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Emissions reduction benefits of a faster, global transition to zero-emission vehicles

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Keywords: CO_2 emissions, light-duty vehicles, heavy-duty vehicles, emerging markets and developing economies (EMDEs)

SUMMARY

Cars, vans, buses, and trucks accounted for 21% of global anthropogenic carbon dioxide (CO_2) emissions in 2020. The governments of the Zero-Emission Vehicles Transition Council (ZEVTC) have committed to accelerating the global transition to zero-emission vehicles (ZEVs) because achieving the deep reductions in vehicle CO_2 emissions needed for climate goals will require policies that support widespread adoption of ZEVs. In this paper, we develop and model the CO_2 emissions impacts of an accelerated global ZEV transition (Ambitious scenario), and then quantify and compare the CO_2 reduction potential of it with both currently adopted policies (Baseline scenario) and recently proposed and announced policies put forth by ZEVTC governments (Progress to Date scenario). We also consider these vehicle CO_2 emission pathways in light of what is likely needed to limit warming to 2 °C and 1.5 °C.

The Baseline scenario projects CO_2 emissions under adopted policies and with anticipated market developments. It assumes that grid decarbonization follows the International Energy Agency (IEA)'s Stated Policies (STEPS) pathway.[1] Under this scenario, we find that well-to-wheel (WTW) CO_2 emissions increase by 32% from 2020 to 2050 because the emissions benefit of ZEV uptake is outpaced by growth in demand for passenger and freight activity. The Progress to Date scenario builds on the Baseline and considers proposals and goals announced by ZEVTC countries since the ZEVTC was launched in November 2020 and up until August 2021. We also considered proposals and goals announced in China, as it is the world's largest vehicle market. As in the Baseline, grid carbon intensity is assumed to follow IEA's STEPS pathway. In the Progress to Date scenario, ZEVTC countries are projected to collectively realize a 42% CO_2 reduction from 2020 to 2050, but an 88% increase in emissions in emerging markets and developing economies over this period leads to a 14% increase globally.

1 "World Energy Model Stated Policies Scenario," International Energy Agency, accessed October 1, 2021, https://www.iea.org/reports/world-energy-model/stated-policies-scenario-steps.

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The Ambitious scenario builds on the Progress to Date for ZEVTC plus China, assuming more rapid progress in leading markets. The resulting economies of scale and learning by doing reduce costs and help commercialize ZEV technologies in other countries with supportive policies. Grid decarbonization is assumed to follow IEA's Sustainable Development Scenario, which is more aggressive than STEPS.[2] The Ambitious scenario results in a considerable decline of vehicle CO_2 emissions in 2050—a 73% reduction compared to 2020. Cumulative CO_2 emissions between 2020 and 2050 are reduced by nearly 100 billion tonnes (Gt) compared to the Baseline and that is equivalent to 3 years of annual energy-related CO_2 emissions or 12 years of vehicles' CO_2 emissions at 2020 levels.[3]

If these vehicles use a share of the remaining global carbon budget proportional to their 2020 emissions, the Ambitious scenario is compatible with a 2 °C pathway. However, considerable work needs to be done to achieve a 67% chance at limiting warming to 1.5 °C. Stringent complementary policies are needed, and combined, these need to reduce vehicle CO_2 emissions by 40% to 60% by 2030 and to near zero by 2050.

Results also show that the three largest vehicle markets—China, the United States, and the European Union—have the greatest mitigation potential, and key regions such as the Association of Southeast Asian Nations (ASEAN), Latin America, the Middle East, and Africa also have considerable mitigation potential. Additionally, because most recent proposals and goals focus on passenger cars and vans, heavy-duty vehicles (HDVs) account for half of the remaining mitigation potential when comparing the Ambitious scenario with Progress to Date. Achieving the full mitigation potential of ZEVs requires a truly global transition and stepping up ambition, especially on HDVs. More ambitious efforts could include accelerating replacement of the existing vehicle fleet with ZEVs, maximizing uptake of efficiency technologies for conventional vehicles and ZEVs, and large-scale avoid and shift policies.

INTRODUCTION

In November 2020, ministers and representatives from several of the world's major vehicle markets established the Zero Emission Vehicles Transition Council (ZEVTC).[4] The members of ZEVTC represent about half of global vehicle sales and 63% of global ZEV sales, and these countries have committed to accelerate a global transition to ZEVs. This transition is crucial for decarbonizing road transport and meeting climate goals.[5] ZEVs—specifically battery-electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs)—are the only technologies that can achieve deep decarbonization of road transport on a life-cycle emissions basis within the time frame of the Paris Agreement.[6]

Since the ZEVTC launched, several members have announced targets for phasing out sales of new combustion engine vehicles and other new policies, including vehicle CO_2 standards, fiscal incentives for ZEVs, charging infrastructure investments, and consumer campaigns, all of which support an accelerated transition away from combustion engine vehicles. Still more developments are expected in the next couple of years.

2 "World Energy Model Sustainable Development Scenario," International Energy Agency, accessed October 1, 2021, https://www.iea.org/reports/world-energy-model/sustainable-development-scenario-sds.

3 "Global Energy Review 2021, CO_2 Emissions," International Energy Agency, accessed October 1, 2021, https://www.iea.org/reports/global-energy-review-2021/co2-emissions.

4 Members of the ZEVTC are the United Kingdom, Canada, Denmark, France, Germany, India, Italy, Japan, Mexico, Netherlands, Norway, Republic of Korea, Spain, Sweden, and the United States. In addition, the European Commission is an observer and California is separately a member.

5 U.K. Climate Change Committee, "The Role of Zero Emissions Vehicles in Global Pathways Meeting the Paris Agreement," (July 2021), https://www.theccc.org.uk/publication/the-role-of-zero-emissions-vehicles-in-global-road-transport-pathways/.

6 Stephanie Searle, Georg Bieker, and Chelsea Baldino, *Decarbonizing road transport by 2050: Zero emission pathways for passenger vehicles*, (ICCT: Washington, D.C., 2021), https://theicct.org/publications/zevtc-decarbonizing-by-2050-jul2021.

In its mission statement, the ZEVTC also stated that it wishes to ensure that the transition to ZEVs "is truly global, leaving no country or region behind."[7] This requires a global understanding of ZEV uptake and vehicle emissions, particularly as emerging markets and developing economies (EMDEs) are expected to see large growth in on-road vehicle sales in the coming decades.

This paper evaluates the state of the ZEV transition globally and has a special focus on ZEVTC members, in order to inform government actions that seek to move the on-road sector toward a pathway compatible with the Paris Agreement. We use ICCT's Roadmap model to combine historical data and policy information and develop projections of ZEV uptake and CO_2 emissions for all countries to 2050 based on currently adopted policies; then we consider the current outlook for further ZEV uptake if ZEVTC members follow through on recently announced proposals and goals that have not yet been formally adopted. We compare these two policy scenarios with a third one, an ambitious pathway for ZEV uptake, and assess the compatibility of each scenario with limiting global warming to 1.5 °C and 2 °C. The paper concludes with a discussion of policy implications.

METHODS

Modeling approach

We projected CO_2 emissions for each scenario using ICCT's Roadmap model 1.8.2.[8] Our scenarios and modeling cover 190 countries. This paper presents results for the ZEVTC members, China, and a variety of other key markets, including EMDEs.

We model the global fleet of cars, vans, buses, medium trucks, and heavy trucks, and have considered greater segment detail in the scenario development for select countries, including all ZEVTC members and China. The emissions modeling includes all major powertrains and fuel types. We estimate well-to-wheel CO_2 emissions from transportation fuels but exclude vehicle and infrastructure manufacturing and end-of-life emissions, as these are addressed in a previous paper.[9] We considered vehicle sales data through 2020 and global vehicle market forecasts to 2023, to account for a potential recovery in vehicle sales from 2020 levels. We calibrated country-specific vehicle stock and mileage data to align model estimates of road transport energy consumption in 2020 with the International Energy Agency's (IEA) world energy balance statistics. Long-term vehicle sales projections from 2023 to 2050 were calibrated based on activity growth projections developed by the U.S. Energy Information Administration (EIA), the European Commission, IEA, and the ICCT's China Model and India Emissions Model.[10] We find that the ZEVTC members accounted for 48% of the global vehicle market in 2020, but are projected to account for only 38% in 2050; meanwhile, the combined market share of EMDEs (excluding those that are ZEVTC members) is projected to grow from 20% in 2020 to 32% in 2050.

Scenario details

We constructed three policy scenarios, and each is described in more detail below:

» **Baseline** scenario reflects global ZEV uptake through 2020 and accounts for the projected CO_2 emissions effects of adopted policies and anticipated market developments affecting ZEV sales till 2050.

7 "Joint statement of the Zero Emission Vehicle Transition Council," news release, November 27, 2020, https://www.gov.uk/government/news/joint-statement-of-the-zero-emission-vehicle-transition-council.

8 "Roadmap Model Documentation," ICCT, accessed October 1, 2021, https://theicct.github.io/roadmap-doc/.

9 Searle, Bieker, and Baldino, *Zero emission pathways for passenger vehicles*.

10 "Roadmap Model Documentation."

