www.theicct.org

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BRIEFING

OCTOBER 2018

Modernizing vehicle regulations for electrification

This briefing summarizes existing regulatory practices and develops design principles to adapt vehicle efficiency standards in the 2020–2030 time frame to enable a transition to zero-emission vehicles over the 2030–2050 time frame.

INTRODUCTION

To mitigate the worst consequences of climate change, the transport sector will need to effectively transition to all zero-emission vehicles by around the middle of the 21st century. This need to shift to emission-free vehicles, primarily electric-drive vehicles powered by renewable sources, has been acknowledged by many major governments, as shown in Figure 1. The goals are to shift to all new zero-emission vehicles by 2025 in Norway, 2030 in Netherlands, 2040 for France and the United Kingdom, and 2050 for Germany and many subnational governments. The figure also includes 2010–2017 new vehicle electric shares for the world at 1% and for Norway at 40%, for context. The goals are ambitious and timelines vary, but the zero-emission vision is increasingly becoming universal.

Prepared by Nic Lutsey

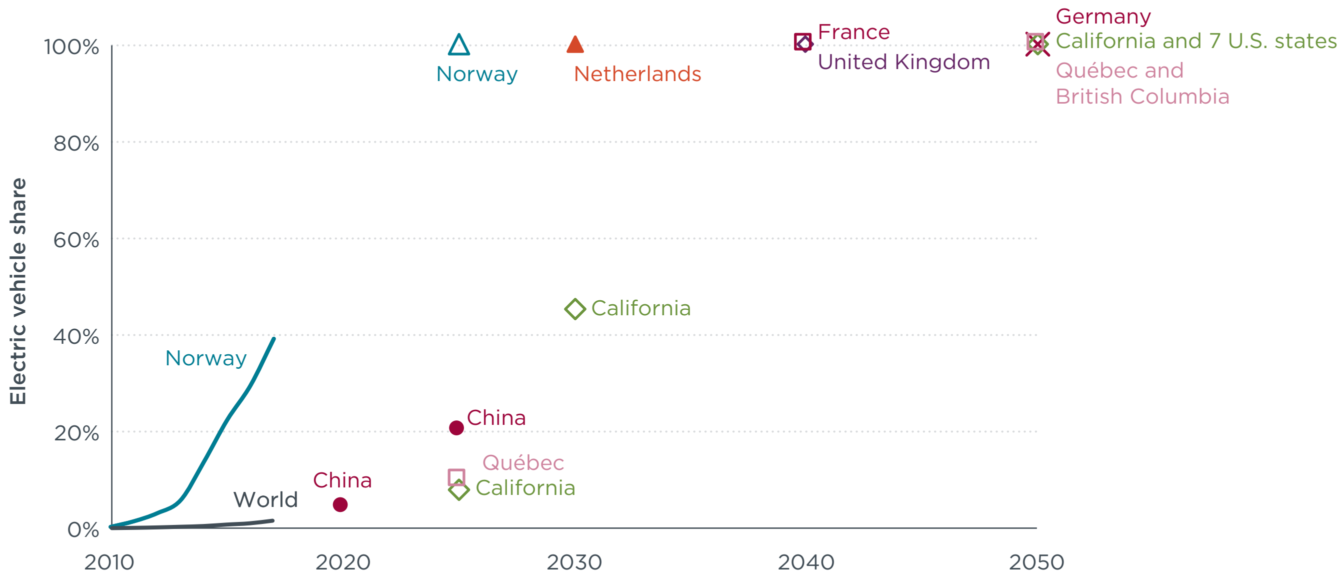

Figure 1. Electric vehicle policy goals, targets, and announcements, 2020–2050.

Although the time frame to achieve all new zero-emission vehicles remains uncertain and will vary by region, early steps in this transition are underway. Annual electric vehicle sales have increased globally from hundreds in 2011 to 1.2 million in 2017. Electric vehicle uptake is increasing in several markets around the world, especially in China, Europe, and the United States. The progress is linked to a range of supporting policies, including targeted zero-emission vehicle (ZEV) regulation, consumer incentives, charging infrastructure deployment, and local promotional activities to break down the prevailing electric vehicle barriers.

Key barriers for electric vehicles entering the mainstream market are the relatively limited model offerings and their high cost compared to conventional combustion vehicles. Electric model offerings that feature more vehicle types and brands are proliferating especially across China, Europe, and North America. As battery costs continue to decline through the early 2020s, electric vehicles approach cost-competitiveness when fuel savings are included in the consumer proposition.[1] However, for vehicle price parity on initial cost, greater electric vehicle production will be required.

Automaker announcements and investments suggest that high-volume battery and electric vehicle production is on the way in major markets. Summing the announced investments from automakers indicates that hundreds of new electric models, more than $150 billion in investments, and a more than ten-fold increase in electric vehicle sales are on the way by 2025.[2] With these announcements, many automakers, including the Volkswagen Group and the Nissan-Renault-Mitsubishi alliance, have now stated their electric vehicle deployment is likely to reach 20%–30% by 2025. Coinciding with

1 Peter Slowik, Nic Lutsey. *Evolution of incentives to sustain the transition to a global electric vehicle fleet* (ICCT: Washington DC, 2016). https://www.theicct.org/publications/evolution-incentives-sustain-transition-global-electric-vehicle-fleet

2 Nic Lutsey, Mikhail Grant, Sandra Wappelhorst, Huan Zhou, *Power play: How governments are spurring the electric vehicle industry* (ICCT: Washington DC, 2018). https://www.theicct.org/publications/global-electric-vehicle-industry

their volume announcements, several automakers have made statements about electric vehicle profitability and cost parity with their conventional vehicles by 2025.

This briefing summarizes existing practices and develops design principles related to adapting vehicle efficiency and CO_2 standards in the 2020–2030 time frame to enable a long-term transition to zero-emission vehicles. Regulations so far have been developed almost exclusively for incremental efficiency improvements. The analysis fills gaps in the prevailing regulatory analysis regarding emission trade-offs from regulatory incentives, how targeted ZEV regulations could accelerate the shift to electric, and how electric vehicles change the fundamental math on incremental percent-per-year CO_2 standards. The focus of the briefing is on the markets of China, Europe, and the United States, which represent 90% of the world's electric vehicle sales and have regulatory frameworks to further drive the market. Due to the higher energy use, CO_2 emissions, and vehicle production volume globally for passenger vehicles, this briefing covers exclusively electric-drive light-duty vehicles.[3]

ELECTRIC VEHICLES IN REGULATIONS

This section analyzes expected electric vehicle uptake with prevailing fuel consumption, CO_2 emission, and greenhouse gas (GHG) emission standards. The figures include adopted regulations to 2020, and to 2025 in some cases, as well as announced policy proposals and targets to 2025 and 2030. After discussion on China, Europe, and the United States, their electric vehicle regulatory provisions are compared.

CHINA

China is the largest electric vehicle market, with about half of the world's new electric vehicle sales and 1.2 million cumulative light-duty electric vehicles sold through 2017. The overall light-duty vehicle market, at about 25 million in annual sales, is also the world's largest. Electric vehicle sales in China amounted to approximately 2% of all new light-duty vehicle sales in 2017. Leading major markets in China, like Beijing, Shanghai, and Shenzhen, each had electric vehicle sales that were 5% to 11% of new vehicle sales.[4]

Figure 2 shows how fuel consumption standards require reduced fuel use from new vehicles from seven down to five liters per 100 kilometers (L/100km) over the period from 2015 to 2020.[5] The standards include provisions that count electric vehicles as consuming zero fuel, and include multipliers to count each more than once, as an additional incentive. In late 2017, China finalized its New Energy Vehicle (NEV) regulation, requiring that electric vehicles be increasingly deployed, up from 2% in 2017

---

3 This briefing includes battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs), and hydrogen fuel cells (HFCVs) as the electric-drive types, although most data and government analyses are focused on plug-in electric types. Electric-drive freight trucks, and especially buses, are advancing as well, and their regulatory and technical issues could have some similarities but also many commercial and business case differences from passenger vehicles.

4 Dale Hall, Hongyang Cui, Nic Lutsey, *Electric vehicle capitals of the world: What markets are leading the transition to electric?* (ICCT: Washington DC, 2017). https://www.theicct.org/publications/EV-capitals-of-the-world-2017

5 Hui He, Zifei Yang, *China Phase 4 passenger car fuel consumption standard proposal,* (ICCT: Washington DC, 2014). https://www.theicct.org/publications/china-phase-4-passenger-car-fuel-consumption-standard-proposal. Here and throughout, CO_2 and electric vehicle data that are not associated with adopted standards are marked with dashed lines.

to an estimated 4% of new light-duty vehicles by 2020.[6] The two regulations for fuel consumption and NEVs are linked in that excess credits in the NEV regulation reduce the amount of fuel consumption improvement for which automakers are responsible.

