035 as a result of increasing ZEV uptake in the lower ambition scenario. For HDVs, emission savings in the higher ambition scenario are 7.1 and 4.2 times greater in 2030 and 2035, respectively, compared to the lower ambition scenario. Cumulatively, emission savings over the entire period from 2021 to 2030 would be 5.1 times greater for LDVs and 6.9 times greater for HDVs in the higher ambition scenario than in the lower ambition scenario (Table 2).

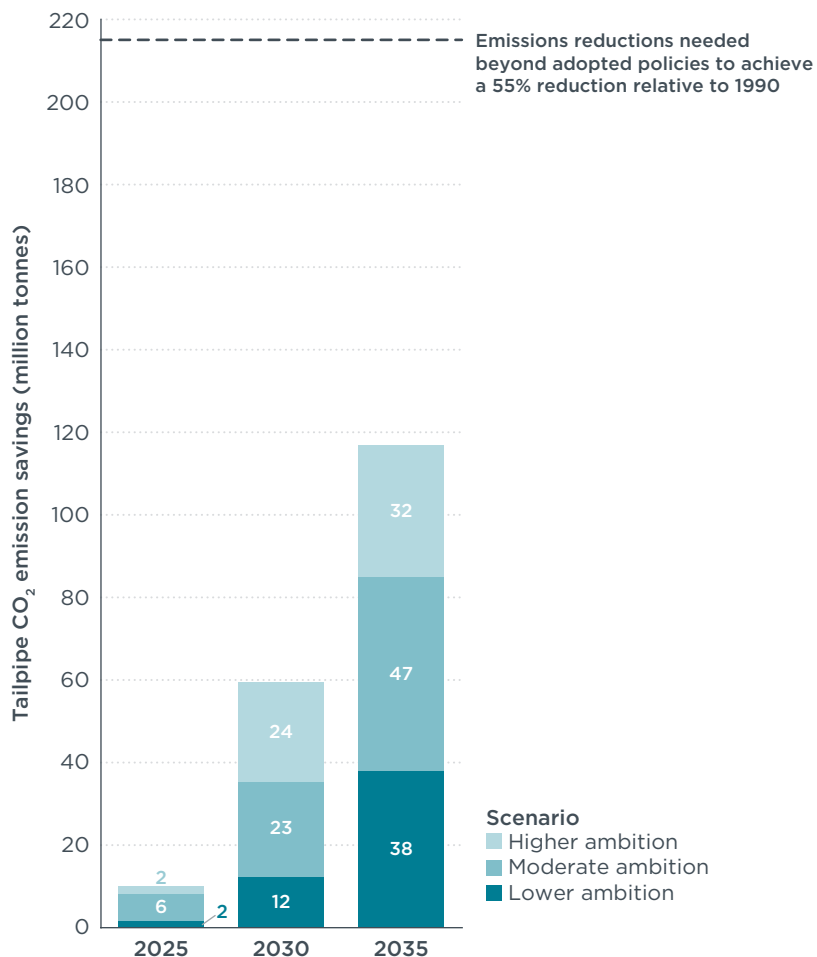


Figure 4. Light-duty tailpipe CO₂ emission savings under new policy scenarios relative to the adopted policies scenario in 2025, 2030, and 2035. Data labels show incremental CO₂ savings for each additional level of ambition. The dashed line represents additional emissions reductions needed beyond the adopted policies scenario, which already achieves emissions reductions of 27 Mt CO₂ in 2030, to achieve a 55% reduction relative to 1990.

By 2050, all three new policy scenarios would achieve substantial reductions in LDV tailpipe CO₂ emissions, but this progress relies on implementation and enforcement of the respective policies, including a 100% ZEV sales benchmark by or before 2040. Later 100% ZEV sales targets for HDVs result in a much wider range of emissions reductions in 2050. Cumulatively from 2021 to 2050, LDVs and HDVs in the higher ambition scenario would avoid emitting 1.7 and 2.2 times as much tailpipe CO₂ as in the lower ambition scenario, respectively (Table 2). Results for 2030 and 2050 are similar for well-to-wheel emissions, for which cumulative CO₂-equivalent emissions from LDVs and HDVs are 26%-27% higher than tailpipe emissions (see Appendix).

Table 2. Cumulative tailpipe CO₂ emissions savings from 2021 to 2030 and 2021 to 2050 under new policy scenarios relative to the adopted policies scenario.

Scenario	Cumulative CO ₂ emissions savings, Mt CO ₂			
	Passenger cars and vans		Trucks and buses	
	2030	2050	2030	2050
Lower ambition	40	2,040	4	790
Moderate ambition	130	2,970	8	1,200
Higher ambition	200	3,520	30	1,720

2030 ECONOMY-WIDE GREENHOUSE GAS REDUCTION TARGET

The EU is in the process of revising its 2030 economy-wide greenhouse gas emissions reduction target from at least 40% to at least 55% compared to 1990 levels. In 1990, LDVs and HDVs in the EU emitted approximately 600 Mt CO₂, with 440 Mt CO₂ from LDVs and 160 Mt CO₂ from HDVs.¹¹ Figure 5 shows the projected tailpipe CO₂ emissions from LDVs and HDVs combined under each scenario, compared to a 55% reduction from the 1990 emissions level. By 2030, CO₂ emission reductions of only 2%–11% would be achieved under the new policy scenarios, none of which would be sufficient to meet economy-wide reduction targets. Considering LDVs individually, CO₂ emission reductions of about 20% would be achieved under the higher ambition scenario, which is much closer but still falls considerably short of a 55% reduction in this individual subsector.

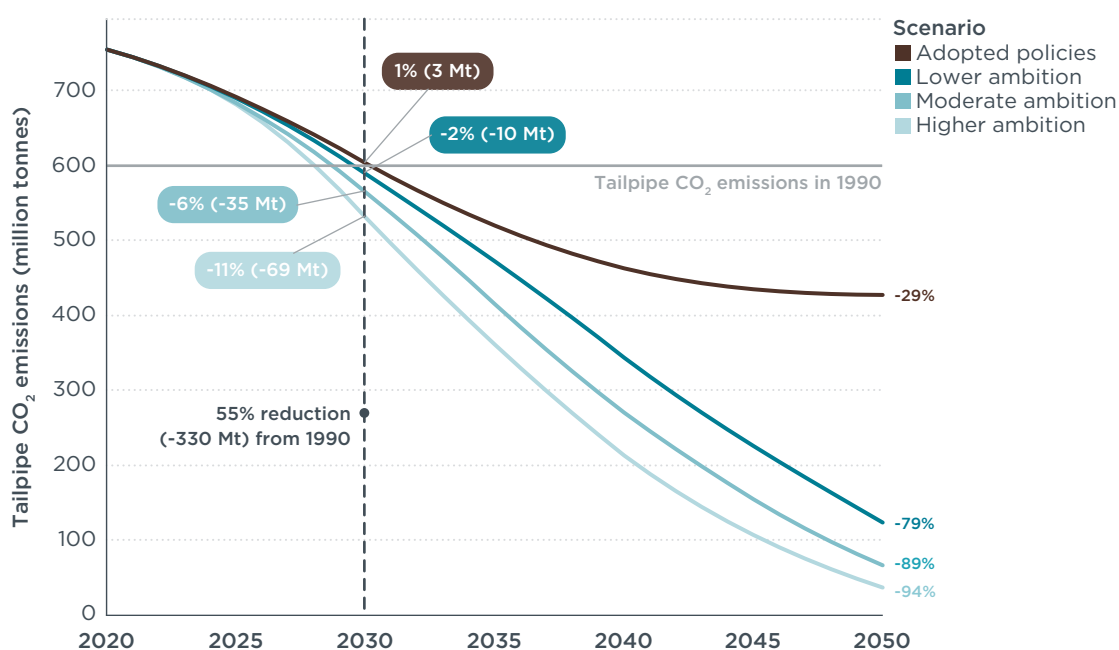


Figure 5. Combined LDV and HDV tailpipe CO₂ emissions under each policy scenario compared to economy-wide emissions reduction targets in 2030. Data labels show percent reductions in CO₂ emissions in each policy scenario for 2030 and 2050 relative to 1990.