» **Progress to Date** scenario builds from the Baseline and additionally considers proposals, consultations, and goals that have been announced by ZEVTC countries since the ZEVTC was launched in November 2020 and up to August 2021. We also considered China's goals and proposals in this scenario because it is the world's largest vehicle market.

» **Ambitious** scenario builds on the Progress to Date scenario for ZEVTC plus China and on the Baseline scenario for EMDEs and other countries. It assumes a faster ZEV transition in ZEVTC countries, China, EMDEs, and other countries and is considered ambitious yet feasible.

Baseline

The Baseline scenario uses historical ZEV sales shares in all countries and projects ZEV uptake based on policies adopted as of August 2021. We consider existing sales requirements for ZEVs and plug-in hybrids, fleet rules, and performance standards for new vehicle CO_2 emissions and efficiency. A detailed analysis of these is in a previously published companion paper.[11] We approximate the effects of fiscal incentives and province- and local-level policies by assuming some business-as-usual ZEV sales growth in all countries to 2050. This assumes no new policies but includes some anticipated market-driven increases in ZEV sales in response to falling ZEV purchase costs and total cost of ownership savings.

The Baseline scenario is not a prediction of the future. Instead, it is a plausible picture of what could happen absent new policies and is a reference for evaluating the benefits of further policy action. As of August 2021, approximately 30 major CO_2 regulations and ZEV rules had been adopted in ZEVTC countries and China and thus we consider these policies in our Baseline scenario. Both the Baseline and Progress to Date scenarios follow the assumptions of IEA's Stated Policies Scenario (STEPS) for calculating well-to-tank (WTT) emissions of the electricity used to power vehicles.[12]

Progress to Date

An additional 30 or so major new ZEV policies and targets were announced by ZEVTC countries and China in the past couple of years but had not yet been finalized and made legally binding as of August 2021. We consider these policies in our Progress to Date scenario.

There are at least 17 additional policies in the pipeline that are expected to be proposed by ZEVTC countries and China within the next 2 years. We did not model these, however, because the details and stringency are still under development. Hence, these expected policies are an opportunity to close the gap between the Progress to Date and Ambitious scenarios. An appendix table summarizes these policies and assumptions, including the ones we did not model.

Ambitious

The Ambitious scenario assumes an accelerated and widespread ZEV transition. It builds on the Progress to Date for ZEVTC plus China by assuming that more rapid progress is made in leading markets, driven by more stringent and comprehensive ZEV policies (see Table 1). The resulting economies of scale reduce costs and help commercialize ZEV technologies in other countries with supportive ZEV uptake policies. Another critical assumption of this scenario is that along with the phase out of sales of new internal

11 Dale Hall et al., *Decarbonizing road transport by 2050: Effective policies to accelerate the transition to zero-emission vehicles*, (ICCT: Washington, D.C., 2021), https://theicct.org/sites/default/files/publications/ZEVTC_EffectivePolicies_dec2021.pdf.

12 "Stated Policies Scenario."

combustion engine vehicles, the electricity grid becomes substantially cleaner, following the assumptions of IEA's Sustainable Development Scenario.[13]

The Ambitious scenario is designed to push the envelope but stay within our judgment of technical feasibility. For this we considered progressive positions put forth by governments, ICCT's own assessment of technically feasible scale up of ZEV production and policy-driven market uptake,[14] and assessments by us and other researchers of how fast the ZEV transition needs to be to align with the Paris Agreement.[15]

The Ambitious scenario assumes all countries follow one of three pathways in Table 1, except in a few cases where government ZEV targets are ahead of these pathways. These pathways are generally consistent with other large-scale global vehicle electrification studies such as BNEF's Electric Vehicle Outlook,[16] the United Nation's Climate Action Pathway,[17] IEA's Net Zero 2050 All Electric Case,[18] and the University of California, Berkeley's 2035 Report.[19]

Table 1. Ambitious scenario assumptions for three groups of countries. Group A – EU countries, Canada, China, Iceland, Norway, United Kingdom, United States (states with ambitious policies); Group B – India, Japan, Mexico, Republic of Korea, United States (states without ambitious policies); Group C – All other countries. Values in 2025 are exponentially interpolated from 2020 sales shares and 2030 targets.

Pathway	Vehicle type	2025	2030	2035	2040	2045
A	Car	30%	75%	100%	100%	100%
	Van	30%	75%	100%	100%	100%
	Bus	33%	90%	100%	100%	100%
	Medium truck	20%	50%	90%	100%	100%
	Heavy truck	6%	40%	75%	100%	100%
B	Car	12%	60%	90%	100%	100%
	Van	6%	60%	90%	100%	100%
	Bus	8%	75%	90%	100%	100%
	Medium truck	4%	40%	75%	100%	100%
	Heavy truck	3%	30%	60%	90%	100%
C	Car	3%	30%	60%	90%	100%
	Van	2%	30%	60%	90%	100%
	Bus	3%	60%	90%	100%	100%
	Medium truck	2%	30%	60%	90%	100%
	Heavy truck	1%	20%	40%	75%	100%

13 Sustainable Development Scenario.

14 Joshua Miller et al., *Decarbonizing road transport by 2050: Accelerating the global transition to zero-emission vehicles*, (ICCT: Washington, D.C., 2021), https://theicct.org/sites/default/files/publications/ZEVTC_Accelerating-transition_dec2021.pdf

15 Claire Buysse et al., *The role of the European Union's vehicle CO_2 standards in achieving the European Green Deal*, (ICCT: Washington, D.C., 2021) https://theicct.org/publications/eu-vehicle-standards-green-deal-mar21.

16 BloombergNEF, *Electric vehicle outlook 2021*, (New York: BNEF, 2021), https://about.bnef.com/electric-vehicle-outlook/.

17 "Climate Action Pathway, Transport Vision and Summary," United Nations, 2021, https://unfccc.int/sites/default/files/resource/Transport_Vision&Summary_2.1.pdf

18 Stéphanie Bouckaert et al., *Net zero by 2050*, (Paris: International Energy Agency, 2021), https://www.iea.org/reports/net-zero-by-2050

19 "2035 The Report – Transportation," University of California, Berkeley's Goldman School of Public Policy, University of California, Berkeley, 2021, https://www.2035report.com/.

RESULTS

ZEV uptake

In 2020, ZEV sales shares were highly heterogenous among regions and vehicle types. Average ZEV sales shares across ZEVTC markets were approximately 3% for cars, 1% for vans, and 12% for buses; meanwhile, the ZEV sales shares in the ROW except China averaged less than 0.5% for cars and only a fraction of a percent for other vehicle types (Table 2).

In 2020, Norway had the highest ZEV sales share for cars and vans and the third-highest sales share for buses. The Netherlands ranked first for buses and had the second-highest sales share for cars. China had the second-highest sales share for buses. Among ZEVTC members, all European countries except Italy had higher ZEV sales shares for cars than the ZEVTC average. For medium trucks, several countries had ZEV sales shares greater than 1%, with Germany and the Netherlands ranking first and second. However, for heavy trucks, no country exceeded a ZEV sales share of 0.5%.

Table 2. ZEV share of total sales in 2020.

Region	Car	Van	Bus	Medium truck	Heavy truck
Canada	2.3%	0.0%	1.7%	0.0%	0.0%
Denmark	7.2%	1.5%	2.3%	0.0%	0.4%
France	6.7%	2.2%	2.6%	1.9%	0.0%
Germany	6.7%	3.2%	5.9%	6.5%	0.1%
India	0.2%	0.0%	0.4%	0.0%	0.0%
Italy	2.4%	1.2%	0.7%	0.1%	0.0%
Japan	0.4%	0.1%	0.1%	0.0%	0.0%
Mexico	0.5%	0.0%	0.0%	0.0%	0.0%
Netherlands	20.5%	2.8%	69.4%	3.4%	0.2%
Norway	54.3%	8.0%	16.5%	0.1%	0.4%
Republic of Korea	1.8%	0.0%	0.0%	0.0%	0.0%
Spain	7.2%	1.5%	1.8%	0.2%	0.0%
Sweden	9.5%	6.1%	9.9%	0.0%	0.3%
United Kingdom	6.6%	1.8%	6.2%	2.8%	0.1%
United States	1.7%	1.0%	0.6%	0.0%	0.0%
ZEVTC average	2.9%	1.1%	11.7%	0.8%	0.0%
EU-27 average	5.3%	2.0%	6.1%	3.5%	0.0%
China	5.0%	2.3%	22.9%	1.3%	0.2%
Rest of world average	0.4%	0.2%	0.0%	0.0%	0.0%
Global average	2.9%	0.9%	3.7%	0.5%	0.0%

Projected ZEV sales shares by scenario

Without further policy action (Baseline scenario), ZEV sales shares among the ZEVTC countries and China are assumed to increase to approximately one-third for cars and vans, half for buses, and less than one-fifth for trucks by 2050 (Figure 1). ZEV sales

shares in the ROW are assumed to lag these trajectories by about a decade, except for buses, which are assumed to reach a ZEV sales share of 40% by 2050. In the Progress to Date scenario, ZEV sales shares increase substantially for cars and vans, as these have been the focus of actions such as the European Commission's proposal to revise its CO_2 standards and ZEV goals in the United States and Canada. In this scenario, ZEVs account for one-half of all cars and vans sold globally in 2050, but more than 80% of global truck sales are still internal combustion engine vehicles.