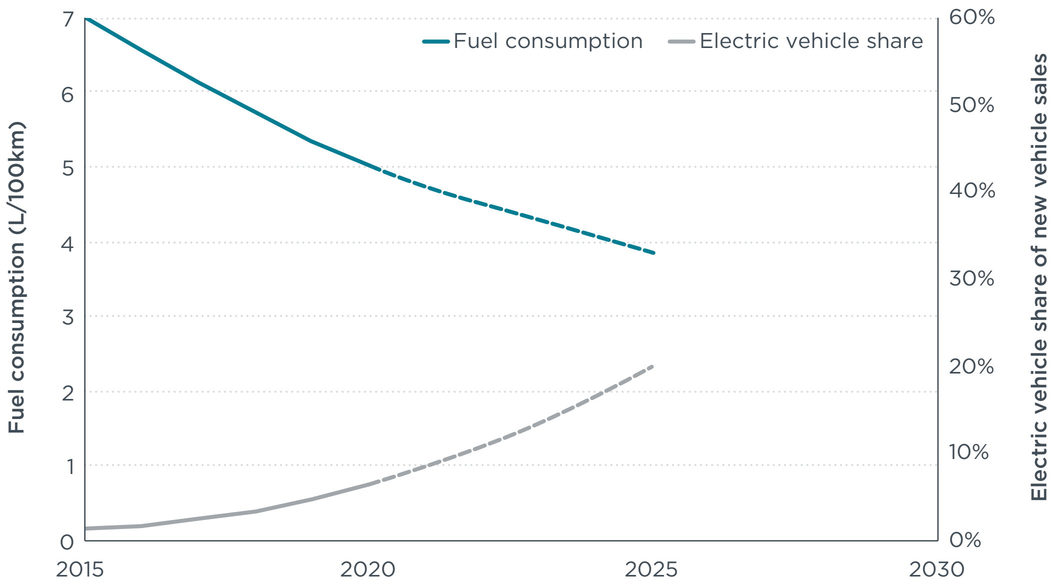

Figure 2. Adopted and estimated fuel consumption and electric vehicle share to meet policy goals through 2025 in China.

China has a goal of 7 million electric vehicle sales annually, meaning 20% of all new vehicles.[7] This goal includes both light- and heavy-duty vehicles. As light-duty vehicles are very likely to remain further along their path toward electrification, this 20% goal would appear to be the lower-bound electric share for light-duty vehicles, whereas heavy-duty vehicles are more likely to be slower to electrify. China has a goal to reduce fuel consumption of light-duty vehicles to four L/100 km by 2025,[8] but associated regulations have not yet been proposed. No official 2030 policy goals for overall new vehicle fuel consumption or NEVs have been announced.

EUROPE

Europe is the world's second largest electric vehicle market, with about a quarter of the world's new electric vehicle sales in 2017 and 900,000 cumulative light-duty electric vehicles sold through 2017.[9] This includes the major electric vehicle markets of France, Germany, Netherlands, Norway, and the United Kingdom. Of Europe's light-duty vehicle market of more than 15 million in annual sales, electric vehicles amounted to nearly 2% of new vehicle sales in 2017. Leading national markets in 2017 include Norway, with a 39% electric share of new vehicles, Iceland with 14%, and Sweden with 5%.

6 Hongyang Cui, *China's New Energy Vehicle mandate policy (final rule)* (ICCT policy update) (ICCT: Washington DC, 2018). https://www.theicct.org/publications/china-nev-mandate-final-policy-update-20180111

7 Ministry of Industry and Information Technology. "Medium- and long-term development plan for auto industry," (2017). http://www.miit.gov.cn/n1146290/n4388791/c5600433/content.html

8 Ministry of Industry and Information Technology. "Medium- and long-term development plan for auto industry," (2017). http://www.miit.gov.cn/n1146290/n4388791/c5600433/content.html

9 Throughout this report, Europe refers to the European Economic Area (thus including, e.g., Norway).

Figure 3 illustrates the European Union's regulations to reduce new vehicle grams of CO_2 per kilometer (g/km). The adopted regulations would take the fleet from 120 g/km in 2015 to 95 g/km by 2021. The November 2017 proposed regulations would further reduce emissions by 15% (to 81 g/km) in 2025 and by 30% (to 67 g/km) by 2030.[10] The adopted 2021 CO_2 standards include provisions to count electric vehicles as having zero emissions (i.e., not counting upstream emissions) and include super credits as an additional incentive.

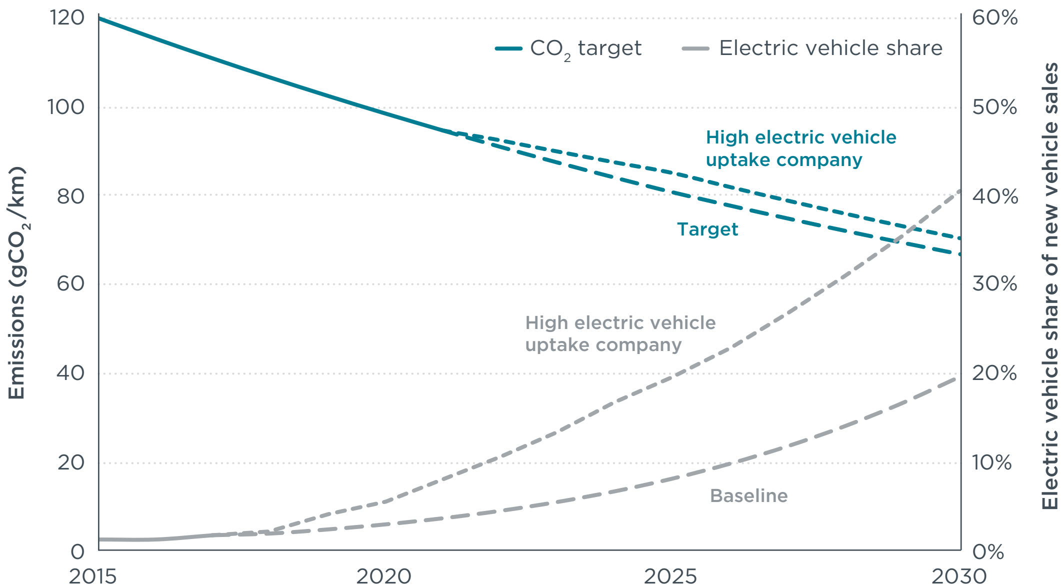

Figure 3. Adopted and proposed carbon dioxide emission targets and electric vehicle share through 2030 in Europe.

In the proposed 2025 and 2030 European Union CO_2 regulation targets, accounting of electric vehicles as zero continues, but super credits are removed. The most prominent proposed change for 2025 and 2030 is the introduction of a novel zero and low emission (ZLEV) provision as an inducement for companies to shift to electric drive. With the ZLEV incentives, a company surpassing ZLEV benchmarks receives leniency in its CO_2 targets. To receive the maximum benefit, a company with a 20% ZLEV share in 2025 receives a 5% less stringent 2025 CO_2 target (85 g/km instead of 81 g/km).[11] Similarly, in 2030, a company with at least a 35% ZLEV share is allowed a 5% less stringent CO_2 target (70 g/km instead of 67 g/km). A "high electric vehicle uptake company" is depicted in Figure 3 to show the electric share and leniency in its CO_2 target.[12] The baseline electric vehicle penetration, as assessed for a fleet complying with the proposed CO_2 regulation, increases to 11% in 2025 and to 20% in 2030.[13]

---

10 CO_2 g/km values here are from the New European Driving Cycle. These are based on European Commission, "Proposal for a regulation. Post 2020 light vehicle CO_2 regulation(s)," 8 November 2017, http://ec.europa.eu/info/law/better-regulation/initiatives/com-2017-676_en

11 Jan Dornoff, Joshua Miller, Peter Mock, Uwe Tietge, *The European Commission regulatory proposal for post-2020 CO_2 targets for cars and vans* (ICCT: Washington DC, 2018). https://www.theicct.org/publications/ec-proposal-post-2020-co2-targets-briefing-20180109

12 Here, as throughout this paper, the assumed 2030 Europe electric share to meet the maximum ZLEV 35% credit provisions includes 30% BEV and 10% PHEV, as PHEVs receive partial ZLEV credit.

13 Based on Dan Meszler et al., *CO_2 reduction technologies for the European car and van fleet: A 2025-2030 assessment* (ICCT: Washington DC, 2016), https://www.theicct.org/publications/co2-reduction-technologies-european-car-and-van-fleet-2025-2030-assessment and Nic Lutsey, Integrating electric vehicles within U.S. and European efficiency regulations (ICCT: Washington DC, 2017)., https://www.theicct.org/integrating-EVs-vehicle-CO2-regs

UNITED STATES

The U.S. electric vehicle market follows China and Europe as the third largest, representing about a sixth of the world's new electric vehicle sales in 2017 and more than 750,000 cumulative light-duty electric vehicles sold through 2017. Of the 17 million annual light-duty vehicle sales in 2017, electric vehicles amounted to about a 1% share. California, with its Zero Emission Vehicle (ZEV) regulation, requires that an increasing share of new vehicles are electric-drive vehicles through 2025. Nine other states representing about 29% of U.S. vehicle sales also have adopted California's ZEV regulation. In 2017, California's electric share was nearly 5%, more than four times that of the U.S. average.

Figure 4 shows the adopted GHG standards in the United States, with a CO_2 emission rate that declines from about 270 to 173 g/mile, based on adopted standards from 2016 to 2025.[14] The associated electric vehicle share in the figure for 2025 is shown with two separate estimates. The lower estimate for 2025 is shown as 2%, based on U.S. Department of Transportation's analysis that excludes the implementation of the ZEV regulation. The higher estimate of 5% in 2025 is based on the U.S. EPA analysis, which includes industry compliance with the ZEV regulation. After the adopted 2025 standards, hypothetical targets that get more stringent from 2025 to 2030 at 5% per year are included for illustrative purposes.[15] With uncertainty about the ongoing midterm evaluation process to review the 2025 standards, it is conceivable that progress on GHG reductions and electric shares will slow considerably from what is shown in the figure, starting in 2021.