Reductions of CO₂ emissions from road transport are expected to be lower than the 2030 economy-wide target when modeled according to abatement cost. To achieve the 2030 target under the most ambitious regulatory scenario for transport in the Commission’s recent impact assessment,¹² cost-efficient emissions reductions from

¹¹ European Environment Agency, “EU Greenhouse Gas Inventory.”

¹² This regulatory-based scenario, “REG”, assumes the most stringent CO₂ emission standards for LDVs and HDVs of all scenarios in the impact assessment, with a 60% reduction in fleet-wide type approval targets for cars.

road transport are only 24.7% in 2030 relative to 2005, which corresponds to a 2.7% reduction relative to 1990 due to the growth of road transport emissions (29% between 1990 and 2005).¹³ However, the underlying technology cost assumptions, particularly for batteries, have not been published and have been overestimated in the past.¹⁴ Further, the van stock shares of PHEVs and battery-electric vehicles are nearly equivalent in all policy scenarios in 2030, despite the higher manufacturing costs and lower CO₂ benefit for PHEVs.

If LDVs and HDVs achieve less than the 2030 economy-wide emissions reduction target of 55%, as projected under all policy scenarios we evaluated and the Commission's impact assessment, other economic sectors would need to reduce their emissions beyond what is already required to reach the 2030 target. For an economy-wide target of 55%, these additional emissions reductions would amount to 261 Mt CO₂-334 Mt CO₂. Adding this difference on top of a 55% reduction from 1990, other economic sectors combined would need to reduce emissions by approximately 1,170 Mt CO₂-equivalent in total from 2018 levels. In the previous decade from 2008 to 2018, emissions reductions from these sectors have only amounted to 560 Mt CO₂-equivalent, roughly half of what would be needed by 2030. Further reductions would also be needed if other transport subsectors similarly achieve less than a 55% emissions reduction.

2050 EU GREEN DEAL TARGETS

The EU Green Deal targets a 90% reduction in emissions from the transport sector by 2050 relative to 1990. To measure the effect of LDV and HDV policy scenarios on meeting this target, we develop simplified projections of tailpipe CO₂ emissions from other transport subsectors that represent an ambitious yet feasible mitigation trajectory (see Appendix). By 2050, the vast majority of residual CO₂ emissions from transport are expected to be from aviation and marine navigation.

In Figure 6, we compare projected total transport sector tailpipe CO₂ emissions in 2050 to the EU Green Deal's 90% greenhouse gas emissions reduction target. Emissions from LDVs and HDVs are shown for each of the new policy scenarios while other subsector emissions projections for 2050 are held constant across scenarios. In the lower ambition scenario, tailpipe emissions from road transport alone would exceed the total transport sector 2050 target. Factoring in residual tailpipe emissions from other transport sectors, even the higher ambition scenario would fail to achieve the targeted 90% reduction in transport sector tailpipe CO₂ emissions by 2050.

13 European Commission, "Commission Staff Working Document Impact Assessment" (September 17, 2020), <https://ec.europa.eu/transparency/regdoc/rep/10102/2020/EN/SWD-2020-176-F1-EN-MAIN-PART-2.PDF>.

14 Thomas Earl, Lucien Mathieu, and Carlos Calvo Ambel, "The Future of Transport in the European Commission's 2050 Strategy: Identifying the Limitations in PRIMES Transport Modelling and Its Implications for Policy Makers, Citizens, and the Climate" (Transport & Environment, August 2018), https://www.transportenvironment.org/sites/te/files/2018_07_2050_model_paper_final.pdf.

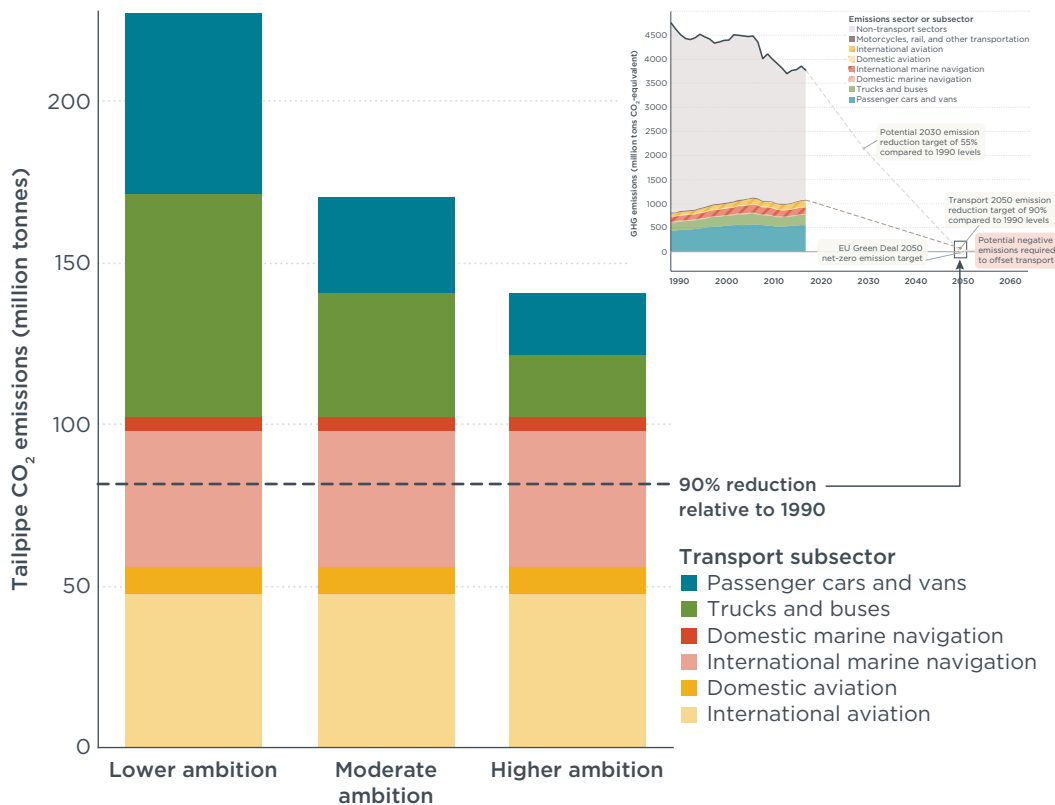


Figure 6. Residual tailpipe CO₂ emissions in 2050 by transport subsector under each new policy scenario compared to a 90% reduction in CO₂ emissions relative to 1990. We assume motorcycle, rail, and other road transportation emissions are net-zero by 2050. Subsector emission trajectories are described in the Appendix.

Underlying these 2050 projections are ambitious emissions reductions from aviation and marine navigation, and near net-zero emissions from rail, motorcycles, and other non-road transport subsectors. We expect that achieving the EU Green Deal target for transport will require similarly ambitious policy actions for each of these subsectors. This analysis does not account for indirect emissions from transport and reducing well-to-wheel emissions by 90% would require complementary energy policies. Even if the 90% emissions reduction target were met across the transport sector, any remaining emissions in 2050 would need to be offset by negative emissions from other sectors in order for the EU to achieve net-zero economy-wide greenhouse gas emissions.

CONCLUSIONS AND RECOMMENDATIONS

This analysis projects LDV and HDV tailpipe CO₂ emissions in the EU under four policy scenarios which reflect varying rates of ZLEV uptake and improvement in the real-world energy efficiency of PHEVs and ICE vehicles. We compared the resulting emissions pathways against current and proposed EU economy-wide greenhouse gas reduction targets for 2030 and 2050, as well as the 2050 target for transport sector emission reductions in the EU Green Deal. Below are several recommendations that can be gleaned from this analysis for the upcoming review of vehicle CO₂ standards in the EU.