The Ambitious scenario assumes a significantly more rapid transition to ZEVs in all regions and for all vehicle types. In this scenario, ZEVs account for more than 90% of new car, van, and bus sales in ZEVTC markets by 2035 and more than 90% of car, van, bus, and truck sales globally by 2040. See Appendix Figure A2 for more details.

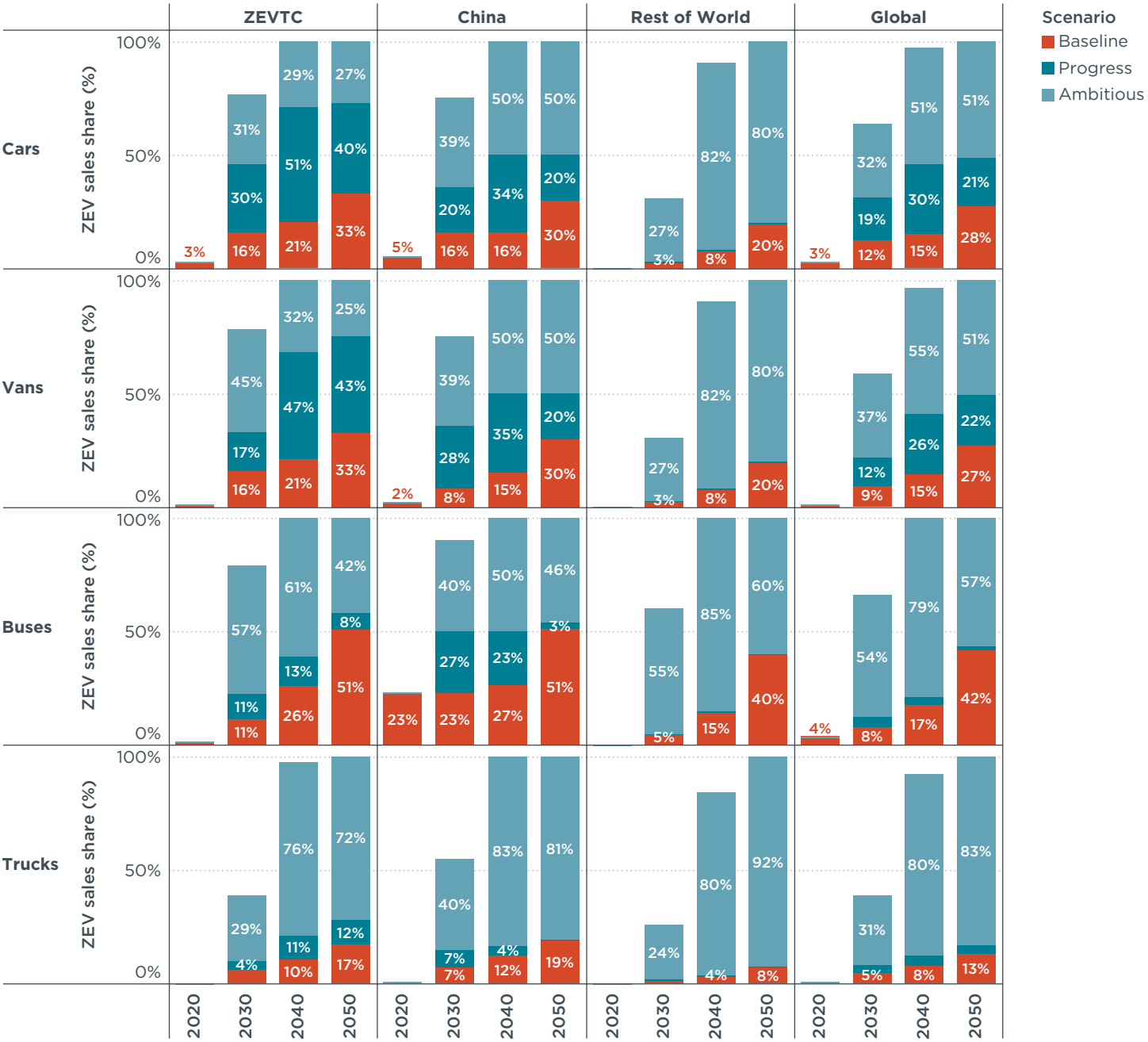

Figure 1. Projected ZEV sales share by scenario, average of ZEVTC countries, China, average of Rest of World, and average global.

Annual CO_2 emission pathways

In the Baseline scenario, growth in vehicle activity is projected to outpace ZEV uptake and lead to net CO_2 emissions growth in China, India, Mexico, and EMDEs (Figure 2). Some ZEVTC markets are projected to achieve reductions in CO_2 emissions due to a combination of slower activity growth and more substantial ZEV uptake and vehicle efficiency improvements. The combined impact of adopted policies leads the ZEVTC as a whole to achieve a net CO_2 emission reduction by 2050, even as some ZEVTC countries see emissions increase from 2020 levels.

The Progress to Date scenario leads to markedly better outcomes for most ZEVTC markets, including the European Union, United States, Canada, Mexico, Norway, and United Kingdom, and to relatively limited gains in India, Japan, and the Republic of Korea. In China and India, there is some progress compared to the Baseline scenario due to the implementation of announced ZEV goals, but these benefits are likely to be outweighed by continued growth in vehicle activity (See Fig A3). The need for more ambition with respect to heavy-duty vehicles is especially evident among ZEVTC markets in the Progress to Date scenario, in which cars and vans account for 88% of projected emission reductions. An important outlier is the United Kingdom, which has launched consultations to end the sale of non-ZEV heavy-duty vehicles by 2040, 5 years after a similar goal for cars and vans.

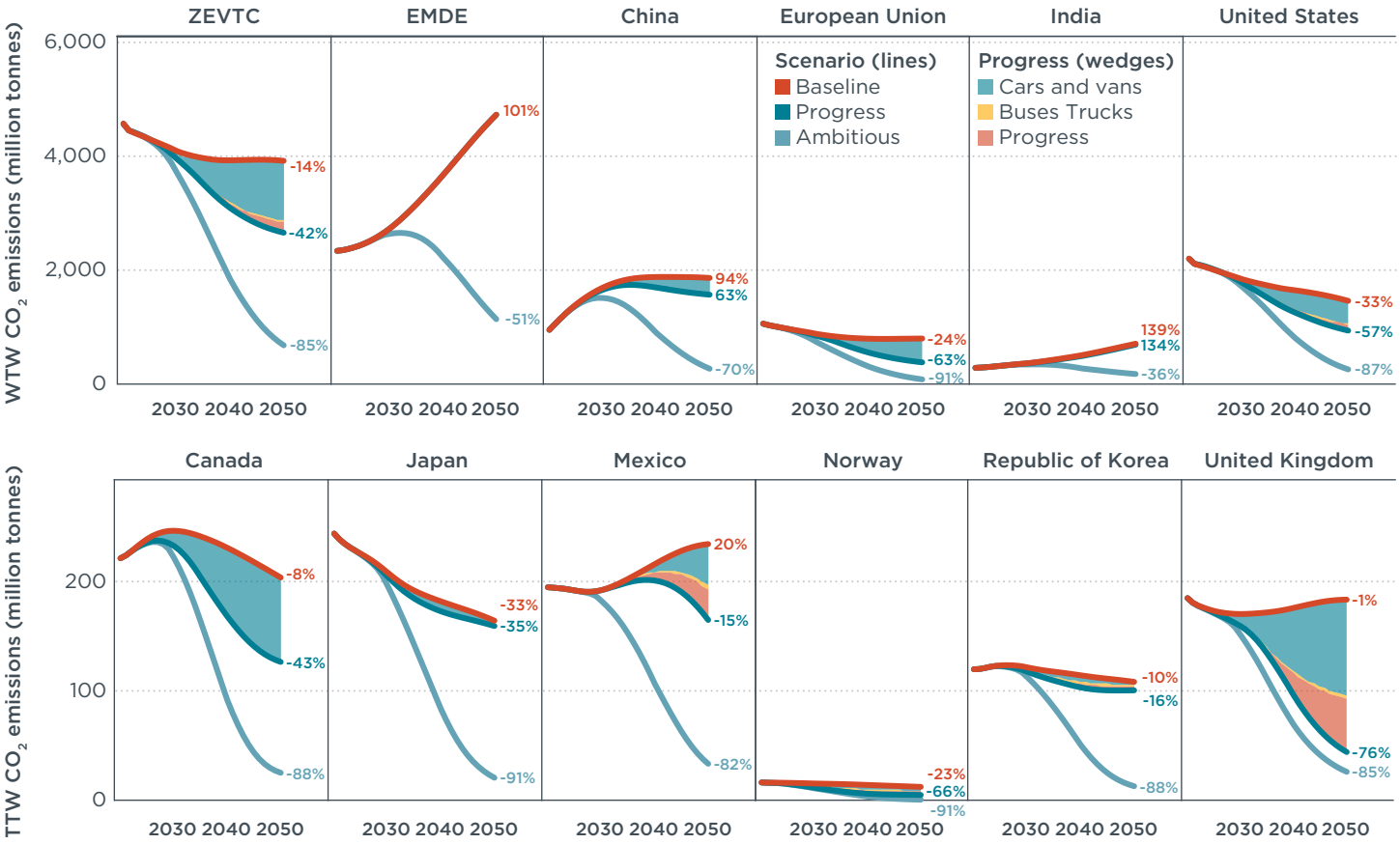

Figure 2. Projected CO_2 emissions by scenario for ZEVTC members, China, and EMDEs.