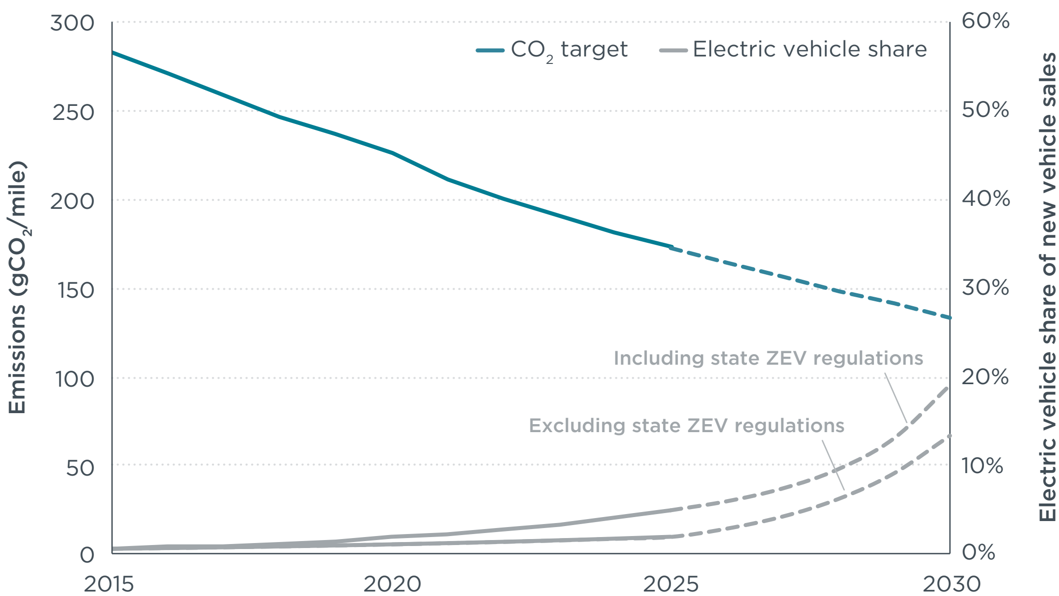

Figure 4. Adopted and potential carbon dioxide emission targets and estimated electric vehicle share through 2030 in the United States.

---

14 U.S. Environmental Protection Agency, National Highway Traffic Safety Administration, & California Air Resources Board. "Draft technical assessment report: Midterm evaluation of light-duty vehicle greenhouse gas emission standards and corporate average fuel economy standards for model years 2022–2025" (EPA-420-D-16-900) (2016). https://nepis.epa.gov/Exe/ZyPDF.cgi/P100OXEO.PDF?Dockey=P100OXEO.PDF

15 California Air Resources Board, "CARB finds vehicle standards are achievable and cost-effective," March 24, 2017, https://ww2.arb.ca.gov/news/carb-finds-vehicle-standards-are-achievable-and-cost-effective and Nic Lutsey, Dan Meszler, Aaron Isenstadt, John German, Josh Miller, *Efficiency technology and cost assessment for U.S. 2025–2030 light-duty vehicles* (ICCT: Washington DC, 2017), http://www.theicct.org/US-2030-technology-cost-assessment.

The California market is a separate case within the United States due to its targeted ZEV regulation to increase the share of electric vehicles through 2025. To minimally comply with the ZEV regulation, the new vehicle fleet would reach 8% electric vehicles by 2025 from 5% in 2017, increasing at 6% per year. The emission-reduction trajectory shows the California fleet with the same GHG standards as federally adopted through 2025. For post-2025, the lower electric share is based on California adopting a performance standard at 5% per year, leading to approximately 18% in 2030.[16] Figure 5 also illustrates a trajectory for California's goal for 5-million zero-emission vehicles in the state by 2030.[17]

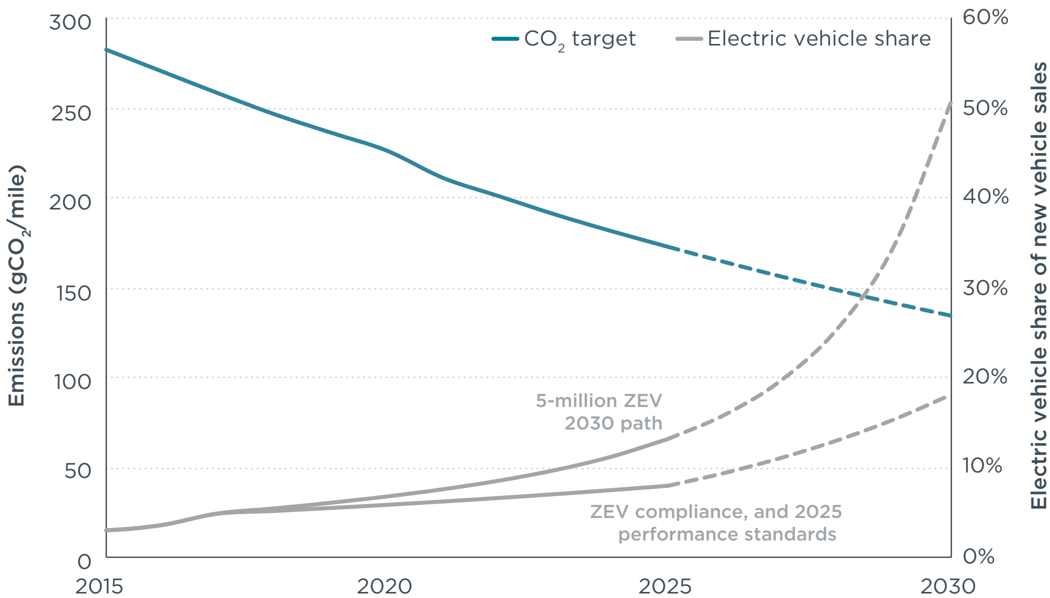

Figure 5. Adopted and potential carbon dioxide emission targets and estimated electric vehicle share through 2030 in California.

SUMMARY OF ELECTRIC VEHICLE REGULATORY PROVISIONS

These three major electric vehicle markets have adopted several similar provisions to promote electric vehicles. First, consistent with all these regulations, fully battery electric vehicles are counted as having zero emissions, as are hydrogen fuel cell vehicles. Plug-in hybrid vehicles are counted as zero for the estimated percentage of their driving that is powered from electricity, which is approximately proportional to their electric range. This counting of electric vehicle emissions as zero is typical, despite regulators' acknowledgement of electricity (and hydrogen) upstream emissions and energy use.

The second regulatory provision that is sometimes applied is the additional counting of electric vehicles—called "multipliers" in the United States and "super

16 Nic Lutsey, Dan Meszler, Aaron Isenstadt, John German, Josh Miller, *Efficiency technology and cost assessment for U.S. 2025–2030 light-duty vehicles* (ICCT: Washington DC, 2017). http://www.theicct.org/US-2030-technology-cost-assessment

17 The range in 2030 is from 36% to 50% share, depending on the 2018-2030 growth rate, from International Council on Clean Transportation, "Update: California's electric vehicle market," (ICCT, May 31, 2017), https://www.theicct.org/publications/update-californias-electric-vehicle-market

credits" in Europe. With such provisions, electric vehicles of zero g/km are counted multiple times, increasing their relative compliance impact. Simply put, compared to regulatory standards that are set at 120 g/km, a conventional hybrid, with 30% lower emissions at 80 g/km, provides a 40 g/km reduction. A zero-emission vehicle provides a 120 g/km reduction (i.e., three times the hybrid reduction), and a 2.0 multiplier effectively then provides 240 g/km in compliance value (i.e., six times the value of the hybrid). This combination of zero g/km and multipliers makes electric vehicles' cost-effectiveness similar to advanced combustion and hybrid technologies.[18] The U.S. multipliers phase down from 2.0 to 1.3 from 2017 to 2021 and are not available thereafter. Super credits in Europe phase out by 2023. China's multipliers fall from three in 2018–2019 to two for the 2020 standards. Plug-in hybrids have lower multiplier values than for fully electric vehicles.

Two of the regulations—in Europe and the United States—also use threshold-based regulatory incentives to spur electric vehicle deployment. In the United States, from 2022 to 2025, zero g/mile is allowed for up to 200,000 cumulative electric vehicles per company—or up to 600,000 for companies that sell a total of 300,000 electric vehicles within model years 2019–2021. Only two companies surpassed 40,000 electric vehicles sales in 2017 in the United States, so meeting the sales thresholds would represent a major increase and is unlikely for most companies. The ZLEV benchmarks proposed in Europe's 2025 and 2030 CO_2 standards are based on sales shares. The EU regulatory incentives would allow more lenient CO_2 standards for automakers that surpass the 15% ZLEV benchmark for 2025 or the 30% ZLEV benchmark for 2030. Several Europe-based automakers have indicated goals of 15%–25% electric vehicles by 2025, so the incentives are built to encourage them to at least meet these announced goals.