LIGHT-DUTY VEHICLE CO₂ STANDARDS

Our analysis yields several implications for the post-2021 CO₂ standards for passenger cars and vans, which will be revised in 2021. For this upcoming revision, we recommend the following:

- » **Set the overall stringency of the 2030 fleet-average type-approval targets for passenger cars and vans as close to 0 gCO₂/km as feasible.** The stringency of

these standards plays a significant role in reducing the 2030 emissions gap and setting the EU on a trajectory to achieve the EU Green Deal target for transport in 2050. As recent ICCT analyses show, battery-electric vehicles can achieve this target and reduce CO₂ emissions more cost-efficiently than PHEV uptake or incremental improvements in ICE efficiency.¹⁵ Several EU and European Economic Area member countries have already signaled the viability of 100% ZEV or ZLEV sales targets in 2030, including Ireland, the Netherlands, Sweden, Iceland, and Norway (2025).

- » **Consider stronger 2025 CO₂ standards and a fleet-average maximum for CO₂ emissions from remaining ICE vehicles.** If ZLEV benchmarks are exceeded by 5 percentage points, current fleet-average type-approval targets would not require improvements in efficiency and, on the contrary, would allow for an increase in ICE emission levels. However, further efficiency improvements can be achieved at relatively low cost. Since a substantial number of ICE vehicles will still be sold before the EU reaches a 100% ZEV sales share, post-2021 standards should aim to maximize readily available improvements in ICE technology and to prevent backsliding of emissions, which has been seen in recent years.¹⁶ An emissions cap on ICE vehicles and more stringent 2025 type-approval targets in line with the higher ambition scenario could substantially shrink the 2030 gap between road transport emissions and the proposed 2030 economy-wide greenhouse gas emissions reduction target.
- » **Closely monitor real-world CO₂ performance and expedite the adjustment of manufacturers' average CO₂ emissions.** The EU is transitioning from the New European Driving Cycle (NEDC) to the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) test cycle. Type-approval targets for 2025 and 2030 will be derived using manufacturer-specific conversion factors based on the ratio of WLTP to NEDC CO₂ emissions in 2020. Close monitoring of this data is important to prevent manufacturers from inflating the WLTP-NEDC ratio, and therefore decreasing the stringency of adopted WLTP targets.¹⁷ To prevent growth in the gap between type-approval and real-world CO₂ emissions, we suggest the Commission expedite the timeline for using real-world fuel and electricity consumption data collected by mandatory on-board devices to monitor real-world CO₂ emissions, devise mechanisms to prevent the gap from growing, and adjust manufacturers' average CO₂ emissions to their real-world performance.
- » **Account for the real-world usage of PHEVs and incentivize CO₂ emissions reductions.** In real-world conditions, PHEVs currently emit two to four times the type-approval CO₂ value, on average. Policies should better account for their real-world usage, including by adjusting the utility factor, a measure of the portion of kilometers driven in charge-depleting mode, assumed in the regulation. If PHEVs are part of a decarbonization strategy for road transport, we recommend that member states incentivize only those PHEV models capable of rapid charging and with limited combustion engine power to increase the share of kilometers driven in charge-depleting mode.

15 Dan Meszler, John German, Peter Mock, and Anup Bandivadekar, *CO₂ Reduction Technologies for the European Car and van Fleet: A 2025-2030 Assessment* (ICCT: Washington, DC, 2016), <https://theicct.org/publications/co2-reduction-technologies-european-car-and-van-fleet-2025-2030-assessment>; Sonsolos Diaz, Peter Mock, and Dan Meszler, *Pathways to de-carbonization: The European passenger car market in the years 2021-2035*, (ICCT: Washington, DC, in press).

16 Uwe Tietge, Peter Mock, and Jan Dornoff, *CO₂ Emissions from New Passenger Cars in Europe: Car Manufacturers' Performance in 2019*, (ICCT: Washington, DC, 2020), <https://theicct.org/publications/co2-new-passenger-cars-europe-aug2020>.

17 Jan Dornoff, Uwe Tietge, and Peter Mock, *On the Way to 'Real-World' CO₂ Values: The European Passenger Car Market in Its First Year after Introducing the WLTP*, (ICCT: Washington, DC, 2020), <https://theicct.org/publications/way-real-world-co2-values-european-passenger-car-market-its-first-year-after>.

- » **Review and publish the underlying assumptions that determine the cost-efficient emissions reduction potential from road transport.** The decarbonization potential of road transport in the Commission's impact assessment modeling has historically been limited by outdated technology cost projections and 5-year time intervals that were not able to capture disruptive changes like ZEV uptake. As the most recent assessment has important implications for determining the stringency of vehicle CO₂ standards needed to meet the 2030 economy-wide emissions reduction target, we recommend reviewing the underlying assumptions such that the proposed vehicle CO₂ standards account for technology and cost uncertainties.

HEAVY-DUTY VEHICLE CO₂ STANDARDS

With respect to the upcoming review of HDV CO₂ standards, our analysis indicates that a level of stringency comparable to the higher ambition scenario is more consistent with achieving the EU Green Deal transport target and the proposed net zero economy-wide greenhouse gas target for 2050. Future analysis will inform more detailed policy recommendations for the 2022 review of the HDV CO₂ standards.

FURTHER RESEARCH

This paper focuses on the role of CO₂ standards in achieving emissions reductions for LDVs and HDVs. We did not explicitly model the potential effects of other transport policies, such as expanding the EU emission trading system to include road transport, revising the Clean Vehicles or Renewable Energy Directives, or implementing CO₂ emissions monitoring and reporting procedures that support consumer access to information about real-world fuel and energy consumption.¹⁸ Additional policies at the EU member state and local levels could influence emissions from road transport, such as ZEV targets, zero-emission zones, accelerated vehicle scrappage,¹⁹ and fiscal policies. Significant deployment of ZEV infrastructure, including charging stations and upstream grid upgrades, will play a major role in supporting ZEV uptake and ensuring its feasibility across the EU. In addition, shifts in passenger and freight movement to less carbon-intensive modes of transport could further reduce emissions from road transport and in the transport sector as a whole.

18 Several other studies investigate these transport policies in detail, including: Jon Stenning, Ha Bui, and Alexandra Pavelka, "Decarbonising European Transport and Heating Fuels - Is the EU ETS the Right Tool?" (European Climate Foundation, June 2020), <https://europeanclimate.org/wp-content/uploads/2020/06/01-07-2020-decarbonising-european-transport-and-heating-fuels-full-report.pdf>; Christof Timpe, Dominik Seebach, Joß Bracker, and Peter Kasten, "Improving the Accounting of Renewable Electricity in Transport within the New EU Renewable Energy Directive" (Institute for Applied Ecology, Öko-Institut e.V, June 16, 2017), <https://www.oeko.de/fileadmin/oekodoc/Improving-accounting-of-renewable-electricity-in-transport.pdf>; Benoit Martin, Julien Pestiaux, Quentin Schobbens, Julie Emmrich, and Markus Hagemann, "A Radical Transformation of Mobility in Europe: Exploring the Decarbonisation of the Transport Sector by 2040: Explorative Scenario and Related Policy Packages" (Climact and NewClimate Institute, September 2020), <https://newclimate.org/2020/09/04/a-radical-transformation-of-mobility-in-europe/>; Jan Dornoff, *One Goal, Multiple Pathways: A Review of Approaches for Transferring on-Board Fuel Consumption Meter Data to the European Commission*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/transferring_obfcm_fuel_data_ec.

19 Georg Bieker and Peter Mock, *Green Vehicle Replacement Programs as a Response to the COVID-19 Crisis: Lessons Learned from Past Programs and Guidelines for the Future*, (ICCT: Washington, DC, 2020), <https://theicct.org/publications/vehicle-replacement-programs-covid-19-may2020>.

APPENDIX

GLOSSARY OF ACRONYMS

BEV	Battery electric vehicle
CO ₂ e	Carbon dioxide equivalent
HDT	Heavy-duty truck
HDV	Heavy-duty vehicle
ICE	Internal combustion engine
LDV	Light-duty vehicle
MDT	Medium-duty truck
NEDC	New European Driving Cycle
PHEV	Plug-in hybrid electric vehicle
WLTP	Worldwide Harmonized Light Vehicles Test Procedure
ZEV	Zero-emission vehicle
ZLEV	Zero- and low-emission vehicle

DETAILED SCENARIOS AND MODELING APPROACH

Roadmap model

We use the ICCT's Roadmap model to evaluate the impacts of each policy scenario on EU LDV and HDV tailpipe CO₂ emissions annually from 2020 to 2050. For LDVs, we model passenger cars and vans separately. For HDVs, we model three vehicle types: medium-duty trucks (MDTs), heavy-duty truck (HDTs), and buses. MDTs correspond to category N2 and N3 vehicles with a Gross Vehicle Weight Rating (GVWR) less than 15 tonnes; HDTs correspond to category N3 vehicles with a GVWR greater than 15 tonnes; buses correspond to category M3 vehicles.