The Ambitious scenario sees every region make significant improvements compared to 2020, and in most cases, these emission reductions are at least double those in the Progress to Date scenario. Regions with the smallest changes between the Progress to Date and Ambitious scenarios are those with at least several stringent policies already in the pipeline, and these include the European Union, the United States (California

and other MOU states),[20] Norway, and the United Kingdom. For EMDEs, the Ambitious scenario is the inverse of the Baseline scenario: annual vehicle CO_2 emissions in 2050 are about half of what they were in 2020, rather than double.

Cumulative CO_2 emissions and carbon budget

To compare the global vehicle CO_2 emissions trajectories for each policy scenario with pathways compatible with 2 °C and 1.5 °C of warming, as derived from IPCC's carbon budgets, we look at cumulative emissions. These are shown in Figure 3.[21] In the Baseline and Progress to Date scenarios, global vehicle CO_2 emissions increase by 32% and 14%, respectively, from 2020 to 2050, with projected global growth in vehicle activity outpacing policy progress in both cases. In contrast, the Ambitious scenario results in a considerable decline of emissions by 2050—73% below 2020 levels. Cumulative vehicle CO_2 emissions from 2020 to 2050 total 296 Gt in the Baseline, 275 Gt under Progress to Date, and 197 Gt in the Ambitious scenario.

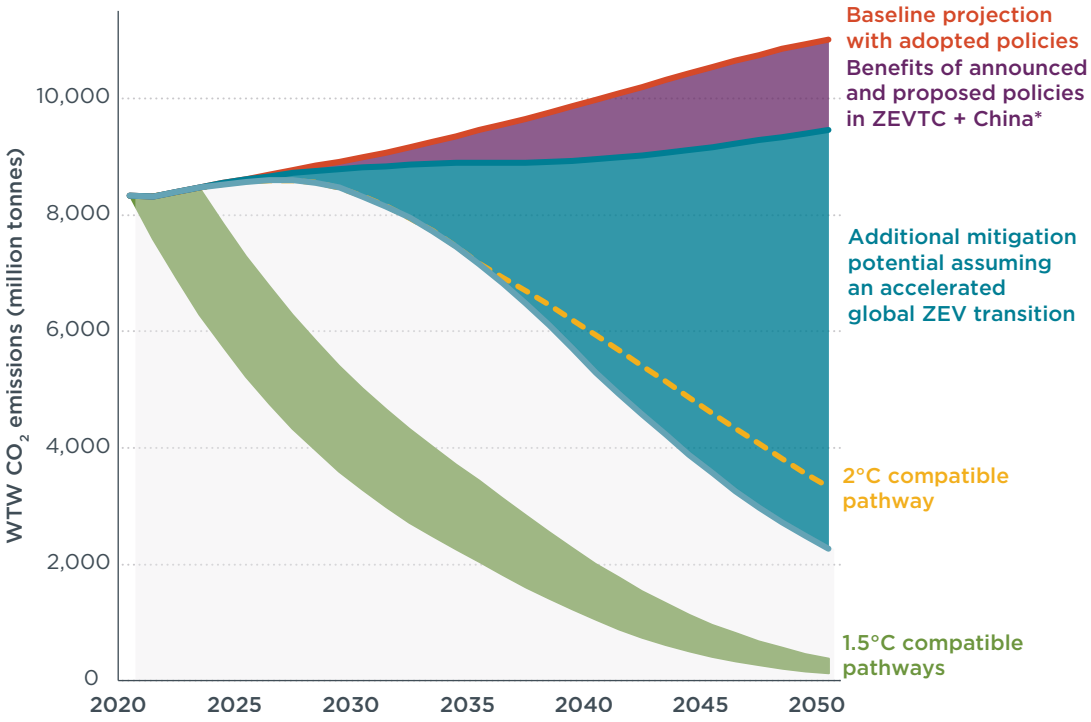

Figure 3. Global WTW CO_2 emissions from cars, vans, buses, and trucks compared to 1.5 °C and 2 °C compatible emissions pathways.

*The Progress to Date scenario considers proposals and goals that were announced by ZEVTC countries since the ZEVTC was launched in November 2020 and up until August 2021.

In 2020, cars, vans, buses, and trucks collectively accounted for 21% of global anthropogenic CO_2 emissions.[22] If, for the sake of analysis, it is assumed that these vehicles can emit a proportional share of the remaining global carbon budget until 2050, the Ambitious scenario is compatible with a 67% chance of limiting warming to 2 °C (dotted yellow pathway). However, considerably more ZEV deployment would be

20 "Multi-State ZEV Action Plan: Accelerating the Adoption of Zero Emission Vehicles 2018–2021," NESCAUM ZEV Task Force, 2018, https://www.nescaum.org/documents/2018-zev-action-plan.pdf.

21 "Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change," IPCC, 2021, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf.

22 In 2020, estimated global anthropogenic CO_2 emissions were approximately 38.9 Gt CO_2, 34.8 Gt CO_2 of which was from fossil fuels and roughly 4.1 Gt CO_2 of which was from land-use change. See slides 12 and 42 of https://www.globalcarbonproject.org/carbonbudget/21/files/GCP_CarbonBudget_2021.pdf. ICCT's estimate of 2020 well-to-wheel CO_2 emissions from cars, vans, buses, and trucks is 8.3 Gt CO_2, equivalent to 21% of global anthropogenic CO_2 emissions.

needed to close the gap with a 1.5 °C pathway, which is shown as the shaded green area. The lower bound of the green assumes vehicles use a proportional share of the remaining budget, whereas the upper bound assumes vehicles use 50% more than that, which would require more rapid reductions in other sectors. Stringent, complementary policies are thus needed to maintain a chance at 1.5 °C. Combined, these actions would need to reduce vehicle CO_2 emissions 40% to 60% by 2030, 80% to 90% by 2040, and to near zero by 2050. Such actions could include accelerating replacement of the existing vehicle fleet with ZEVs, maximizing uptake of efficiency technologies for conventional vehicles and ZEVs, and large-scale avoid and shift policies.

Cumulative CO_2 reduction potential by region, scenario, and vehicle type

Figure 4 shows cumulative CO_2 reduction potential by region and scenario in panel a; it then shows each scenario's marginal benefits by vehicle type, for the Progress to Date scenario compared to the Baseline in panel b and for the Ambitious scenario compared to Progress to Date in panel c.

As shown in panel a, EMDEs have the largest combined mitigation potential, all of which comes from policies assumed under the Ambitious scenario, and they are followed by the four major vehicle markets: China, the United States, the European Union, and India. The extent to which regions are currently aligned with the Ambitious scenario varies considerably. The Progress to Date scenario would achieve one-fifth of identified mitigation potential globally, 19% of mitigation potential in China, roughly half of it in the United States and European Union, and 6% in India. Regions with smaller percentages mean comparatively more policy effort is needed to close the gap with the Ambitious scenario.