Table 1 summarizes the provisions in place in the three main electric vehicle markets described above. China, Europe, and the United States together represent more than 90% of all electric vehicles sold globally through 2017, and their regulatory frameworks often are followed elsewhere. Specifically, the federal Canadian standards,[19] along with the Québec ZEV regulation, are similar to the U.S.-California regulatory dynamic. As discussed above and summarized in the table, these major markets use regulations in somewhat different ways. China, Europe, and the United States each apply advantageous electric vehicle crediting including zero accounting and multipliers. Notably, though, the proposed 2025-and-later Europe and 2022-2025 U.S. regulations have removed multipliers.

18 Nic Lutsey, *Integrating electric vehicles within U.S. and European efficiency regulations* (ICCT: Washington DC, 2017). https://www.theicct.org/integrating-EVs-vehicle-CO2-regs

19 The federal Canadian regulation is similar in stringency to the U.S. standards, but its regulation includes electric vehicle multiplier values that are somewhat higher than in the United States, and its grid CO_2 intensity is substantially lower.

Table 1. Electric vehicle provisions in California, China, Europe, U.S. regulations.

Electric vehicle regulatory provisions	China	Europe		U.S.		California
	2020	2020	2025/2030[a]	2021	2025[b]	2025[b]
Crediting electric vehicles as zero (g/km, g/mile, L/100km)	✓	✓	✓	✓	✓ (with limit)	
Crediting electric vehicles extra with multiplier or super credit in CO_2, GHG, or fuel consumption regulation	✓	✓		✓		
Incentives via reduced stringency in regulation for voluntarily meeting minimum electric vehicle thresholds	✓		✓ (share)		✓ (sales)	
Targeted ZEV regulation to require increased electric vehicle deployment	✓					✓
Inclusion of electricity emissions in vehicle fleet impact assessment				✓	✓	✓

[a] *The EU standards for 2025 and 2030 are as proposed in November 2017.*
[b] *The US standards are presented as adopted in June 2018.*

Several major differences in the regulatory programs stand out from Table 1. A primary distinction is the use of dual standards in California and China, which both have performance standards and direct zero-emission vehicle requirements. The two other regulatory frameworks instead use voluntary minimum-threshold incentives: the European Commission's proposal does so with sales share benchmarks, and the United States does so with its extension of zero g/mile crediting for automakers that surpass sales benchmarks. The use of electric vehicle provisions introduces several risks, which are only to a limited extent accounted for in the regulatory analyses. For example, there are increased electricity production emissions as the provisions shift compliance approaches from conventional to electric vehicles. The various regulatory agencies have not conducted rigorous analyses of the effectiveness of the electric vehicle regulatory incentive provisions—for example, their effects on emissions, trade-offs with combustion vehicle emissions, or the ability to accelerate the launch of electric vehicles.

ASSESSMENT

This section fills several of the key gaps identified above in the prevailing regulatory analyses. In terms of the nearer-term impacts, the first part analyzes the lost emissions from electric vehicle regulatory incentive provisions, the effect on combustion vehicles, and how to mitigate the trade-offs between the two. In addition, this section assesses two longer-term implications of the analysis: how moving from performance standards to direct zero-emission requirements shifts the transition to a zero-emission fleet, and how this transition fundamentally changes the math regarding potential annual CO_2-emission reductions.

NEAR-TERM EFFECT OF ELECTRIC VEHICLE PROVISIONS

The regulatory provisions for electric vehicles are designed to increase electric vehicle investment and deployment beyond what would otherwise occur if companies focused on incremental efficiency improvements. As introduced above, counting electric vehicle emissions as zero emissions results in additional emissions that would not have occurred if the fleet of vehicles complied exclusively with conventional vehicles. This approach effectively relies upon separate regulations on the electric power sector to address the associated upstream emissions and the longer-term benefits from more electric vehicles ultimately resulting in lower emissions. Super credits effectively multiply the vehicle regulation incentive and the additional associated emissions. The effect of these provisions is greater if grid electricity has higher CO_2 emissions.

Table 2 summarizes the adopted and proposed fuel consumption, CO_2, and GHG emission standards; the associated electric vehicle shares as analyzed above; and the associated lost CO_2 emissions from the electric vehicle provisions. The lost CO_2 emissions are estimated as done in a related detailed analysis within a working paper on regulatory electric vehicle accounting.[20] As shown, the impact of the use of zero-emission accounting with multipliers in Europe and the United States, and multipliers typically erode from 1% to 18% of the CO_2 benefits from each regulatory period's intended reductions. China has zero emissions accounting, multipliers, and higher grid CO_2 emissions, and therefore has greater near-term lost CO_2 emissions of 17–35% from the regulation. California is the exception without lost CO_2 benefits, with a regulatory requirement for electric vehicles, upstream accounting, and without multipliers.

Table 2. Electric vehicle provisions in California, China, Europe, and U.S. regulations.

	Regulation period	Status	Electric vehicle provisions	New vehicle fuel use or CO_2 reduction over period[a]	Electric vehicle share[b]	Near-term CO_2 impact from electric vehicle provisions[c]
China	2016–2020	Adopted	Zero, multiplier, regulation	29%	3%–7%	-17% to -35%
Europe	2015–2021	Adopted	Zero, multiplier	21%	4%–6%	-11% to -18%
	2022–2025	Proposed	Zero	15%	8%–14%	-4% to -6%
	2026–2030	Proposed	Zero	17%	15%–25%	-8% to -14%
United States	2017–2021	Adopted	Zero, multiplier	11%	2%–3%	-9% to -15%
	2022–2025	Adopted, under review	Zero, multiplier	12%	2%–5%	-1% to -3%
California	2017–2025	Adopted	Regulation	22%	8%–15%	0%

[a] *Test cycle improvement (e.g., excluding conditioning credits).*
[b] *Share of new vehicles in final year of regulation period, includes battery electric, plug-in hybrid, and fuel cell electric, based on regulatory analyses and ICCT scenarios for minimum compliance with the standards.*
[c] *Calculated as change in minimum required CO2 reduction level for all new vehicles in final year of regulation period, after electric vehicle penetration is included, compared to if electric vehicle upstream emissions were accounted for.*

The existence of these eroded CO_2 emission impacts is approximately known at the time of the regulatory analyses, but they are typically not explicitly analyzed. Instead, these provisions were generally deliberated on the basis of whether the industry would likely deploy electric vehicles before 2020 or 2025 if the electric vehicle regulatory incentives were or were not in place. The typical argument was that the high cost of electric vehicles prevented their deployment as a substantial component of each major automaker's compliance approach. As a result, the provisions were included, despite

20 These and the calculations below are based on the methods in Nic Lutsey, *Integrating electric vehicles within U.S. and European efficiency regulations* (ICCT: Washington DC, 2017). https://www.theicct.org/integrating-EVs-vehicle-CO2-regs

the CO_2 losses, as the provisions would serve a broader purpose in accelerating electric vehicles to bring greater decarbonization over the longer-term.

TRADE-OFF IN ELECTRIC UPTAKE AND COMBUSTION IMPROVEMENTS

The trade-off in combustion vehicle improvements due to increased electric vehicles becomes more consequential over time. To better understand this dynamic, internal combustion vehicle CO_2 emissions are analyzed in the particular context of the European CO_2 2025–2030 regulatory context. Figure 6 shows two cases, one for a fleet with base case electric vehicle uptake that increases to 11% in 2025 and 20% in 2030. Essentially this is the same case presented as in Figure 3 above, but now the blue line and left vertical axis are the CO_2 emission rate only for the combustion vehicles, whereas Figure 3 is for the full fleet including electric vehicles. As shown, under a scenario where an auto company chooses to make a major shift to electric to reach the proposal's ZLEV benchmarks, the company will be allowed to produce combustion vehicles with the same CO_2 in 2030 as in 2018.

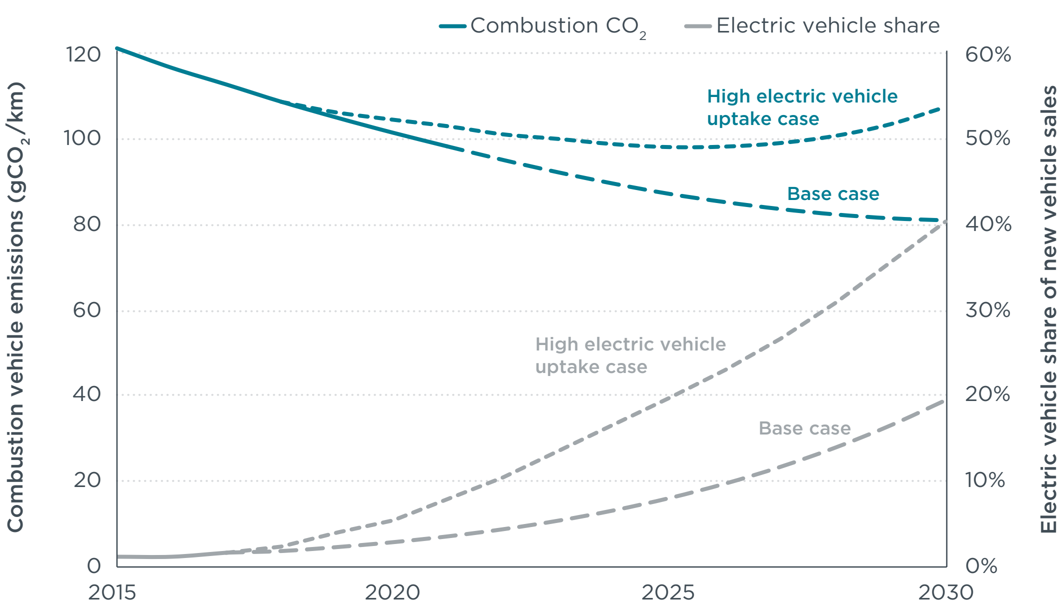

Figure 6. Combustion vehicle CO_2 rate to minimally comply with proposed 2025 and 2030 standards in Europe, given varying electric vehicle shares through 2030.