Building on our previous studies,²⁰ we expanded the Roadmap model to cover all EU-27 countries individually using data from the ICCT Pocketbook for new LDV registrations and the European Automobile Manufacturers Association (ACEA) for new HDV registrations.²¹ ACEA data was also used to characterize the historical stock of vehicles for both categories.²² Eurostat data on new vehicle registrations and stock were used for validation purposes, and for characterizing the registrations and stock for Bulgaria.²³

Historical data from the International Energy Agency was used to set average annual per-vehicle mileages. Vehicle survival curves and relative mileage by vehicle age were derived from TRACCS.²⁴ Survival rates were estimated for each country, vehicle type, and vehicle age by aligning historical data on new vehicle registrations and used

20 Jan Dornoff, Joshua Miller, Peter Mock, and Uwe Tietge, *The European Commission Regulatory Proposal for Post-2020 CO₂ Targets for Cars and Vans*, (ICCT: Washington, DC, 2018), <https://theicct.org/publications/ec-proposal-post-2020-co2-targets-briefing-20180109>; Joshua Miller, *Reducing CO₂ Emissions from Road Transport in the European Union: An Evaluation of Policy Options*, (ICCT: Washington, DC, 2016), <https://theicct.org/publications/reducing-co2-emissions-road-transport-european-union-evaluation-policy-options>; Miller and Jin, *Global Progress toward Soot-Free Diesel Vehicles in 2018*.

21 Peter Mock and Sonsoles Diaz (ed.), *European Vehicle Market Statistics – Pocketbook 2020/21*, (ICCT: Washington, DC, 2020), <http://eupocketbook.org/>; ACEA, "Consolidated Registrations - By Country," (2020), <https://www.acea.be/statistics/tag/category/by-country-registrations>.

22 ACEA, "Report: Vehicles in Use," (2020), <https://www.acea.be/statistics/tag/category/report-vehicles-in-use>.

23 Eurostat Transport Database (accessed November 4, 2020), <https://ec.europa.eu/eurostat/web/transport/data/database>.

24 Giannis Papadimitriou, Leonidas Ntziachristos, Philipp Wüthrich, Benedikt Notter, Mario Keller, Erik Fridell, Hulda Winnes, Linda Styhre, Åke Sjödin "Transport Data Collection Supporting the Quantitative Analysis of Measures Relating to Transport and Climate Change (TRACCS) Final Report Prepared for the Directorate-General for Climate Action," European Commission (2013), https://traccs.emisia.com/server/php/files/Public%20data/TRACCS_Final_Report.zip.

vehicle sales to in-use vehicle stock; these rates were adjusted to preserve realistic rates of annual fleet turnover of between 4% and 10% of stock. Used vehicle flows within the EU were based on historical data from the Ecologic Institute and TRACCS.²⁵

We project new vehicle registrations such that total vehicle activity growth from 2018 to 2050 matches the EU Reference Scenario 2016 for each country and vehicle type.²⁶ Annual stock totals were calculated for 2018–2050 based on new vehicle registrations and survival rates. The EU-wide annual stock growth is shown in Figure A1 for each vehicle type. Average annual vehicle mileages were then calibrated such that model-estimated historical CO₂ emissions align with country-specific European Environment Agency CO₂ data for road transport.²⁷ Vehicle data was not available for Cyprus and Malta and for these countries we use proxy data from Greece and Italy, respectively.

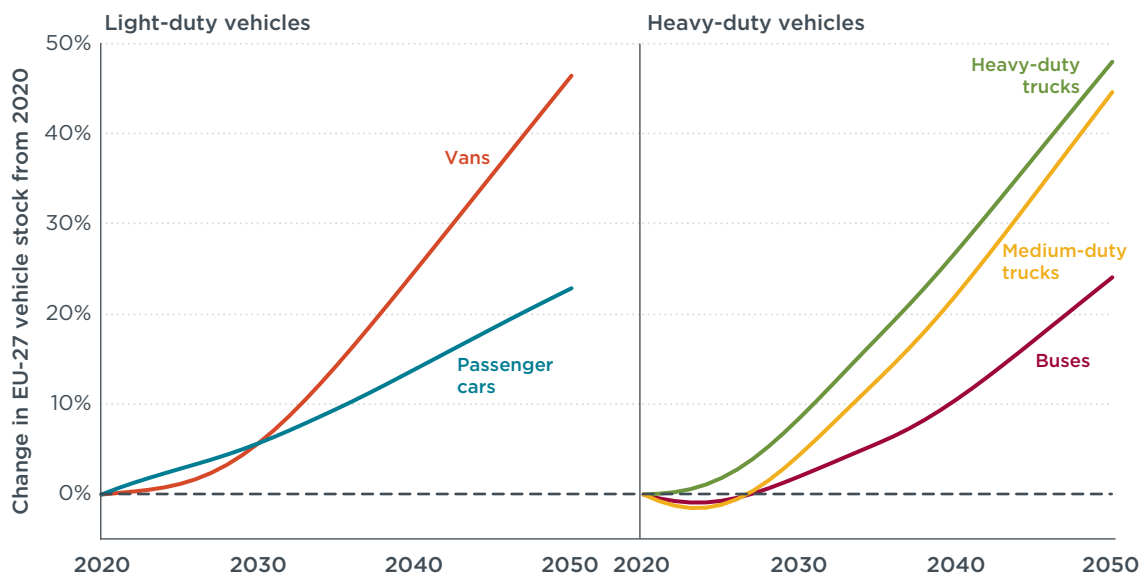


Figure A1. Change in EU-wide vehicle stock for LDVs and HDVs from 2020–2050 relative to 2020.

Adopted policies scenario

Light-duty ZLEV sales shares

In the adopted policies scenario, we assume light-duty weighted²⁸ passenger car ZLEV sales shares increase to reach 20% in 2025 and 40% in 2030 and remain constant through 2050. These sales shares exceed the adopted ZLEV benchmarks by 5 percentage points to achieve the maximum possible relaxation of adopted type approval targets.²⁹ This may be regarded as optimistic; with lenient fleet-average type-approval targets for 2025/30 and the absence of penalties for failing to meet ZLEV benchmarks, there is currently no strong incentive for manufacturers to increase the deployment of ZLEVs in 2022 and beyond. However, combined ZEV and PHEV passenger car sales shares in the EU already reached 11% (unweighted) or 7%

²⁵ Eike Karola Velten, Clemens Brauer, and Jan-Erik Thie, “Used Vehicle Trade and Fleet Composition in Europe,” (Ecologic Institute, 2019) <https://www.ecologic.eu/17575>.

²⁶ Publications Office of the European Union, “EU Reference Scenario 2016 : Energy, Transport and GHG Emissions : Trends to 2050,” (August 16, 2016), <http://op.europa.eu/en/publication-detail/-/publication/aed45f8e-63e3-47fb-9440-a0a14370f243/language-en>.

²⁷ European Environment Agency, “EU Greenhouse Gas Inventory.”

²⁸ Passenger car PHEV sales shares are weighted based on their test cycle CO₂ emissions such that PHEVs with lower emissions count more towards meeting ZLEV benchmarks. For example, the sales shares of passenger car PHEVs with test cycle emissions of 31 g/km would be weighted by a factor of 0.566; test cycle emissions of 45 g/km would be weighted by 0.37. ZEV sales shares are always weighted by a factor of 1.

²⁹ Peter Mock, *CO₂ Emission Standards for Passenger Cars and Light-Commercial Vehicles in the European Union*, (ICCT: Washington, DC, 2019), <https://theicct.org/publications/ldv-co2-stds-eu-2030-update-jan2019>.