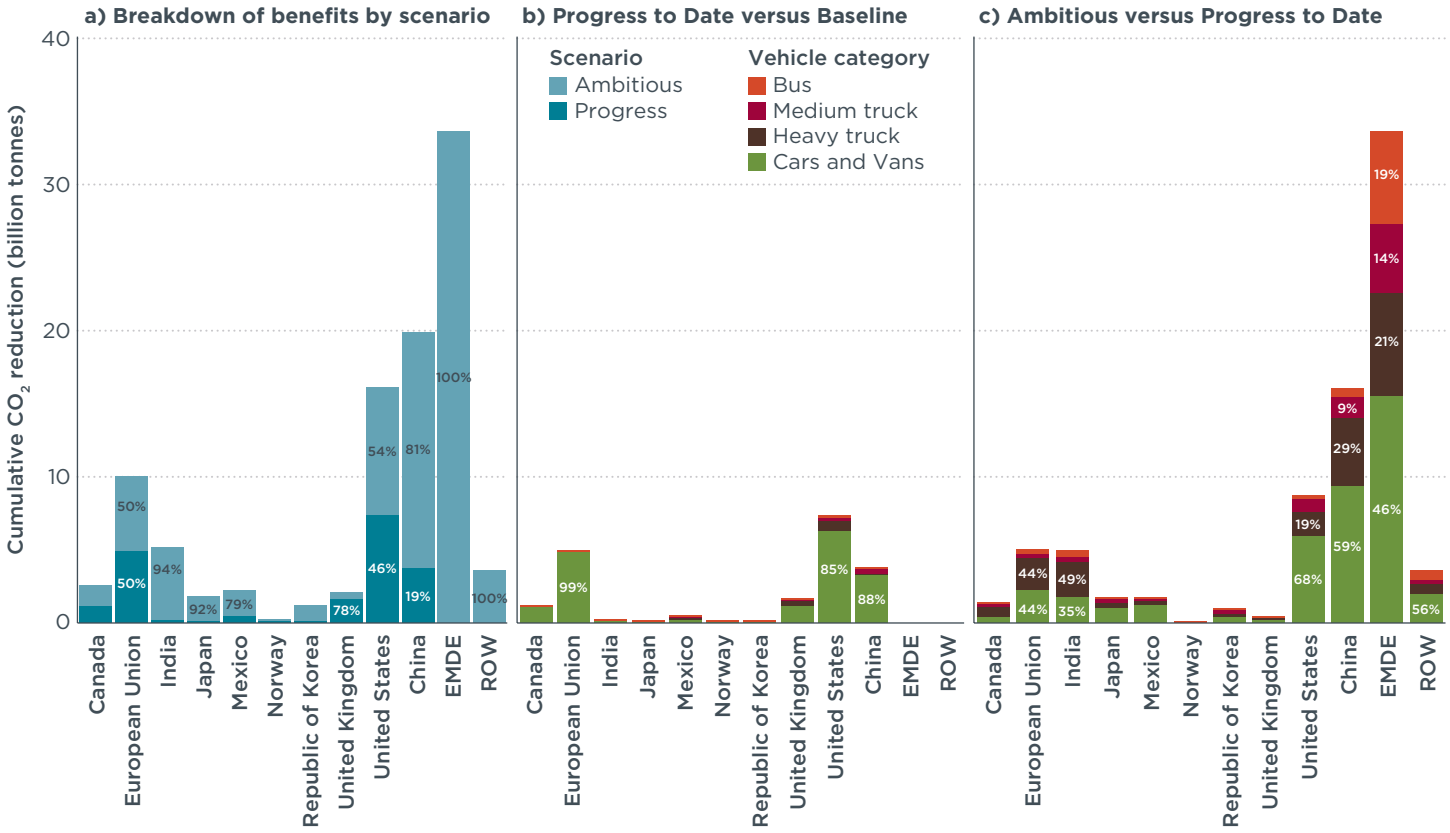

Figure 4. Breakdown of global CO_2 mitigation potential by region, scenario, and vehicle type. For EMDE and ROW, the Baseline and Progress to Date scenarios are identical.

Cars and vans account for the vast majority of the emission reductions expected in the Progress to Date scenario, due to the heavy focus of recent announcements and proposals on light-duty vehicles (panel b). In contrast, assuming governments follow through on these developments, the remaining global mitigation potential is evenly split between light-duty vehicles and heavy-duty vehicles (panel c).

Looking at the regional breakdown of this remaining mitigation potential, EMDEs have greater combined mitigation potential from our Ambitious scenario than China and the United States combined. This is large and diverse set of countries, and as discussed in a companion study, there are a variety of avenues via which ZEV policy frameworks could be strengthened and supported.[23] The breakdown of mitigation potential by vehicle type suggests that the most emissions reduction could be achieved by giving equal policy attention to light-duty vehicles and heavy-duty vehicles in EMDEs.

Figure 5 is an alternate breakdown of global CO_2 mitigation potential, this time grouping countries by geography. After China, the United States, and the European Union, the next regions with the greatest mitigation potential are the Association of Southeast Asian Nations (ASEAN), Latin America, the Middle East, and Africa. These four regions combined represent one-third of the global CO_2 reduction potential in the Ambitious scenario. These regions should be supported by the ZEVTC members to accelerate the ZEV transition and mitigate CO_2 emissions, not only for light-duty vehicles but also for heavy-duty vehicles.

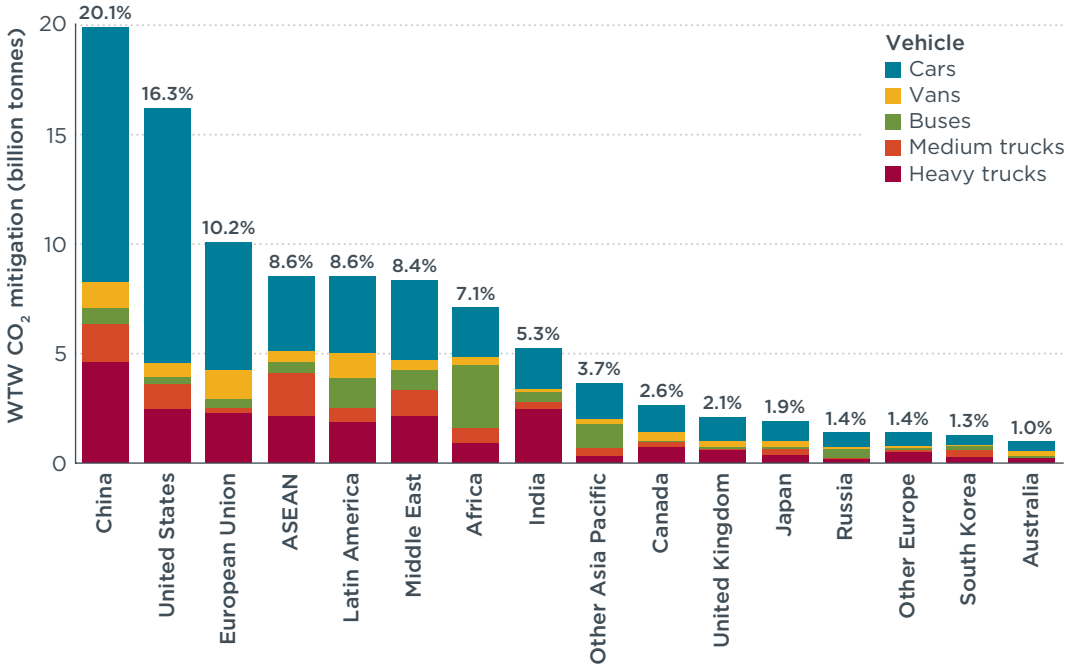

Figure 5. Breakdown of global CO_2 mitigation potential in the Ambitious scenario for key markets.

CONCLUSION

This paper summarized the current state of the global ZEV market and policies, quantified the benefits of recent policy developments by ZEVTC governments, and assessed the additional mitigation potential and need under an accelerated global ZEV transition. Several leading markets have already achieved high ZEV sales shares for new cars and buses, largely due to a combination of stringent CO_2 standards, ZEV rules,

23 Tanzila Khan, Zifei Yang, Sumati Kohli, and Josh Miller, *A critical review of ZEV deployment in emerging markets*, (ICCT: Washington, D.C., 2022), https://theicct.org/publication/zev-market-review-global-feb22/.

and fiscal incentives. Still, heavy trucks have very limited ZEV sales shares in all countries, despite their sizeable contribution to vehicles' CO_2 emissions.

In the past several years, and particularly since the ZEVTC first convened in November 2020, the pace of ZEV policy developments has accelerated. An important next step is to fully adopt and implement the policies underlying the Progress to Date scenario, and to seek additional reductions from policies under development. If ZEVTC governments and China follow through on recent proposals and announcements, they will collectively avoid 20 billion tonnes of CO_2—more than one-fifth of the potential CO_2 benefits that could be achieved by an accelerated global ZEV transition.

ZEVTC governments can further accelerate their own ZEV transitions and partner with interested EMDEs to the same purpose. In the ZEVTC countries, most policies under development focus on light-duty vehicles. However, ensuring a rapid global ZEV transition also for heavy-duty vehicles is crucial to putting the global vehicle fleet on a 2 °C compatible trajectory. To ensure compatibility with the best chances of 2 °C, ZEVTC governments should aim to transition at least 90% of their new car, van, and bus sales and three-quarters of truck sales to ZEVs by 2035 and partner with EMDEs to transition at least 90% of global car, van, bus, and truck sales to ZEVs by 2040. To maintain a chance of limiting warming to 1.5 °C, ZEVTC members should consider even earlier transitions to 100% ZEV sales and complementary measures to accelerate fleet transitions to ZEVs, maximize uptake of efficiency technologies for conventional vehicles and ZEVs, re-align the international used-vehicle trade to enhance vehicle efficiency and accelerate ZEV uptake, and avoid and shift vehicle travel to less carbon-intensive modes.