As shown in Figure 6, if CO_2 and electric vehicle benchmarks are both minimally complied with, combustion vehicle emissions would be allowed to stagnate, or even increase, over the 2021–2030 regulatory period. This would leave a lot of highly cost-effective combustion efficiency technology underutilized. This essentially is true whenever electric vehicles are increasing at rates like those shown in the figure (i.e., from 10% to 30%). This same dynamic is true for California. If California's market reaches its ZEV target of 5 million ZEVs by 2030 (up to 50% ZEV share of new vehicles by 2030), and it maintains GHG standards at less than 6% per year, combustion vehicles will be able to emit higher emissions over time in a compliant vehicle fleet. This indicates that, for the CO_2 and ZEV targets to be compatible, fleet CO_2 annual rates of improvement would need to be greater than the customary 3%–5% per year of current standards around the world. This is further analyzed for longer-term context below (see Table 3).

MITIGATING ELECTRIC AND COMBUSTION VEHICLE CO_2 TRADE-OFFS

As introduced, three of the major regulated markets have electric vehicle targets: California for 5 million zero-emission vehicles by 2030, China for a 20% new electric vehicle share by 2025, and the European Union for a 30% new electric vehicle share by 2030. These regions also have goals related to reducing CO_2 emissions. As a result, it is important to investigate the circumstances under which the electric vehicle provisions result in CO_2 benefits with overall CO_2 stringency, minimum combustion vehicle requirements, or targeted ZEV regulations.

Going beyond the impacts of Table 2, the following analysis factors in the interplay between CO_2 and ZEV requirements to assess the impact of moving from 2030 emission standards in California and Europe to also include a targeted ZEV regulation in parallel. Europe's CO_2 standard is likely to reach up to about a 20% electric share by 2030, whereas achieving the ZLEV benchmark is likely to double that to 40% (see Figure 3). In California, the GHG standards would deliver only about 18% electric vehicle share in 2030, whereas reaching 5 million ZEVs would require up to a 36%–50% electric share by 2030 (see Figure 5).

Figure 7 summarizes the electric vehicle shares and the CO_2 impact from the electric vehicle regulatory provisions in the California, China, Europe, and U.S. 2020–2030 policy contexts. The electric vehicle share (on the horizontal axis) is based on minimum required electric vehicle shares to meet the prevailing CO_2 and electric vehicle regulatory targets. The g/km CO_2 effect (on the vertical axis) is based on the differential impact only from the electric vehicle provisions (i.e., zero accounting, multipliers, requirements for electric vehicles). The circles represent the general uncertainty from this analysis and that of the regulatory agencies implementing the policies. The dashed circles for 2030 Europe and California are hypothetical in that no such regulatory policy has been released.

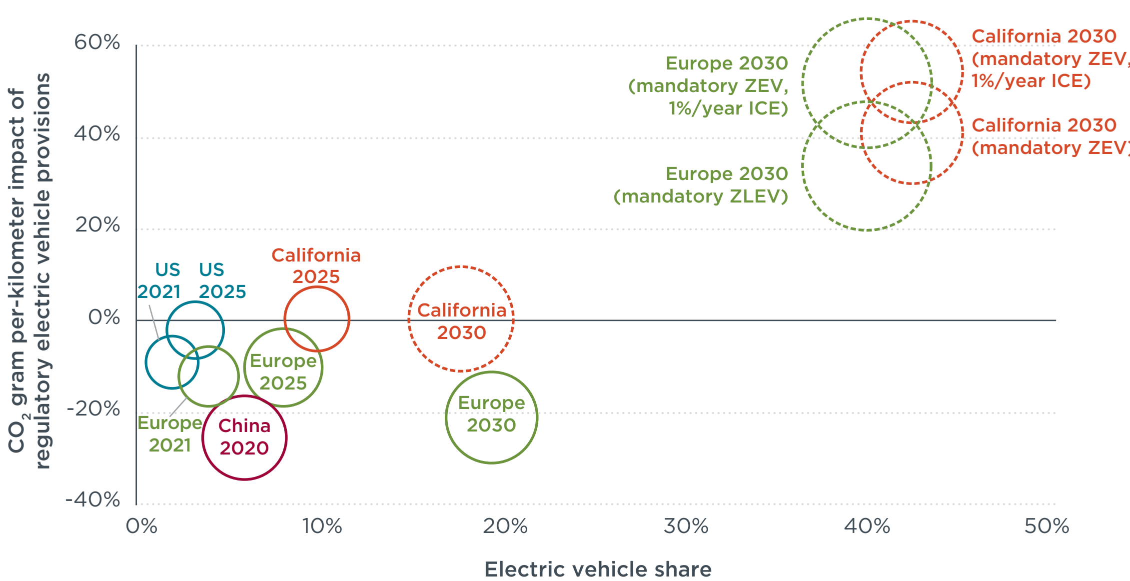

Figure 7. Impact of electric vehicle regulatory provisions on CO_2 emission reduction from the regulation.

Several basic points emerge from Figure 7. The near-term regulations (China 2020, Europe 2021, and US 2021–2025) each contribute to lost CO_2 emission benefits, due to the zero-emission accounting and multipliers. Because electric vehicle deployment in the United States and Europe is low, at about 2%–8%, the total lost CO_2 emission benefits is quite small in the near term. The lost CO_2 benefits are larger in the China 2020 case due to the higher grid CO_2 emissions there. The post-2025 implications for China and the United States are uncertain so they are not assessed in Figure 7. China's targets of four L/100 km and approximately 20% electric vehicles for 2025 suggest that electric vehicle requirements are likely to follow. Because there is high uncertainty about how the 2025 China fuel consumption and NEV regulations could be interlinked with more trade-offs, they are not assessed in the figure. In the United States, the adopted 2017–2025 GHG and ZEV regulations require up to 5% electric share by 2025, but a 2018 regulatory process could relax the U.S. standards and delay the shift toward electrification in the United States.

For California, as shown in Figure 7, if the 2030 target of 5 million electric vehicles were turned into regulatory requirements, there is the potential for increased GHG benefits. If the 2025–2030 policy path is to include GHG standards alone at 5% CO_2 reduction per year, this would deliver about an 18% electric vehicle share by 2030. Moving from 2030 GHG standards alone to also include a ZEV regulation to achieve 5 million ZEVs would likely increase the new electric vehicle share to above 40%. The impact of this would be to increase CO_2 emission benefits by approximately 40%, leading to an ultimate 2030 emission level of 133 g/mile, instead of 151 g/mile, if just 5% per year lower annual CO_2 standards were deployed. Including incremental CO_2 improvements in combustion vehicles of 1% per year alongside the ZEV requirement would increase the CO_2 benefit, resulting in 127 g/mile in 2030.

If Europe persists with 2025 and 2030 CO_2 standards as proposed, the zero emission accounting for electric vehicles will continue to detract from the CO_2 emission benefits from the regulations. In this estimate, the proposed standards would deliver 70 g/km in 2030, rather than 67 g/km, on the NEDC cycle once upstream accounting is considered. Just comparing the 2030 points in Figure 7 provides some clarity on how much greater the CO_2 benefits would be from shifting the ZLEV benchmark to a requirement. Comparing Europe's 2030 CO_2 reduction from performance standards alone to including a parallel ZLEV requirement at 40% electric share would increase the CO_2 benefits in 2030 vehicles by about 40%. This would mean delivering 60, rather than 67, g/km in 2030.

To further quantify these emission effects, cumulative CO_2 impacts are analyzed for the three phases of the European standards ending in 2021, 2025, and 2030. Figure 8 illustrates the CO_2 impact, again, from just the regulatory electric vehicle provisions. The figure's calculations include all the vehicles between the regulatory period dates, assuming 180,000 km over each vehicle's lifetime. The adopted 2021 standards, including super credits and zero accounting, result in a loss of about 20 million metric tons of CO_2. The proposed 2025 and 2030 standards include 16 and 33 million metric tons of lost CO_2 benefit, respectively, due to zero g/km accounting. In terms of the percentage of overall CO_2 emission-reduction benefits in these three periods, the CO_2 losses amount to about 8% in 2016–2021, 16% in 2022–2025, and 27% in 2026–2030. The losses would be greater than illustrated here if any companies surpassed the voluntary ZLEV benchmarks.