(weighted) in 2020,³⁰ signalling an expanding ZLEV market that is likely to outpace the 2025 benchmark. For vans, which currently have limited ZLEV uptake, we assume ZLEV sales shares increase to 15% in 2025 and to 30% in 2030, which meet but do not exceed adopted ZLEV benchmarks.

For passenger cars, we assume ZLEV sales shares are split between battery-electric vehicles (BEV) and PHEVs based on their current relative share of ZLEV sales (~50% BEVs). This reflects the structure of current policies that provide strong incentives not only for BEVs but also for PHEVs. We do not explicitly model PHEV uptake for vans, as current uptake is low and singular development of BEV technology is more cost-efficient. However, projected ZEV and ICE sales shares could be achieved in practice by a combination of ZEVs, PHEVs, and ICE vehicles. The fractions of ZEV, PHEV, and ICE vehicle sales modeled under the adopted policies scenario are shown in Figure A2, summing to 100%, and are compared with the three new policy scenarios.

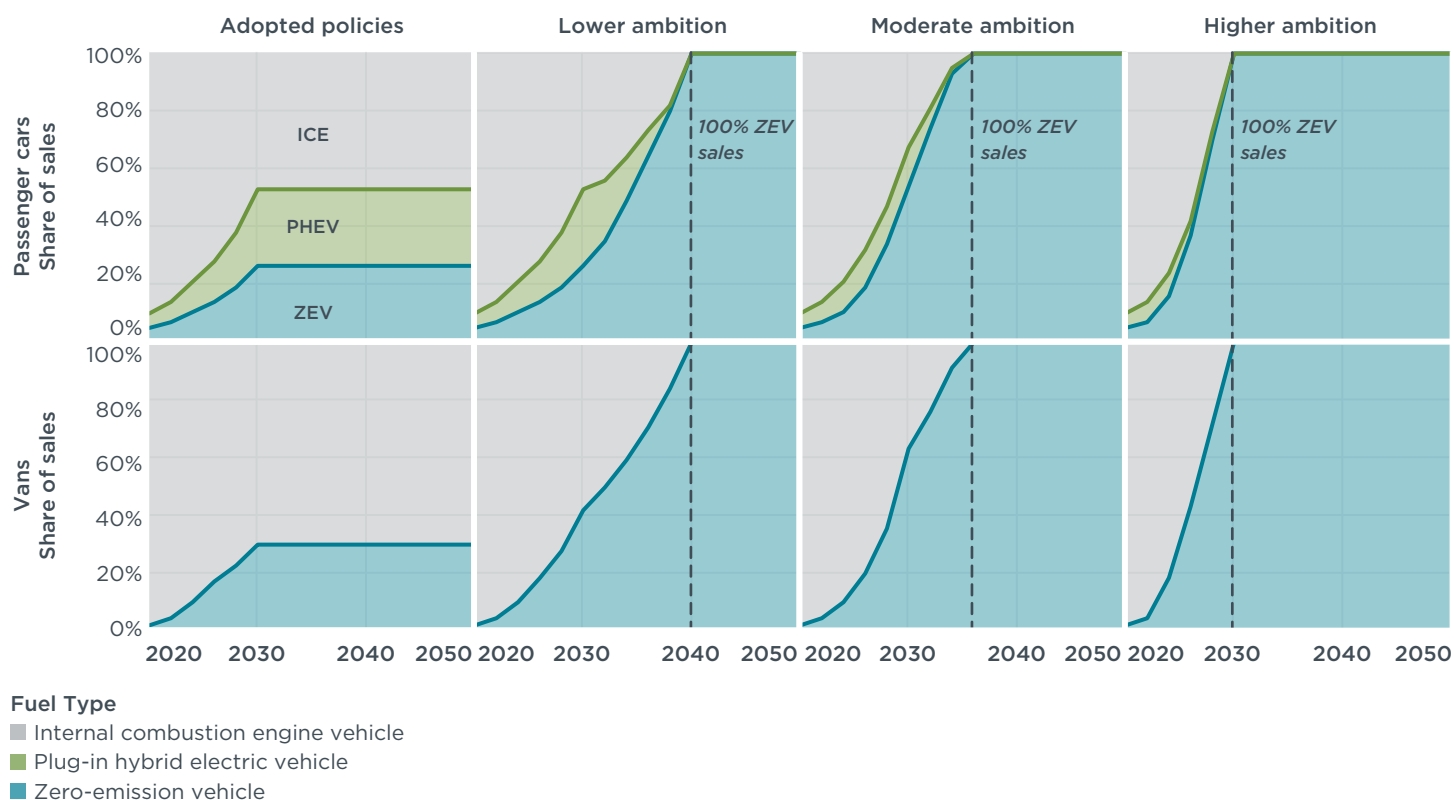


Figure A2. Light-duty vehicle sales shares by technology type under each policy scenario. The market shares of ICE vehicles, PHEVs, and ZEVs sum to 100%.

Light-duty ICE vehicle and PHEV efficiency improvements

We assume light-duty ICE efficiency in the WLTP test cycle improves such that automakers meet adopted fleet-average type-approval targets of 15% in 2025, and 37.5% (passenger cars) and 31% (vans) in 2030, relaxed by 5% for passenger cars based on exceedance of ZLEV sales benchmarks.³¹ In addition to relaxation via benchmarks, projected increases in ZLEV sales shares also weaken the effective stringency of

³⁰ Peter Mock, Uwe Tietge, Sandra Wappelhorst, Georg Bieker, and Jan Dornoff, “Market Monitor: European Passenger Car Registrations, January–November 2020” (ICCT: Washington, DC, 2021), <https://theicct.org/publications/market-monitor-eu-dec2020>.

³¹ Although a small percentage of vans are not regulated by current CO₂ standards, we assume that new passenger cars and vans on average achieve adopted type approval targets; Peter Mock, *EU CO₂ Standard for Passenger Cars and Light-Commercial Vehicles*, (ICCT: Washington, DC, 2014), <http://www.theicct.org/eu-co2-standards-passenger-cars-and-lcvs>; Mock, *CO₂ Emission Standards for Passenger Cars and Light-Commercial Vehicles in the European Union*.

type-approval targets for ICE vehicles in 2025 and 2030 by reducing the contribution of ICE vehicle sales to the fleet-average. For example, projected ZLEV sales shares and current fleet-average type-approval targets for 2030 would only require ICE-equivalent emissions of 140 gCO₂/km WLTP for passenger cars, which is 8% higher than the emissions required under 2020/21 targets given current ZLEV sales shares. Beyond 2030, we assume ICE efficiency remains constant, based on extending the 2030 fleet-average type-approval target without relaxation via ZLEV sales benchmarks. For passenger car PHEVs, we assume present average WLTP emissions of 45 gCO₂/km decrease to 36 gCO₂/km by 2030, which reflects improvements in batteries and electric engines, as well as an increase in the sales-weighted average charge-depleting range. We assume these emissions remain constant through 2050.

Fleet-average type-approval targets, as well as ICE-equivalent and PHEV emissions, from 2020/21 to 2040 under the adopted policies scenario are shown in Table A1 (passenger cars) and Table A2 (vans) and are compared with the three new policy scenarios.

Table A1. Sales shares and type-approval targets for passenger cars under each policy scenario.

Passenger cars						
Metric	Scenario	2021	2025	2030	2035	2040
ZLEV sales share <i>unweighted</i>	Adopted policies	14%	27%	53%		
	Lower ambition			53%	68%	100%
	Moderate ambition			68%	100%	
	Higher ambition			100%		
ZLEV sales share <i>weighted</i>	Adopted policies	10%	20%	40%		
	Lower ambition		20%	42%	64%	100%
	Moderate ambition		21%	63%	100%	
	Higher ambition		29%	100%		
Fleet-average type-approval <i>gCO₂/km WLTP</i>	Adopted policies	115	98	72		
	Lower ambition		93	58	35	0
	Moderate ambition		80	35	0	
	Higher ambition		69	0		
ICE emissions <i>gCO₂/km WLTP</i>	Adopted policies	130	134	140	133	
	Lower ambition		126	112	99	—
	Moderate ambition		109	104	—	
	Higher ambition		103	—		
PHEV emissions <i>gCO₂/km WLTP</i>	Adopted policies	45	38	36		
	Lower ambition			30	24	—
	Moderate ambition		31	23	—	
	Higher ambition			—		

Table A2. Sales shares and type-approval targets for vans under each policy scenario.