GLOSSARY

Battery electric vehicles (BEVs)	Vehicles that run exclusively on electricity derived from on-board batteries, which are charged from an external charging station or Electric Vehicle Supply Equipment (EVSE).
CO_2 standards	Government regulations that set minimum levels of vehicle fuel efficiency or maximum emissions of vehicle carbon dioxide or other greenhouse gases.
Consumer awareness	Consumer familiarity and comfort with the characteristics of electric vehicles and the advantages of EV ownership.
Emerging markets and developing economies (EMDEs)	In this paper series, we analyzed ZEV policies for 117 middle-income and low-income countries. These are referred to as EMDEs throughout.
Fleet purchase requirements	A regulation requiring that a minimum share of a fleet be zero-emission, as a stimulant to market demand. Most fleet purchase requirements today apply to transit buses and to fleets owned by governments.
Fiscal incentives	Government financial policies for promoting electric vehicle ownership. These are often divided into subsidies (such as tax credits, rebates, and exemptions from tolls) and vehicle tax reductions (which can be one-time or annual).
Heavy-duty vehicles (HDVs)	Medium and heavy commercial vehicles including buses and trucks whose maximum gross vehicle weight rating is greater than 3500 kg (3856 kg in the US and Canada).
Hydrogen fuel cell electric vehicles (FCEVs)	Vehicles powered by hydrogen, which is converted to electricity by an onboard fuel cell.
Internal combustion engine vehicles (ICEVs)	Vehicles powered by an internal combustion engine, most commonly fueled by diesel, gasoline, natural gas, or biofuels.
Light-duty vehicles (LDVs)	Cars or trucks whose maximum gross vehicle weight rating is less than 3500 kg (3856 kg in the US and Canada). These are typically passenger cars, vans, and light trucks.
New energy vehicles (NEVs)	The label used in China for electric vehicles (EVs), including BEVs, FCEVs, and PHEVs.
Plug-in hybrid electric vehicles (PHEVs)	Vehicles that can operate on electricity from an onboard battery, but also have an internal combustion engine as a backup source of power. PHEVs charge their batteries from an external charging station or EVSE.
Targets	The aspirational visions set by a government to signal future policy directions. In this document targets refer to goals set to ensure that sales of zero-emission vehicles, as a share of total vehicle sales, are increasing. Targets assist manufacturers of zero-emission vehicles and related infrastructure in planning their products and investments.
Zero-emission vehicles (ZEVs)	Vehicles, such as BEVs and FCEVs, that produce zero exhaust emissions. PHEVs, which still produce exhaust emissions when operating in charge-sustaining mode, are not counted as ZEVs in this paper.
ZEV regulations	Regulations requiring that ZEVs account for a certain share of new vehicle sales by each automaker, with the share increasing over time.

APPENDIX

The Appendix contains supplementary figures and tables that provide additional details regarding the assumptions made in the main model and add clarity to some of the primary findings.

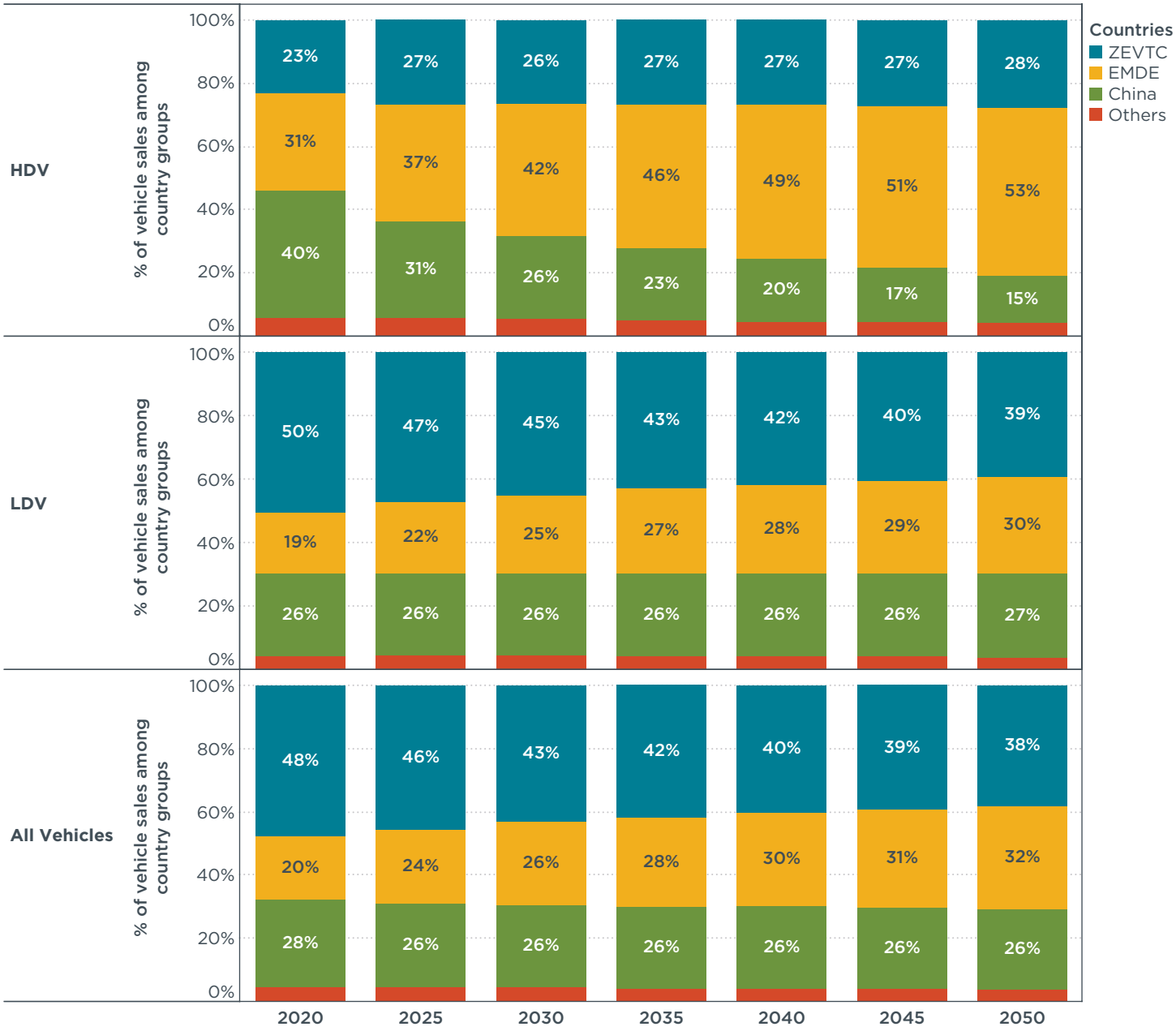

Figure A1. Vehicle sales by country group and vehicle type.

Table A1. Assumptions of global minimum ZEV sales shares in the Baseline scenario.

Vehicle	Region	2025	2030	2035	2040	2045	2050
PC	ZEVTC and China	5%	8%	11%	15%	21%	30%
LCV	ZEVTC and China	5%	8%	11%	15%	21%	30%
Bus	ZEVTC and China	7%	10%	15%	25%	35%	50%
MDT	ZEVTC and China	3%	5%	7%	10%	15%	20%
HDT	ZEVTC and China	2%	3%	4%	5%	7%	10%
PC	Rest of World	2%	3%	5%	8%	13%	20%
LCV	Rest of World	2%	3%	5%	8%	13%	20%
Bus	Rest of World	3%	5%	10%	15%	25%	40%
MDT	Rest of World	1%	2%	3%	4%	6%	10%
HDT	Rest of World	1%	1%	2%	3%	4%	5%

PC = Passenger cars; LCV = Light commercial vehicles (less than 3.5 tonnes); MDT = Medium-duty trucks (between 3.5 and 15-16 tonnes depend on the region); HDT = Heavy-duty trucks (over 15-16 tonnes). Country-specific policies and assumptions overwrite these defaults in cases where such policies exist.

Table A2. Summary of key policies in ZEVTC countries and China as of August 2021.

Region	Baseline	Progress to Date	Outlook*
California	**Advanced Clean Cars I:** 40% GHG reduction from MY2012 to MY2025 and 8% ZEV and plug-in hybrid sales by 2025	Not modeled: **Advanced Clean Cars II**. Details released after cut-off date. Please see Additional Notes below.	Phase II HDV GHG rule for trailers (2023)
	Innovative Clean Transit: 100% ZE transit bus sales by 2029	**EO-N-79-20:** 100% ZE LDV sales by 2035; 100% ZE HDV operations by 2045; and 100% ZE drayage operations by 2035 where feasible	
	Advanced Clean Trucks: 40% ZE sales of Class 7-8 tractors, 55% ZE sales of Class 4-8 trucks, and 75% ZE sales of Class 2b-3 vehicles by 2035	**2020 Mobile Source Strategy**: 85% ZE and PHEV LDV stock by 2045; 100% ZE HDV sales by 2035	
	Phase II HDV GHG standards: 16%–30% GHG reduction MY2018–2027	**Advanced Clean Fleets:** 100% ZE HDV sales for public fleets by 2027; 100% ZE private and federal fleet operations by 2035–2042; 100% ZE HDV sales across all segments by 2040.	
Canada	**LDV GHG standards**: 5% annual stringency improvement in emissions intensity from 2023 to 2026; 1.5% between 2020 and 2022	**Building a green economy:** 100% ZE LDV sales by 2035 (supersedes Quebec's similar policy)	LDV GHG standards (2023)
	HDV GHG standards: Aligned with U.S. Phase II HDV GHG standards		HDV GHG standards (2023/2024) – typically a year behind U.S. standards.
	British Columbia: 100% ZE LDV sales by 2040		Quebec and British Columbia ZE HDV targets