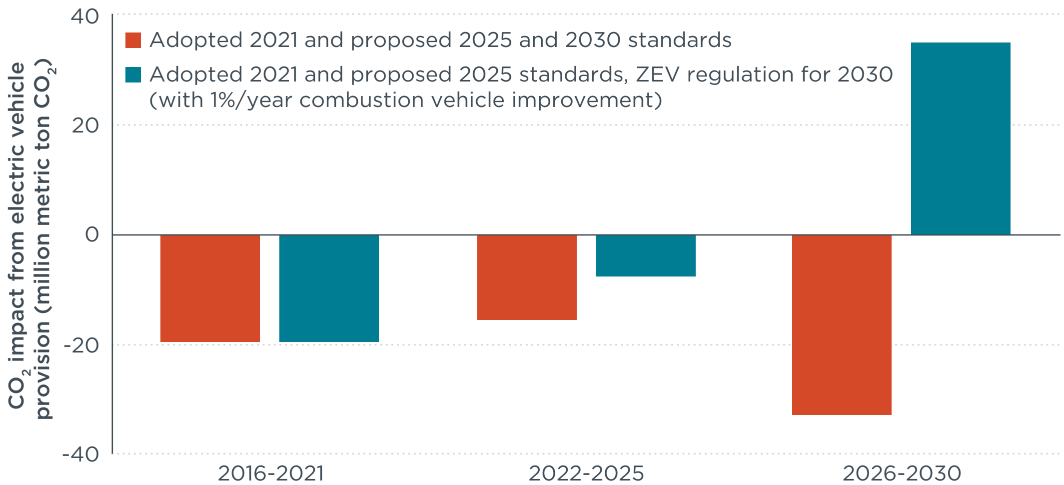

Figure 8. Electric vehicle CO_2 impacts from electric vehicle regulatory provisions for three regulation periods in Europe, proposed and modified approaches.

Also shown in Figure 8 is a path that can recover the lost CO_2 tons from the electric vehicle provisions from 2016–2022 by modifying the proposed 2030 standard. The modified scenario in blue shows the proposed 2025 standards, but with a conversion of the 2030 ZLEV benchmarks to be mandatory, and also requiring CO_2 improvements of 1% per year for 2026–2030 combustion vehicles. That modified scenario results in 2026–2030 benefits of 35 million metric tons of CO_2. This scenario would effectively "pay back" the lost CO_2 from electric vehicle regulatory incentives from the previous years of 2016–2025, ensuring the electric vehicles are providing a direct environmental benefit by 2030. This also would effectively ensure the new vehicle fleet is on a path toward broader electrification. This provides a clear indication of how the European Union can modify its 2025–2030 CO_2 proposal to ensure environmentally beneficial electric vehicle provisions.

SHIFT TO ELECTRIC-DRIVE FROM DIRECT REGULATION

Perhaps the most substantial question of this research is to what extent electric vehicle regulatory requirements could shift the transition to a zero-emission fleet forward. As analyzed above, electric vehicle incentives (multipliers, voluntary benchmarks within standards) are not launching a mainstream market, but they can provide an effective incentive in the initial pre-2025 launch phase without major lost CO_2 benefits. Targeted ZEV requirements have the ability to launch the mainstream electric market much faster.

The ability to accelerate the electric vehicle launch by converting the ZLEV benchmarks to a ZEV regulation is assessed in Figure 9. The figure illustrates the conventional vehicle and electric vehicle technology paths that approximate the European situation of regulating CO_2 as proposed, which is to say without a ZEV regulation, and with a ZEV regulation. As analyzed above, the proposed CO_2 standards drive as much as 11% electric vehicles in 2025, and up to 20% in 2030. If the ZLEV benchmarks were converted to a ZEV regulation, those electric vehicle penetrations increase to 20% in 2025 and 40% in 2040. The figure fits those two paths to illustrate long-term logistical uptake curves. The proposed policy path is the adopted standards through 2021, the proposed standards through 2030, and a hypothetical path to all new zero-emission vehicles after 2045. The accelerated path converts the 2030 ZLEV benchmarks to ZEV requirements, essentially shifting the electric-drive deployment forward by 5 years. This shift to a requirement would bring the 50% conventional vehicle share point forward from 2037 to 2032.

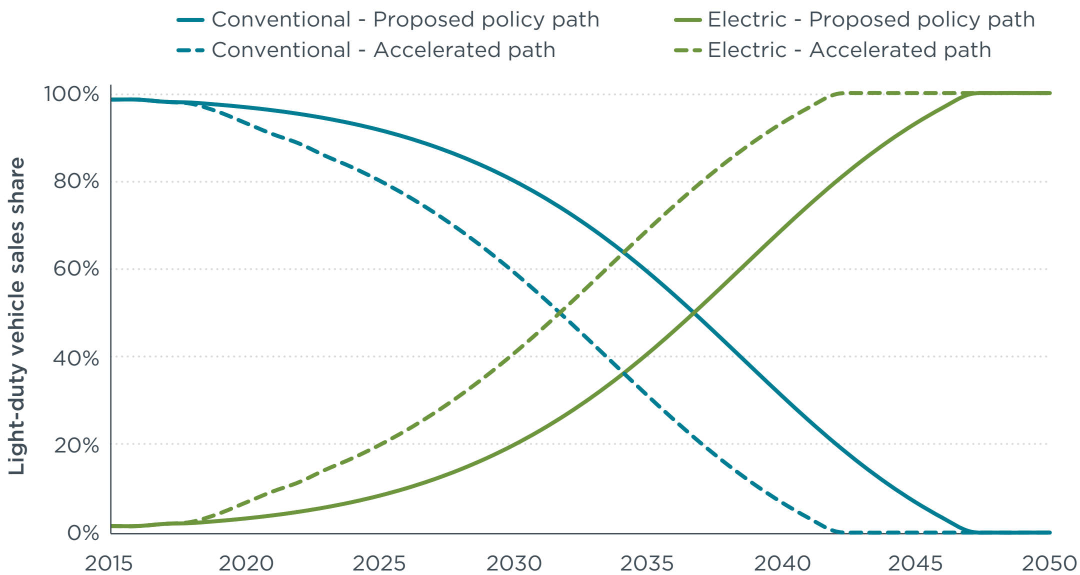

Figure 9. Conventional vehicle and electric vehicle shares in baseline and accelerated electric deployment scenarios in Europe, 2015–2050.

There is, of course, no guarantee that a ZEV 2030 requirement would shift the industry to the accelerated path for all zero-emission vehicles beyond 2030 without continued ZEV regulations after 2030. However, the continued shift to zero-emission vehicles post-2030 could be likely for several reasons, primarily due to the substantial volumes involved in a market the size of Europe's. The accelerated timeline results in more than 1 million annual electric vehicles being sold in 2021, 3 million in 2025, and 6 million in 2030. This accelerated path ensures leading companies move to scale and profitability. Because of many companies announcing their commitment to such scale, which is further discussed below, this does seem feasible. In addition, the auto companies that are lagging on electrification would benefit from large-scale battery suppliers that achieve high volume. With 40% market share in 2030, the market transformation would be well underway.

HOW ELECTRIC VEHICLES CHANGE THE MATH ON ANNUAL CO_2 REDUCTION

As a final related analysis, the basic math regarding CO_2 emission reductions amid the long-term electric transition are investigated further. Regulatory fuel consumption, CO_2, and GHG standards around the world typically have required incremental improvements at 3%–5% per year annual reduction in CO_2 emission rate per kilometer from new vehicles. When electric vehicle penetration is increasing as rapidly as it is expected to in the 2020–2030 time frame, electric vehicles become the dominant driver for lower CO_2 emissions. This occurs because electric vehicles provide a much greater CO_2 reduction (i.e., up to 100%, based on zero emission accounting), overwhelming the compliance impact of incremental combustion vehicles. Per the above analysis, if electric vehicle shares increase within 3%-5% per year regulatory CO_2 reductions, combustion vehicles can emit higher CO_2 emissions. This interplay between CO_2 standards, combustion vehicle improvements, and increasing electric vehicle penetration is analyzed below.

Table 3 shows the annual regulation CO_2 improvement for given zero-emission vehicle transition periods, from 10 to 30 years, and for given combustion vehicle annual CO_2 improvement, from 1% to 4% per year. Moving down in the table's rows is indicative of a slower transition to electric vehicles, and moving across the columns to the right reflects greater improvements in combustion vehicle efficiency. The table considers the transition period as the time to shift from 10% to 90% new zero-emission vehicle sales, as the first 10% and the last 10% are likely to be the slower parts based on historical adoption of most technologies. Illustrative time periods are given to match the transition timing most governments have discussed (i.e., by 2030, 2040, and 2050). Zero-emission vehicles are assumed to be counted as zero in the regulations, because no regulatory agencies are establishing long-term upstream life-cycle fuel cycle emission frameworks. As a result, the basic math in the table does not depend on baseline combustion vehicle, grid emissions, or regional context.

Table 3. Annual regulation CO_2 rate of improvement for a given zero-emission vehicle transition period (10–30 years) and given combustion vehicle CO_2 improvement rates.

Transition period from 10% to 90% zero-emission share of new vehicles	Annual regulation CO_2 reduction rate for given combustion vehicle CO_2 reduction rate of 1%–4%			
	1% per year combustion improvement	2% per year combustion improvement	3% per year combustion improvement	4% per year combustion improvement
10 years (e.g., 2020 to 2030)	21%	22%	23%	24%
20 years (e.g., 2020 to 2040)	12%	13%	14%	14%
30 years (e.g., 2020 to 2050)	8%	9%	10%	11%

Table 3 shows that electric vehicle transition requires much greater CO_2 improvements than have been adopted in any vehicle regulation in world. Historically, CO_2 regulations typically have resulted in 3%–5% CO_2 g/km of improvement per year, but even in the least aggressive 30-year shift to electric would require an 8%–11% CO_2 rate of improvement per year over that entire period. If the transition is meant to be faster—as in the goals of France, Netherlands, Norway, and the United Kingdom—the CO_2 improvement will have to be more than 20% per year.