Vans						
Metric	Scenario	2020	2025	2030	2035	2040
ZLEV sales share	Adopted policies	2%	15%	30%		
	Lower ambition			42%	65%	100%
	Moderate ambition			63%	100%	
	Higher ambition			29%	100%	
Fleet-average type-approval gCO₂/km WLTP	Adopted policies	178	151	123		
	Lower ambition			89	52	0
	Moderate ambition		133	53	0	
	Higher ambition		116	0		
ICE emissions gCO₂/km WLTP	Adopted policies	182	178	175		
	Lower ambition			161	146	—
	Moderate ambition		157	152	—	
	Higher ambition		171	—		

Note: Weighted and unweighted ZLEV sales shares are equivalent

Light-duty vehicle real-world CO₂ gap

We assume a baseline gap of 15% (ICE vehicles) and 160% (PHEVs) between real-world and WLTP tailpipe CO₂ emissions,³² based on a constant conversion ratio between WLTP and NEDC emissions of 1.21 (ICE vehicles) and 1.0 (PHEVs).³³ In the absence of enforcement of real-world CO₂ reductions, we assume the ratio between real-world and WLTP tailpipe CO₂ emissions for ICE vehicles grows by 1% per year for both passenger cars and vans through 2030.³⁴ We assume this emissions gap stops growing after 2030, when the European Commission is expected to propose a mechanism to adjust manufacturers' average CO₂ emissions to their real-world performance, and the gap remains constant through 2050.³⁵

For PHEVs, we assume the real-world tailpipe-to-WLTP CO₂ emissions gap grows to reach 250% by 2030. This corresponds to a 36% increase in the average charge depleting range,³⁶ which decreases the share of kilometers driven in charge-sustaining mode by 28% in the WLTP cycle but only 11% in real-world conditions, as well as alignment with the growth in the ICE real-world gap when driven in charge-sustaining mode.³⁷ As for ICE vehicles, the gap remains constant after 2030. The evolution of the real-world tailpipe CO₂ gap for ICE vehicles and PHEVs under the adopted policies scenario is shown in Table A3 and is compared with the three new policy scenarios.

32 Dornoff, Tietge, and Mock, *On the Way to 'Real-World' CO₂ Values: The European Passenger Car Market in Its First Year after Introducing the WLTP*; Patrick Plötz, Cornelius Moll, Yaoming Li, Georg Bieker, and Peter Mock, *Real-World Usage of Plug-in Hybrid Electric Vehicles: Fuel Consumption, Electric Driving, and CO₂ Emissions* (ICCT: Washington, DC, 2020), <https://theicct.org/publications/phev-real-world-usage-sept2020>.

33 Stefanos Tsiakmakis, Georgios Fontaras, Claudio Cubito, Jelica Pavlovic, Konstantinos Anagnostopoulos, and Biagio Ciuffo, "From NEDC to WLTP Effect on the Type-Approval CO₂ Emissions of Light-Duty Vehicles [JRC Science for Policy Report]," (Joint Research Centre, 2017), <https://ec.europa.eu/jrc/en/publication/euro-scientific-and-technical-research-reports/nedc-wltp-effect-type-approval-co2-emissions-light-duty-vehicles>.

34 Alex Stewart, Alastair Hope-Morley, Peter Mock, and Uwe Tietge, "Quantifying the impact of real-world driving on total CO₂ emissions from UK cars and vans," (Committee on Climate Change, September 2015), <https://www.theccc.org.uk/publication/impact-of-real-world-driving-emissions/>.

35 Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 Setting CO₂ Emission Performance Standards for New Passenger Cars and for New Light Commercial Vehicles, and Repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (Text with EEA Relevance.), Pub. L. No. 32019R0631, 111 OJ L 13 (2019), <http://data.europa.eu/eli/reg/2019/631/oj/eng>.

36 This translates into a 24% increase in the average real-world utility factor under currently observed charging frequency (less than one full charge in three of four driving days).

37 Plötz, Moll, Li, Bieker, and Mock, *Real-World Usage of Plug-in Hybrid Electric Vehicles: Fuel Consumption, Electric Driving, and CO₂ Emissions*.

Table A3. Real-world CO₂ gap under each policy scenario relative to WLTP test cycle emissions.

Real-world tailpipe-to-WLTP CO ₂ emissions gap							
Metric	Scenario	2020	2025	2027	2030	2035	
ICE vehicles	Adopted policies	15%	21%	23%	26%		
	Lower ambition						
	Moderate ambition			23%			
	Higher ambition			21%			
PHEVs	Adopted policies	160%	210%	220%	250%		
	Lower ambition			250%	220%		
	Moderate ambition			90%			
	Higher ambition			220%	60%		

Heavy-duty ZLEV sales shares

For MDTs and HDTs, we assume heavy-duty ZLEV sales shares increase to reach 1.5% for regulated³⁸ vehicles and 3.5% for unregulated vehicles in 2025 and remain constant through 2050. These sales shares exceed the adopted ZLEV benchmarks to achieve the maximum relaxation of the adopted 2025 CO₂ target for regulated vehicles. We assume the benchmarks are exceeded with the highest allowable sales share of ZLEVs in unregulated vehicles, which tend to have less demanding duty cycles and are more readily electrified. Similar to vans, we model ZLEVs using a ZEV-equivalent sales share that, in practice, could be achieved by a combination of ZEVs, PHEVs, and ICE vehicles. For urban buses, which correspond to 46% of bus sales based on proposed duty cycle allocations,³⁹ we assume ZEV sales shares increase to 30.1% in 2026 and remain constant through 2050. This achieves the minimum ZEV share of the clean vehicle sales target set out by the Commission's Clean Vehicles Directive for 2026-2030.⁴⁰ For coach buses, which correspond to the remaining 54% of bus sales, we assume a 0% ZEV sales share.

Heavy-duty ICE vehicle efficiency improvements

We assume heavy-duty ICE efficiency improves at a constant rate per year such that automakers meet adopted fleet-average CO₂ targets of 15% in 2025 and 30% in 2030 for regulated vehicles, relaxed by 3% based on exceedance of ZLEV sales benchmarks.⁴¹ We assume no further improvement in ICE efficiency for regulated vehicles through 2050. For unregulated vehicles, including buses, we assume ICE efficiency improves by 0.5% per year through 2050.

Lower, moderate, and higher ambition scenarios

Light-duty ZLEV sales shares

In new policy scenarios, we assume ZLEV sales shares align with the adopted policies scenario through 2030 (lower ambition), 2025 (moderate ambition), or 2023 (higher ambition). ZEV sales shares then continue increasing to reach 100% in 2040 (lower ambition), 2035 (moderate ambition), or 2030 (higher ambition). For passenger cars, these ZEV sales shares outpace PHEV sales shares, which gradually decrease to 0%.

38 Current CO₂ standards only regulate large trucks, which account for approximately two-thirds of CO₂ emissions from heavy-duty vehicles.

39 Martin Rexeis and Stefan Hausberger, "Report on Task 1: Analysis of the Potential Scope of an Extended HDV CO₂ Certification," Institute of Internal Combustion Engines and Thermodynamics (2018), <https://graz.pure.elsevier.com/en/publications/report-on-task-1-analysis-of-the-potential-scope-of-an-extended-h>.

40 European Commission, "Clean Vehicles Directive."

41 Felipe Rodríguez, *CO₂ Standards for Heavy-Duty Vehicles in the European Union* (ICCT: Washington, DC, 2019), <https://theicct.org/publications/co2-stds-hdv-eu-20190416>.