Region	Baseline	Progress to Date	Outlook*
China	**Phase V passenger car standards**: 20% reduction in fuel consumption 2020–2025	**New Energy Vehicle Industrial Development Plan 2021–2035:** 20% NEV sales (aggregate of LDV and HDV) by 2025; 100% NEV stock for public fleets by 2035; new BEV passenger cars achieve an energy intensity of 12.1 kWh/100 km by 2025.	NEV standards for commercial vehicles
	Passenger car NEV mandate (dual credit) policy 2021–2023: 18% NEV credit; NEV sales share depends on compliance strategy.	**China SAE Plan for LDV Sales:** 40% NEV by 2030 and 50% NEV by 2035. 95% BEV sales (of NEV) predicted by 2035.	Stage 4 HDV efficiency standards
	Stage 3 LCV standards: 20% reduction in fuel consumption 2012–2020		
	Stage 3 HDV standards: 15% reduction in fuel consumption 2015–2020		
	Green Mobility Action Plan 2019–2022: 60% NEV urban bus stock in key polluting regions and 50% in others by 2022; 80% NEV urban bus sales in key polluting regions by 2022.		
Denmark	775,000 BEV or PHEV LDVs in the national fleet by 2030.	**Integrated Climate and Energy Plan**: 100% LDV sales by 2035 (same as the European Union).	
EU-27	**LDV CO_2 standards:** 37.5% CO_2 reduction for new cars and 31% for vans 2021–2030	**Proposed LDV CO_2 standards (July 2021):** 100% CO_2 reduction for new cars and vans by 2035	HDV CO_2 standards (proposal expected 2022)
	HDV CO_2 standards: 30% CO_2 reduction for regulated trucks 2020–2030		
	Clean Vehicles Directive: Member state procurements 2026–2030: 17.6–38.5% zero- and low-emission LDV; 7–15% alternative fuel trucks; 16.5–32.5% ZE buses		
France	Not modeled: 100% ZE LDV sales by 2040 (would be superseded by proposed EU LDV CO_2 standards)	Not modeled: **Multiannual Energy Programming** and **Hydrogen Roadmap and Industrial Development** targets for ZE and PHEV LDV and HDV stock	
Germany		**Climate Action Program 2030:** 7–10 million EV stock by 2030	
India	**India FAME II**: 2% ZE passenger car sales and 7% bus sales by 2022	**Transport Minister Speech and EV30@30 target:** 30% ZE passenger car sales by 2030	Increased ethanol blending of fuels
	India BEE Fuel Efficiency: 113 gCO_2/km from 2022 for LDVs		Scrappage program for HDVs
	India BEE HDV Fuel Efficiency: average 10.4% reduction in fuel consumption 2018–2021 for trucks and buses > 12 tonnes GVW		Increased incentives under FAME II
	Not modeled: State-level EV policies		Gigafactories and battery manufacturing scheme; National Hydrogen Mission
Italy		Not modeled: **Integrated National Energy and Climate Plan**: 85% ZEV and PHEV LDV and government vehicle sales by 2030.	

Region	Baseline	Progress to Date	Outlook*
Japan	**New Fuel Efficiency Standards for Passenger Cars:** 32.4% increase in fuel economy 2016–2030	**Japan Strategic Commission for the New Era of Automobiles Report:** Passenger car sales are 20%–30% BEV, 20%–30% PHEV, 30%–40% HEV, and 3% FCEV in 2030.	
	New Fuel Efficiency Standards for Trucks and Buses: 13.4%–14.3% increase in fuel economy 2015–2025		
Mexico	**LDV CO_2 Standards**: Passenger cars and light trucks standards: 12% reduction in CO_2 from 2013–2018	**Secretariat of Environment and Natural Resources:** 100% PHEV and ZE LDV and HDV sales by 2050	
Netherlands	**Climate Agreement 2019:** 100% ZE passenger car sales by 2030	**Mission Zero:** 100% ZE bus sales by 2025	
		Zero Emission Zone for major cities: May impact HDV sales/lead to a faster growth of ZEV sales than the European Union by 2025	
Norway		**National Transport Plan 2018–2029:** 100% ZE LDV sales by 2025; 100% ZE or biogas urban bus sales, 75% ZE coach sales, 50% ZE truck sales in 2030	
Republic of Korea	**2030 LDV CO_2 Standards:** Passenger car standards: 28% reduction in CO_2 2020–2030; Light commercial vehicle standards: 12% reduction in CO_2 2020–2030	33% ZE passenger car sales by 2030	Increase EV subsidies
		Hydrogen Economy Roadmap: 40,000 FCEV trucks and 30,000 buses by 2040	
Spain		Not modeled: **Integrated National Energy and Climate Change Plan 2021–2030:** 100% ZE LDV sales by 2040 (superseded by proposed EU LDV CO_2 standards)	
Sweden		Not modeled: **Climate Policy Action Plan**: 100% ZE and PHEV passenger car sales by 2030	
United Kingdom		**Consultations to end the sale of non-ZEV cars, vans, buses, coaches, and heavy commercial vehicles:** 100% PHEV and ZE LDV sales by 2030; 100% ZE LDV sales by 2035; 100% ZE HDV sales by 2040	London Zero Emission Zone

Region	Baseline	Progress to Date	Outlook*
United States**	**Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule MY2021–2026:** 1.5% improvement in stringency every year.	Realignment with California LDV GHG standards by 2026	LDV GHG standards (proposal released December 2021)
	Advanced Clean Cars I: California and Section 177 states	**Advanced Clean Cars II:** California and Section 177 states	HDV NO_x standards (proposal announced March 2022 and not modeled)
	Phase II HDV GHG standards: 16%–30% GHG reduction MY2018–2027	**Multi-state MOU (15 states + DC) with International ZEV Alliance:** ZE LDV sales reach 100% by 2050	Phase III HDV GHG standards (2022/2023)
	Not modeled: **New Jersey Regulation S2252/A4819:** 85% ZE LDV sales by 2040 (superseded by ACC II in Progress to Date scenario)	**Multi-state MOU (15 states + DC):** ZE HDV sales reach 30% by 2030 and 100% by 2045	
		Massachusetts Clean Energy and Climate Plan 2030: 100% ZE LDV sales by 2035	
		Biden's Infrastructure Plan: Electrification of 50,000 transit buses, 100,000 school buses, and 645,000 government vehicles (about 412,000 of which are trucks) by 2030	
		Biden's LDV Sales Target: 50% ZEV and PHEV sales by 2030	

*The "Outlook" column includes new policies that are expected to be proposed by ZEVTC countries within the next 2–3 years but are not modeled.

**California's policies are delineated separately since California is a ZEVTC member.

Additional notes for Table A2.	
California	As of October 2021, the draft ACC II rule would allow up to 20% sales in 2035 of PHEVs with a minimum of 50 miles of all-electric range. If finalized as is, the proposed rule would result in smaller benefits than what is modeled here as a strict 100% ZEV sales requirement in 2035 based on EO-N-79-20.
Denmark	Integrated Climate and Energy Plan: 100% ZE LDV sales by 2035; 100% Bus stock by 2030 (might not be implemented due to EU market rules)
India	India is a member of the EV30@30 campaign: http://www.cleanenergyministerial.org/campaign-clean-energy-ministerial/ev3030-campaign
Germany	Climate Action Program 2030: 7–10 million ZEV stock by 2030. Our modeling indicates this target is likely to be met if the European Commission's proposed revisions to the LDV CO_2 standards are adopted. The Climate Action Program 2030 also sets a target for one-third of mileage by heavy goods vehicles to be electric or based on electricity-based fuels by 2030. Although not modeled here, attainment of that target would likely lower Germany's projected 2030 emissions.
Mexico	Electric vehicles include BEV, FCEV, and PHEV: https://www.conuee.gob.mx/transparencia/boletines/transporte/19ForodeEEeT/1_Semarnat.pdf
Netherlands	Mission Zero: 100% bus sales by 2025. The Netherlands appears likely to reach this target based on its already high ZEV sales share for buses in 2020.
Sweden	Climate Policy Action Plan: 100% ZE and PHEV passenger car sales by 2030. Depending on the share of PHEVs, this could be met if the European Commission's proposed revisions to the LDV CO_2 standards are adopted.
United States	As of August 2021, the Trump administration's SAFE rule was the latest adopted version. In December 2021, EPA released its final rule under the Biden administration, and it will produce greater emission benefits than the SAFE rule that is incorporated in the Baseline of this analysis.
Global MOU	In December 2021, 15 governments—including several ZEVTC members—published a "Memorandum of Understanding (MOU) on zero-emission medium- and heavy-duty vehicles." These countries committed to "working together to enable 100% zero-emission new truck and bus sales by 2040 with an interim goal of 30% zero-emission vehicle sales by 2030, to facilitate achievement of net-zero carbon emissions by 2050." This commitment is not modeled here, since it took place several months after August 2021, the cut-off for our study. Future inclusion in the Progress to Date scenario would significantly improve the outlook for countries that signed it, except for Norway and the United Kingdom, which had already made similar commitments.
Glasgow declaration	In December 2021, 28 national governments signed the "COP26 declaration on accelerating the transition to 100% zero emission cars and vans," pledging to work toward 100% zero-emission car and van sales by 2040 globally and 2035 for leading markets. This commitment is not modeled here, since it took place several months after August 2021, the cut-off for our study. Future inclusion in the Progress to Date scenario would significantly improve the outlook for countries that signed it, except for countries like Canada, Norway, and the United Kingdom, which had already made similar commitments.