As shown, achieving greater improvements from combustion vehicles (i.e., moving from left to right), has a much smaller impact than the transition to electric vehicles. The 20-year scenario is probably the closest to a complete transition to zero-emission new vehicles by 2050, allowing for the last 10 years, from 2040 to 2050, for a slower diffusion across harder-to-reach vehicle segments, such as high-mileage vehicles and niche low-volume vehicle types. From this, it can be inferred that with a transition to 100% zero-emission vehicles by 2050, CO_2 regulations with 12%–14% annual CO_2 improvement from 2020–2040 would be needed. This is roughly 3 times the historical CO_2 improvement rates. These calculations make it clear that, from 2025 on, much higher annual CO_2 reductions are needed from regulations to be compatible with phasing electric vehicles into the fleet.

DISCUSSION

Based on this analysis it is evident that the 2020–2030 time period is a key turning point for electric vehicles, and for vehicle regulations to integrate them. Electric vehicles will transition from needing major incentives to reaching cost parity in many vehicle segments. This opens up many previously unencountered issues about how to modernize the standards. To conclude the briefing, this section summarizes principles for incorporating electric vehicle provisions within efficiency regulations, discusses the emerging rationale for direct electric vehicle requirements, and draws final conclusions.

PRINCIPLES FOR ELECTRIC VEHICLE REGULATORY PROVISIONS

Several principles regarding regulatory design emerge to best incorporate electric vehicles into vehicle regulations. The principles below are based on the analysis above as well as the intent of the regulations to ensure maximum near-term benefits mainly from combustion vehicles, as well as long-term benefits that increasingly come from electric-drive vehicles.

Quantify near-term effects of electric vehicle incentives. As analyzed (see Figure 7), regulatory electric vehicle incentives limit combustion vehicle improvements and result in lost CO_2 emission benefits. The effects vary and can be substantial depending on overall regulation stringency, electric vehicle share, and grid CO_2 intensity. All regulatory agencies have failed to directly analyze how their regulatory flexibilities are changing compliance and electric vehicle shares within their regulatory assessments. Quantifying the effects, including the lost benefits from the provisions, is the starting point for assessing their worth. The European 2030 case constrains the CO_2 trade-off from electric vehicle regulatory incentives to 5% of CO_2 emissions, but it fails to assess the lost emissions from continuing to count electric vehicles as having zero emissions through 2030. The China case could gain from quantifying the expected L/100 km and NEV shares when setting the post-2020 standards, especially due to the two regulations' explicit trade-offs.

Phase out the use of electric vehicle multipliers. Artificial electric vehicle incentives like multipliers or super credits especially detract from the explicit purpose of the standards, which is to reduce emissions. Such regulatory incentives can have a useful role while electric vehicle shares are below 5%, beyond which the lost emission benefits become too great to justify. The phaseout of multipliers in Europe and the United States in 2022–2023 shows the increased understanding of this principle, namely that artificial incentives serve as temporary, early-market sparks for these larger markets. The use of multipliers in China's 2020 fuel consumption regulations, resulting in the most substantial trade-off in CO_2 benefits of potentially greater than 30%, demonstrates the importance of phasing out multipliers.

Ensure combustion and electrification trends are compatible within CO_2 standards. Regularly occurring combustion improvement of several percent per year can be expected alongside long-term electrification. Quantifying the effect on the combustion vehicles is critical to see if the electric vehicle provisions are compatible with the overall CO_2 emissions level. The European case (see Figure 6) shows a mismatch where achieving the ZLEV benchmark makes the 2025 and 2030 standards ineffectual in driving cost-effective CO_2 improvements from combustion vehicles. In this situation, stronger CO_2 standards, direct ZEV requirements, or minimum combustion vehicle requirements are warranted to better align the trends. The California post-2025 standards will have a similar dynamic as they consider performance standards and their ambitious 5-million-electric-vehicle goal for 2030. The federal 2025 U.S. standards are not stringent enough to cause this mismatch between combustion vehicle improvement and electric vehicle uptake. With electric vehicle cost parity around 2025–2030, it will become important for regulatory agencies to consider how electric vehicles drive down the overall compliance cost of CO_2 regulations.

Define the rationale for electric vehicle regulatory incentives. The use of regulatory flexibilities, including zero-emission counting, multiplier provisions, and any caps or thresholds for them, tend to emerge late in the regulatory development process. As a result, not only are their effects hardly analyzed, but they also become dictated by negotiations, rather than as a deliberate, science-driven effort to set standards to drive the longer-term transition to electrification. An improved principle would be for regulatory agencies to clearly define the rationale for artificial electric vehicle incentives over the near-term, quantify their expected effect during the regulatory period, and assess how they impact different automakers (e.g., those focused on exhausting the use of advanced combustion technology versus those more rapidly shifting to electric drive).

State the long-term vision for zero-emission vehicles. It is important that regulators offer a clear post-incentive vision to drive the fleet toward zero emissions. Because regulatory incentives decrease near-term CO_2 benefits, it becomes even more critical for regulators to clarify their vision for when and how electric vehicles deliver greater benefits over the long-term. Without a vision, the prospect seems clear that one regulation at a time keeps trading off CO_2 benefits for electrification. Such a vision could be quantified in two clear ways: showing how stronger CO_2 standards after the artificial incentives make up for the lost CO_2 benefits (see Figure 8) and illustrating how electric vehicle provisions accelerate the path for electrification (see Figure 9). To date, no regulatory agency has quantified when or how the initial lost CO_2 benefits will be made up, how many years their regulatory provisions accelerate the shift to electric drive, or when electric vehicles will drive emission benefits beyond performance standards.

RATIONALE FOR TARGETED ZERO-EMISSION VEHICLE REGULATIONS

The above analysis and principles point to the fundamental question about whether to directly require electric vehicle deployment, as done in California, China, and Québec, and as considered in the 2017 proposed European 2025 and 2030 standards. The positive technology developments, the limitations of incremental 3%–5% reduction-per-year CO_2 standards, and the necessity of a transition to electric-drive for decarbonization further motivate this question. Before making final conclusions, a variety of arguments related to the emerging attractiveness of targeted ZEV regulations are discussed here.

Persisting issues with real-world emissions. The persisting difficulty in reducing real-world emissions from the multitude of conventional vehicles is increasingly a reason for targeted ZEV regulations. More stringent standards push advances in new combustion vehicle technologies. With these developments, the real-world CO_2 and efficiency gains continue to be less than the purported regulatory benefits.[21] There are only a few regulatory agencies worldwide with laboratory testing facilities to scrutinize emission results and with legal authority to ensure regulations translate to real-world benefits. Shifting the power sources from billions of combustion vehicles to a decarbonizing mix of diverse power generation sources largely removes this risk. As the grid decarbonizes, electric vehicles get cleaner as they age, while combustion vehicles, of course, do not. Recognizing that there never will be a perfect regulatory test cycle nor a universal enforcement system, the long-term ultimate goal of combustion-free vehicles becomes clearer. Focusing on zero-emission vehicles sidesteps the incremental approach.

Automaker electric vehicle announcements exceed regulatory requirements. Whereas automakers do not proclaim they will substantially surpass future emissions standards, they do increasingly make electric vehicle announcements that outpace existing regulatory requirements. Figure 10 shows electric vehicle deployment to comply with 2020–2025 regulations, along with a tally of company electric vehicle statements by 2025. The policy projections shown are the strongest under consideration, as assessed above, including the United States retaining its 2025 standards, California strengthening its ZEV regulation (to meet its 2030 ZEV goal), Europe converting its proposed 2025 benchmark to a requirement, and China converting its 2025 target for a 20% electric vehicle share into a ZEV regulation. These sum to global annual sales of more than 3 million vehicles in 2020 and about 10 million by 2025. The auto industry announcements, at more than 15 million annual electric vehicle sales in 2025,[22] are about 50% greater than the regulatory requirements. Targeted ZEV regulation translates these announcements into enforceable requirements to ensure mass production. In addition, these companies represent about half of global vehicle sales, so requirements would ensure all manufacturers commit to electrification.