Light-duty ICE vehicle and PHEV efficiency improvements

We assume light-duty WLTP ICE efficiency improves such that automakers meet more stringent fleet-average type-approval targets as shown in Figure 2, after accounting for the effects of ZLEV sales shares. In 2030, we assume type-approval targets for both passenger cars and vans are reduced by 50% (lower ambition), 70% (moderate ambition), or 100% (higher ambition) relative to 2020/21 levels. For passenger cars, this corresponds to WLTP ICE efficiency improvements of 14%–23% by 2030 relative to 2021 levels. These ICE-equivalent WLTP emissions targets for passenger cars could be met with a combination of efficiency technologies, including the continued development and application of the Miller combustion process, variable turbine geometry, cooled low-pressure exhaust gas recirculation, improved energy management, and friction reduction, as well as a reduction in road load, improved transmission, and the deployment of off-cycle eco-innovation technologies.⁴² For vans, more stringent type approval targets correspond to WLTP ICE efficiency improvements of 10%–16% by 2030 relative to 2020 levels. We expect similar efficiency technologies could be deployed in vans as in passenger cars.

For passenger car PHEVs in the lower ambition scenario, we assume WLTP emissions follow the adopted policies scenario through 2025 and then decrease to 24 gCO₂/km by 2035 and remain constant until PHEVs are phased out in 2040. This reflects new improvements in charge-sustaining mode efficiency as well as further improvements in batteries and electric engines and a shift towards models with greater charge-depleting range. In the moderate ambition scenario, PHEV emissions decrease more quickly, reaching 23 gCO₂/km WLTP by 2030 and remaining constant until phase-out in 2035. In the higher ambition scenario, PHEV emissions decrease to the same level (36 gCO₂/km WLTP) as in the adopted policies scenario before their phase-out in 2030.

Light-duty vehicle real-world CO₂ gap

For light-duty ICE vehicles, we assume the real-world tailpipe-to-WLTP CO₂ gap in the lower ambition scenario follows the same trajectory as the adopted policies scenario: 1% growth per year in the real-world tailpipe-to-WLTP ratio, with gap growth stopping in 2030. In the moderate and higher ambition scenarios, we assume the gap growth stops earlier, in 2027 and 2025, respectively, and remains constant until ICE vehicles are phased out.

For PHEVs, we assume the real-world tailpipe-to-WLTP CO₂ emissions gap evolves according to the same real-world utility factor curve as in the adopted policies scenario until 2030 (lower ambition), 2027 (moderate ambition), or 2025 (higher ambition). We assume charging frequency increases to one full charge in three of four driving days in the lower ambition scenario after 2030, which slightly decreases the gap post-2030. In the moderate and higher ambition scenarios, we assume that charging frequency increases to one full charge per driving day after 2027 and 2025, respectively.⁴³

Heavy-duty ZLEV sales shares

In all new policy scenarios, we assume HDV ZEV sales shares align with the adopted policies scenario through 2025. Starting in 2026 in the higher ambition scenario, ZEV sales shares for MDTs and HDTs increase to align with California's Advanced Clean

42 Uwe Tietge, Peter Mock, and Jan Dornoff, *Overview and Evaluation of Eco-Innovations in European Passenger Car CO₂ Standards* (ICCT: Washington, DC, 2018), <https://theicct.org/publications/eco-innovations-european-passenger-car-co2-standards>; Uwe Tietge, Peter Mock, and Jan Dornoff, *CO₂ Emissions from New Passenger Cars in Europe: Car Manufacturers' Performance in 2019*, (ICCT: Washington, DC, 2020), <https://theicct.org/publications/co2-new-passenger-cars-europe-aug2020>; Diaz, Mock, and Meszler, *Pathways to decarbonization: The European passenger car market in the years 2021–2035*.

43 Plötz, Moll, Li, Bieker, and Mock, *Real-World Usage of Plug-in Hybrid Electric Vehicles: Fuel Consumption, Electric Driving, and CO₂ Emissions*.

Trucks regulation.⁴⁴ Transit buses ZEV sales shares similarly align with California's Innovative Clean Transit regulation⁴⁵ in 2030, and other buses align with the Advanced Clean Trucks regulation's ZEV sales requirements for Class 4-8 rigid trucks. These California regulations represent some of the most ambitious sales requirements for HDVs to date. Alignment with the Advanced Clean Trucks regulation continues for five years for all vehicle groups except tractor trucks, representing 65% of HDT sales, which align only for two years. ZEV sales shares then increase to reach 100% in 2040. In moderate and lower ambition scenarios, alignment with California's Advanced Clean Trucks and Innovative Clean Transit regulations lags by five and ten years, with ZEV sales shares reaching 100% in 2045 and 2050, respectively.

Heavy-duty ICE vehicle efficiency improvements

As for ZEV sales shares, we assume HDV ICE efficiency pathways align with the adopted policies scenario through 2025 in all new policy scenarios. Starting in 2026, ICE efficiency increases to reach the full technical potential by 2040 (lower ambition), 2035 (moderate ambition), or 2030 (higher ambition).⁴⁶ We assume the remaining technical potential for MDTs is 43% (urban delivery) and 35% (regional delivery) relative to 2015. For HDTs, we assume 35% remaining technical potential, with an additional 12% improvement for tractor trucks. For buses, we assume the remaining technical potential is equivalent to that of MDTs.

ELECTROFUELS COST ANALYSIS

An earlier ICCT study found that, to be cost viable, electrofuels require policy support levels of at least 1.50 euros per liter diesel equivalent (€/L diesel-eq.).⁴⁷ We consider the amount of electrofuels that could be produced economically in 2030 and 2050 under the most favorable conditions presented in that study and at subsidy levels ranging from 1.50 €/L diesel-eq. to 3.00 €/L diesel-eq.⁴⁸ In Table A4, we compare this potential supply of electrofuels to the projected demand for liquid fuel by LDVs and HDVs in each of our policy scenarios. In these scenarios, liquid fuel demand is projected to account for 99% of total fuel demand by ICE vehicles in both 2030 and 2050.

Table A4. Estimated liquid fuel demand of EU road transport by scenario in petajoules (PJ) in 2030 and 2050 and the projected share that could be met by electrofuels. The projected share is shown as a range for subsidy levels of 1.50 €/L diesel-eq. -3.00 €/L diesel-eq., up to 100%.

	Residual road transport liquid fuel demand (PJ)		Potential share of demand met by electrofuels	
	2030	2050	2030	2050
Adopted policies	7,950	5,720	<1%	1%–7%
Lower ambition	7,760	1,660	<1%	2%–25%
Moderate ambition	7,380	900	<1%	5%–47%
Higher ambition	6,810	505	<1%	8%–84%

44 Claire Buysse and Benjamin Sharpe, *California's Advanced Clean Trucks Regulation: Sales Requirements for Zero-Emission Heavy-Duty Trucks*, (ICCT: Washington, DC, 2020), <https://theicct.org/publications/california-hdv-ev-update-jul2020>.

45 California Air Resources Board, "Innovative Clean Transit 2018," accessed June 26, 2020, <https://ww2.arb.ca.gov/rulemaking/2018/innovative-clean-transit-2018>.

46 Oscar Delgado, Felipe Rodríguez, and Rachel Muncrief, *Fuel Efficiency Technology in European Heavy-Duty Vehicles: Baseline and Potential for the 2020–2030 Timeframe*, (ICCT: Washington, DC, 2017), <https://theicct.org/publications/fuel-efficiency-technology-european-heavy-duty-vehicles-baseline-and-potential-2020>; Felipe Rodríguez, *Trailer CO₂ Certification in the European Union*, (ICCT: Washington, DC, 2018), <https://theicct.org/publications/certification-hd-trailers-europe>.

47 Stephanie Searle and Adam Christensen, *Decarbonization Potential of Electrofuels in the European Union*, (ICCT: Washington, D.C., 2018), <https://theicct.org/publications/decarbonization-potential-electrofuels-eu>.

48 This would result in a wholesale fuel price window of 2.39–3.89 €/L diesel-eq. based on adding 1.50–3.00 €/L diesel-eq. subsidies to the projected wholesale price of conventional diesel fuel in Europe in 2050.