Table A3. Assumptions of shares of ZEVs, PHEVs, and hybrid vehicles in targets that were not exclusively set for ZEVs.

Category	Powertrain	Car	Van	Bus	Medium truck	Heavy truck
EV sales targets including PHEVs*	ZEV	75%	75%	95%	75%	85%
	PHEV	25%	25%	5%	25%	15%
China's new energy vehicle targets	ZEV	90%	60%	80%	100%	100%
	PHEV	10%	40%	20%	0%	0%
Japan's EV sales targets (includes ICE hybrids and PHEVs)	ZEV (includes 5% FCEV)	35%	—	—	—	—
	PHEV	10%	—	—	—	—
	Hybrid	55%	—	—	—	—

* Applicable to various targets set by Denmark, Mexico, Sweden, United Kingdom, and the United States (including California).

Table A4. ZEV sales share pathways of other studies.

Study	Vehicle type	2030	2035	2040	2050
UN 2021	Car	75%	100%		
	Van	75%	100%		
	Bus			100%	
	Truck	40%			
BNEF Net Zero	Car	58%		100%	
	Van	33%		89%	100%
	Bus	76%		99%	100%
	Truck	20%		94%	100%
IEA Net Zero	Car	64%			100%
	Van	72%			100%
	Bus	60%			100%
	Truck	30%			99%
Berkeley 2035	Car		100%		
	Van		100%		
	Bus		100%		
	Truck		100%		

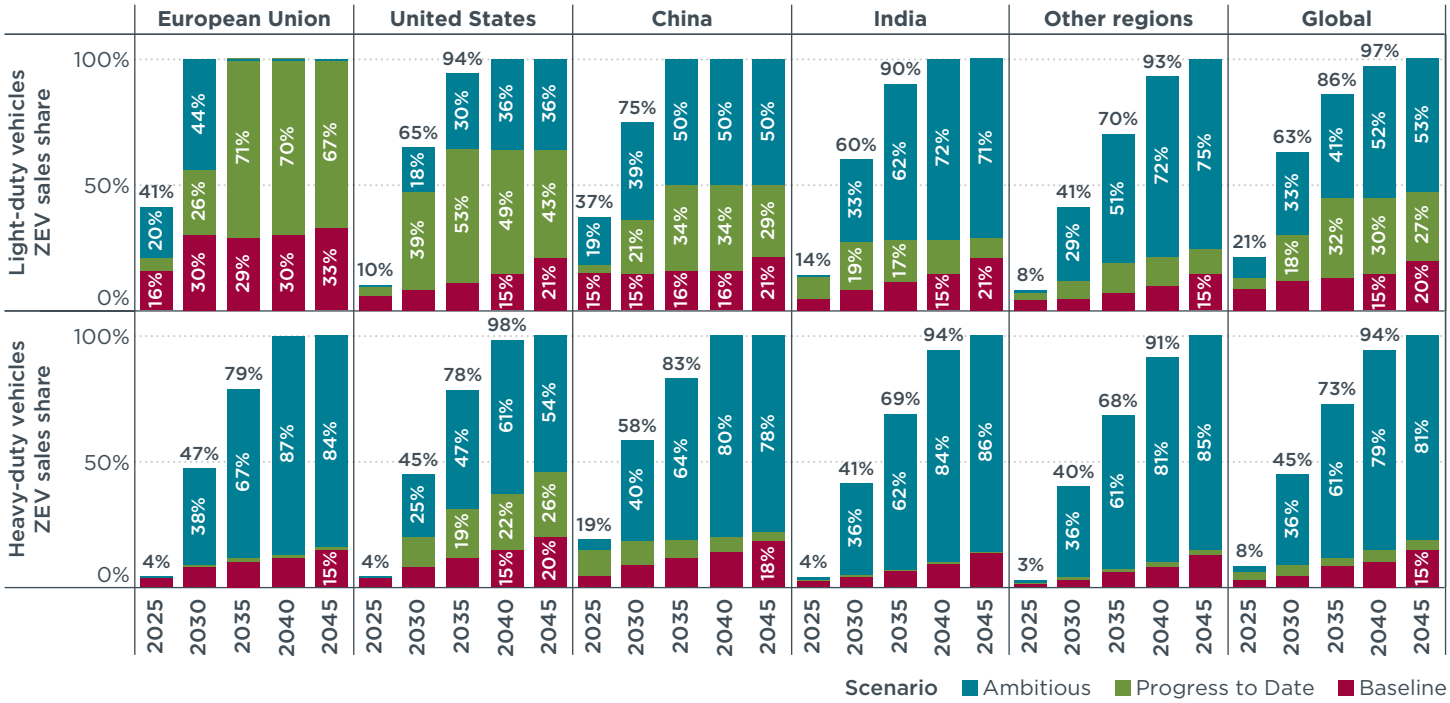

Figure A2. ZEV sales shares in major markets and globally. The Progress to Date bar shows total ZEV sales shares. The Ambitious bar shows ZEV sales shares that are additional to Progress to Date.

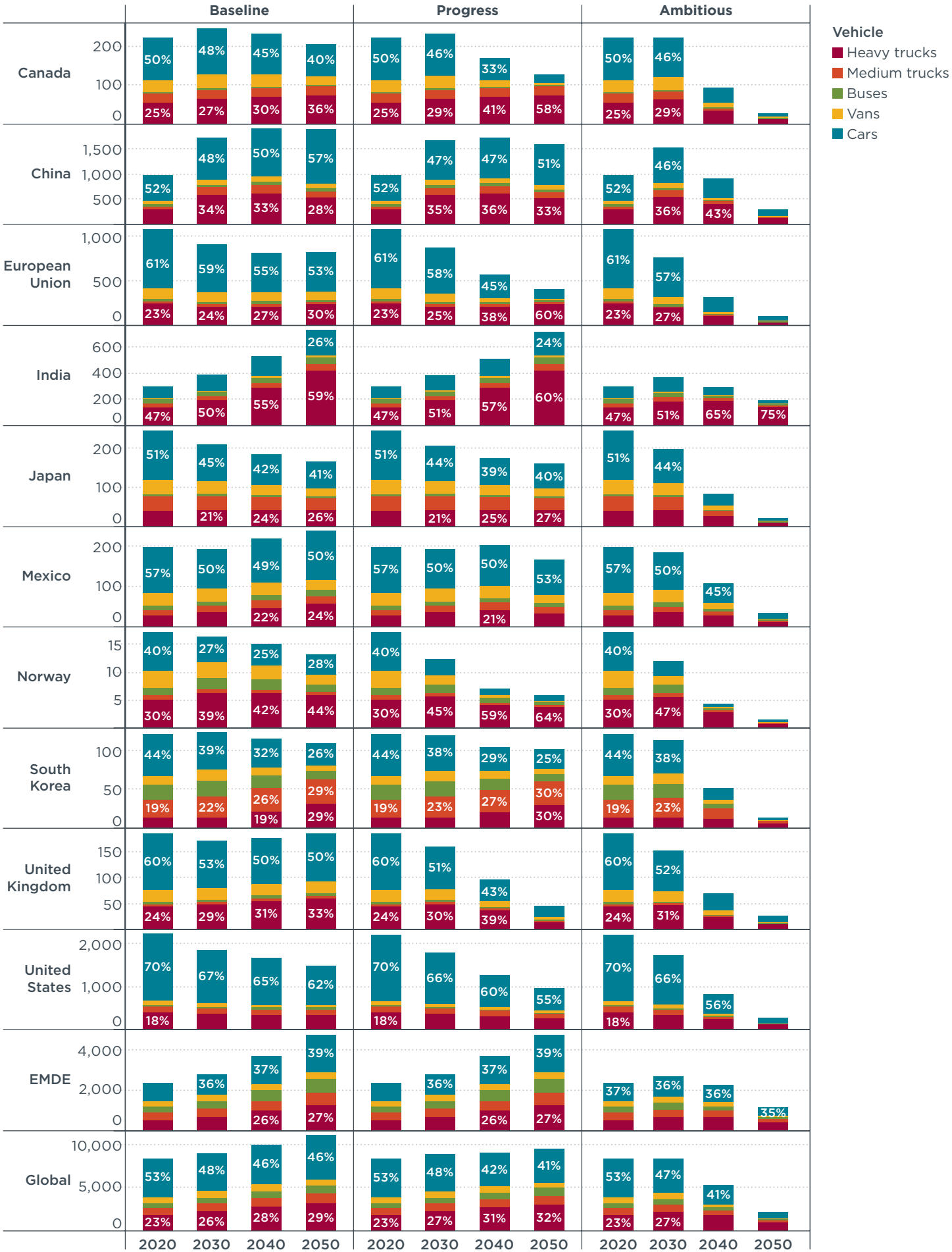

Figure A3. WTW CO_2 emissions projections by region, vehicle type, and scenario.