21 Uwe Tietge, Sonsoles Diaz, Zifei Yang, and Peter Mock, From laboratory to road international – A comparison of official and real-world fuel consumption and CO_2 values for passenger cars in Europe, the United States, China, and Japan (ICCT: Washington DC, 2017). http://www.theicct.org/publications/laboratory-road-intl

22 Nic Lutsey, Mikhail Grant, Sandra Wappelhorst, Huan Zhou, *Power play: How governments are spurring the electric vehicle industry* (ICCT: Washington DC, 2018). https://www.theicct.org/publications/global-electric-vehicle-industry

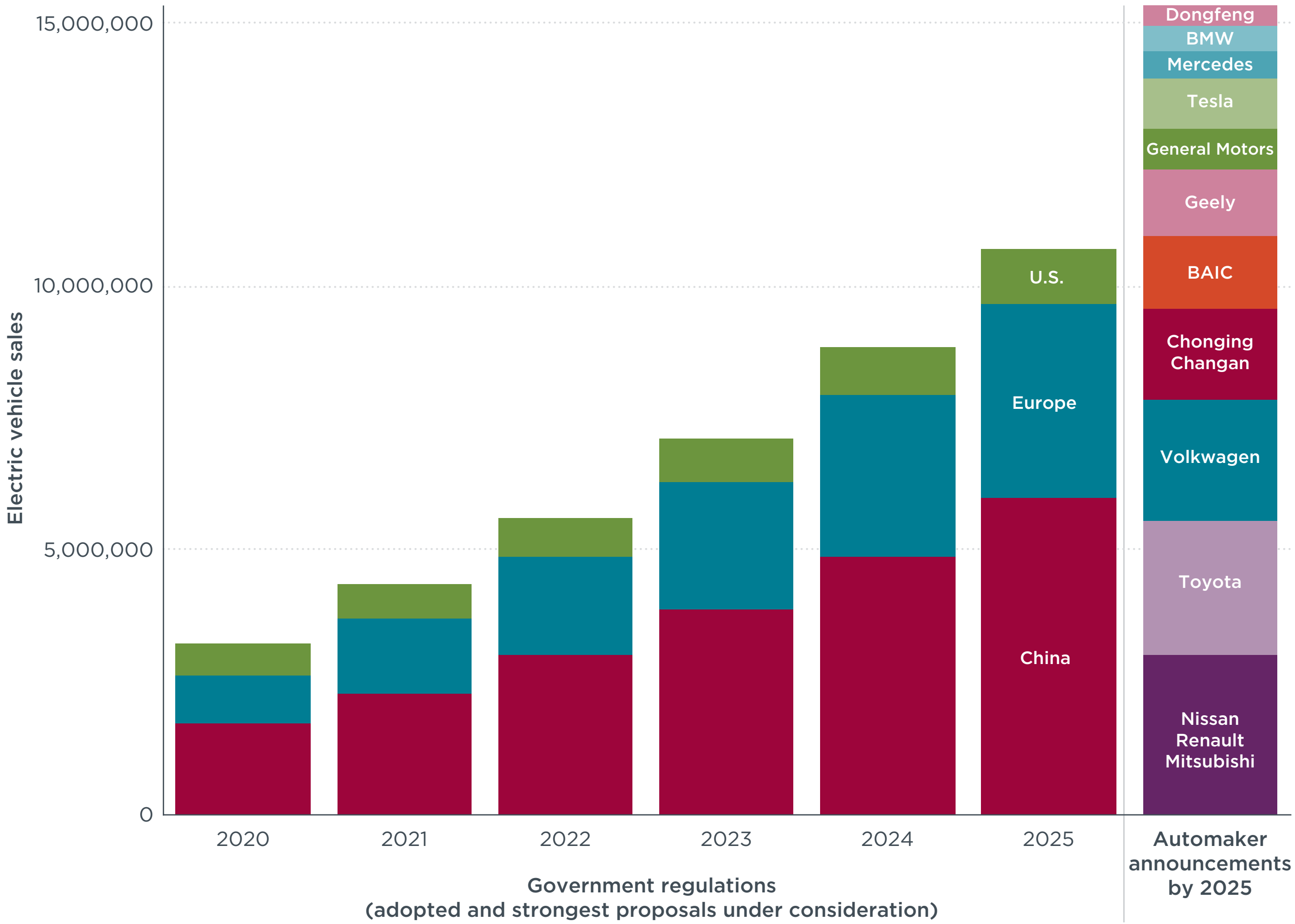

Figure 10. Government regulation and 2025 automaker targets for electric vehicles.

Insufficiency of voluntary electric vehicle goals. Perhaps the most obvious reason of all that governments may be justified in modifying their regulations to require electric vehicles is that incremental standards with voluntary goals will not be sufficient to launch the electric vehicle market. Many voluntary electric vehicle goals have passed without success (e.g., 250,000 for Spain by 2014, 1 million for the United States by 2015).[23] Electric vehicles have multiple barriers to achieving market success. Among them the primary one is the availability of electric models to meet customers' diverse demands. Based on the assessment above, the shift from a voluntary ZLEV benchmark in Europe, as currently proposed, to a ZEV regulation could shift the transition in Europe forward by 5 years. The ZEV regulation has helped bring more than 30 electric vehicle models to market in California, whereas just a small fraction of these models are available in the rest of the United States.[24] As this analysis points out, a swift transition to electric requires much stronger efficiency standards or targeted ZEV

23 Nic Lutsey, *Global climate change mitigation potential from a transition to electric vehicles* (ICCT: Washington DC, 2015). https://www.theicct.org/publications/global-climate-change-mitigation-potential-transition-electric-vehicles

24 Peter Slowik, Nic Lutsey, *Expanding the electric vehicle market in U.S. cities* (ICCT: Washington DC, 2017). www.theicct.org/publications/expanding-electric-vehicle-market-us-cities

regulations, and many major auto companies are now planning on dramatic increases in electric vehicle deployment.

Lack of other options to ensure high availability of electric models. There are many supply-side and demand-side policy options to spur the market. Once there are incremental standards, attractive consumer incentives, consumer campaigns, and a growing charging infrastructure network, this can still leave insufficient model availability as a key impediment. Limited supply can be due to the manufacturer—for example, where it makes 20,000 to 50,000 electric vehicles of a given model—opting to predominantly sell them within a select few markets around the world. This is also reflected at the dealer level. There often are relatively few discrete electric models on hand at local dealer lots at a given time, as compared to the many options on hand for conventional combustion models to which potential customers are accustomed to having access. No government has proposed a mechanism for a dealer-level vehicle supply requirement. Instead, manufacturer-level ZEV regulations are used, and they allow manufacturers and dealers the flexibility to determine where and how they supply and incentivize electric vehicles.

New framework for the transition to zero-emissions. Existing regulatory standards around the world have required incremental 3%–5% per year annual reduction in CO_2 emissions. These incremental rates were in large part due to the lead time necessary to redesign vehicles and their combustion powertrains in 6- to 8-year production cycles. As shown in Table 3, historical per-year fleet improvements are nowhere near the annual changes for a transition to zero-emission new vehicles. Performance standards even for a three-decade transition to a predominantly electric fleet will require 8%–11% per year CO_2 reduction from new vehicles. Many governments are setting targets for much faster electrification, meaning greater than 20% annual CO_2 reductions from new vehicles. Unless regulatory agencies are willing to set this type of strong CO_2 standards, targeted ZEV regulations offer a simpler regulatory framework.

POLICY CONCLUSIONS

As indicated in this analysis, regulatory frameworks are playing catch-up on all these bullish electric vehicle developments. The above discussion of principles for integrating electric vehicle requirements in CO_2 standards and the rationale for considering targeted ZEV regulations lead to two high-level policy conclusions.

Efficiency standards are essential but insufficient to launch a mainstream electric vehicle market. Governments in most major auto markets have set efficiency and CO_2 standards based on incremental efficiency. The strongest possible policies under consideration will deliver up to 5% electric share in the United States, 11% in Europe, and 20% in China by 2025. This results in less than one-tenth of the world's vehicle sales being electric in 2025, with about half in China. Meanwhile, regulations elsewhere are being challenged. Although these developments will expand electric vehicle model availability and reduce costs, this does not equate to a tipping point, to profitability beyond a few market leaders, or to an inevitable transition.

Ensuring the transition to electric by 2050 means much bolder efficiency standards or direct electric vehicle requirements are needed. Many governments aim for decarbonization by midcentury, but their regulations are not yet steered in that direction. By the mid-2020s, regulations will have to pivot from using artificial electric vehicle incentives—for example, multipliers—to using electric vehicles to drive greater emission reductions and put markets on a path toward decarbonization. With electric vehicles becoming cost-effective from 2025 on, much more rapid gains are possible. The transition to all zero-emission vehicles by 2050 entails a 12%–14% annual CO_2 improvement in new vehicles from 2020–2040. This means regulations would need to roughly triple the historical CO_2 improvement rates or include targeted ZEV regulations to drive the transition to a zero-emission fleet. Although much bolder efficiency standards and ZEV regulations can be functionally equivalent, ZEV regulations provide greater assurance in launching the electric market, because automakers' innovative efforts to meet lower test-cycle emission levels with combustion technology keep it in the market.

Although it was beyond the scope of this briefing, this analysis also has implications for the other emerging major auto markets around the world. It is conceivable that the fastest-growing markets could eventually electrify at faster rates due to how China, Europe, and the United States are driving up electric vehicle production volumes. Growing markets across the Asia Pacific, Latin America, and the Middle East have only very limited electric vehicle models available and very low sales. Rather than go through the growing pains described here, newer electric markets can capitalize on the electric vehicle production and adopt post-2025 CO_2 regulations or targeted ZEV regulations that directly require an increasing share of electric-drive vehicles. Without adopting a ZEV regulation, sustained CO_2 standards that advance at 12% or greater annual CO_2 improvement in such markets will drive the transition to ZEVs by 2050, based on our analysis here.

This briefing is focused on the role of regulatory action to catalyze the transition to zero-emission vehicles, but of course many other actions also will be key for the transition. Regulations drive investment, model availability, production scale, and lower costs, but there are other barriers. States and cities develop local policy, use nonfinancial incentives, pave the way for charging infrastructure, and expand consumer awareness. Power utilities are critical not only in helping deploy charging infrastructure but also in integrating electric vehicles with increasingly renewable power sources. Emerging players, especially ride-hailing fleets, could become a major market driver in the shift to zero emissions. Regulations are but one component of electrification, but they play a critical role in spurring the broader industrial shift, and in signaling that shift to the rest of the market, infrastructure, and local players.