We find that, with substantial policy support of 3.00 €/L diesel-eq., electrofuels could not meet even 1% of liquid fuel demand in any of the policy scenarios in 2030, when ICE vehicles are projected to be 72%–87% of the vehicle stock. By 2050, the supply of electrofuels is projected to be an order of magnitude higher than in 2030 but would still only displace a fraction of liquid fuel demand in all policy scenarios, ranging widely from 1%–84% depending on the scenario and subsidy level. The highest levels of displacement occur in the higher ambition scenario, in which ICE vehicles are projected to be only 9% of the vehicle stock, and at the highest subsidy level of 3.00 €/L diesel-eq. At half of this subsidy level, only 8% of liquid fuel demand from the small share of ICE vehicles in this scenario could be met by electrofuels.

While we do not model increasing demand for gaseous fuels (e.g., compressed natural gas) relative to liquid fuels, even the relatively small gaseous fuel demand in 2030 under the adopted policies scenario could not be met by the projected supply of gaseous electrofuels in 2030; this demand could be met with the projected supply of gaseous electrofuels in 2050, but only at the highest 3.00 €/L diesel-eq. subsidy level.

This simple analysis shows that deploying electrofuels in volumes sufficient to meet residual fuel demand by LDVs and HDVs is likely to be very expensive, even with favorable production conditions and a high level of policy support. Additionally, if electrofuels are also used in other transport subsectors, such as aviation, less fuel would be available for LDVs and HDVs. As a result, we do not consider electrofuels to be a viable option for mitigating CO₂ emissions from road transport.

WELL-TO-WHEEL EMISSIONS

Figure A3 shows well-to-wheel CO₂-equivalent (CO₂e) emissions for LDVs and HDVs. We assume the average carbon intensity of EU-27 electricity generation is 235 gCO₂/kWh in 2019 based on International Energy Agency estimates,⁴⁹ which are disaggregated by EU member state based on European Environment Agency data through 2016.⁵⁰ We then apply projected reductions in electricity carbon intensity from the Vision Scenario for the European Union,⁵¹ which are 46% by 2030, 79% by 2040, and 100% by 2050 compared to 2020 levels. We additionally account for losses from transmission, distribution, and charging based on a previous ICCT analysis.⁵² We treat all ZEVs as BEVs.

49 International Energy Agency, “European Union 2020” (2020), <https://www.iea.org/reports/european-union-2020>.

50 CO₂ Intensity of Electricity Generation, (data for 2017, February 28, 2020), <https://www.eea.europa.eu/data-and-maps/data/co2-intensity-of-electricity-generation>.

51 Felix Chr. Matthes, Ruth Blanck, Benjamin Greiner, Dr. Wiebke Zimmer, and Vanessa Cook “The Vision Scenario for the European Union” (Greens/EFA, 2018), <https://www.greens-efa.eu/en/article/document/the-vision-scenario-for-the-european-union-7659/>.

52 Nic Lutsey, *Transition to a Global Zero-Emission Vehicle Fleet: A Collaborative Agenda for Governments*, (ICCT: Washington, DC, 2015), <https://theicct.org/publications/transition-global-zero-emission-vehicle-fleet-collaborative-agenda-governments>.

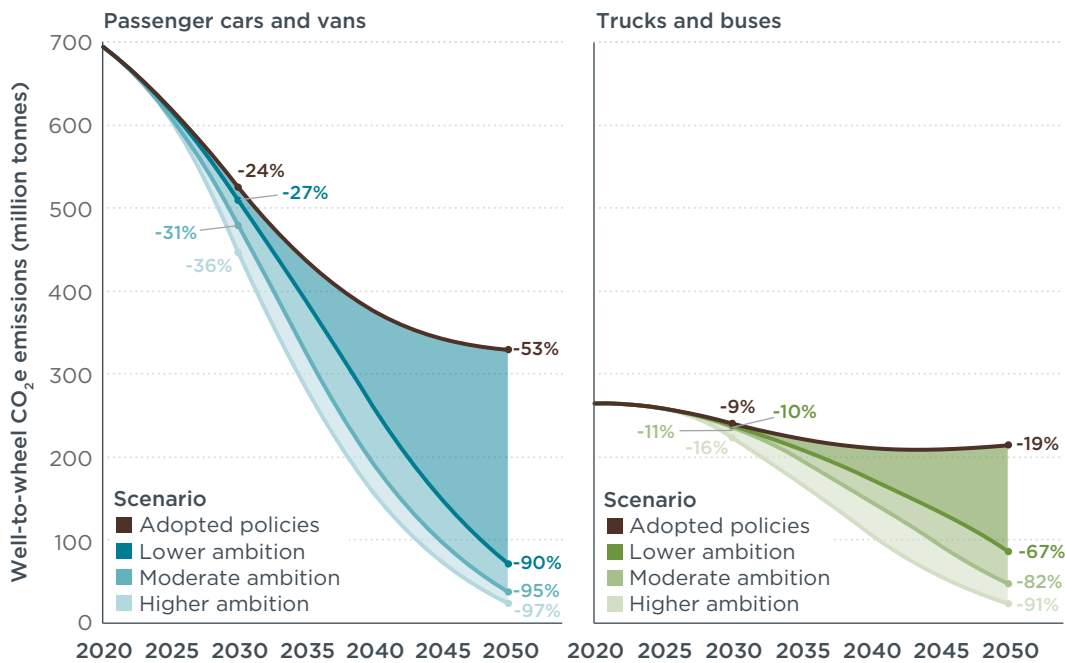


Figure A3. Light- and heavy-duty vehicle well-to-wheel CO₂e emissions under each policy scenario. Data labels show percent reductions in annual CO₂e emissions in each policy scenario in 2030 and 2050 relative to 2020.

TRANSPORT SECTOR DECARBONIZATION ASSUMPTIONS

We assume domestic and international marine navigation emissions will achieve a 75% reduction in emissions by 2050 relative to 2008. The International Maritime Organization set out a 50% reduction target in its initial greenhouse gas strategy, which is due to be revised in 2023 and may target up to 100% emissions reductions. These emissions reductions could be achieved with a combination of short- and long-term measures, including increased operational efficiency, speed reduction, new Energy Efficiency Design Index phases, and a transition to low carbon fuels.⁵³ We assume domestic and international aviation emissions will achieve a 50% reduction in emissions by 2050 relative to 2005, consistent with the target set out by the International Air Transport Association.⁵⁴ These emissions reductions could be achieved with a suite of fuel and operational efficiency measures such as improved air traffic management, electric taxiing, and weight minimization in addition to large-scale deployment of alternative jet fuels.⁵⁵ Despite high-level targets for marine navigation and aviation, achieving such significant emissions reductions will require sustained development and ambitious policy support in each subsector. We assume emissions from other subsectors will reach net zero by 2050. These emissions reductions could be achieved by fully electrifying rail transport by 2050 and phasing out ICE on-road vehicles and associated evaporative emissions. Projected emissions reductions are summarized in Table A5.

⁵³ European Commission, "In-depth Analysis in Support of the Commission Communication, A Clean Planet for All: A European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy" (November 28, 2018), https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf.

⁵⁴ The International Air Transport Association is a member of the Air Transport Action Group, which has adopted the same 2050 target; International Air Transport Association, "Fact Sheet: Climate Change," July 2020, <https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---climate-change/>.

⁵⁵ International Civil Aviation Organization, "2019 Environmental Report: Aviation and the Environment," 2019; Climate Action Network and International Coalition for Sustainable Aviation, "Contribution of the Global Aviation Sector to Achieving Paris Agreement Climate Objectives," (April 4, 2018), https://unfccc.int/sites/default/files/resource/156_CAN%20ICSA%20Aviation%20TD%20submission.pdf.

Table A5. CO₂ emissions in 2050 compared to 2018 by transport subsector.

Subsector	2018	2050	Percent difference in 2050 from 2018
Motorcycles	9.4	0.0	-100%
Rail	4.1	0.0	-100%
Other road transportation	0.1	0.0	-100%
Marine navigation	153.3	46.5	-70%
Aviation	143.0	55.9	-61%

Note: Marine navigation and aviation CO₂ emissions include domestic and international.