BRIEFING

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Zero-emission integration in heavy-duty vehicle regulations: A global review and lessons for China

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INTRODUCTION

Heavy-duty vehicles, dominated by diesel-powered engines, are a major contributor to greenhouse gas (GHG) emissions and air pollution. In China, trucks make up 10.9% of the on-road vehicle fleet, but are responsible for 83.5% of nitrogen oxides (NO_x) and 90.1% of particulate matter (PM) pollution from all vehicles.[1] Medium- and heavy-duty vehicles in China contribute 46.9% of overall GHG emissions from road transport activities.[2]

The fast pace of electrification in the passenger vehicle and bus segments has not occurred with heavy-duty trucks. Still, manufacturers and commercial fleets are making pledges to electrify trucks and vans in their production and operations. The movement toward zero-emission heavy duty vehicles (ZE-HDVs) is gaining momentum, but barriers like limited ZE-HDV model availability, higher vehicle prices compared with ICEs, incipient demand, and limited recharging and refueling infrastructure can hinder the pace of ZE-HDV adoption.

Important policy windows on the horizon in China and elsewhere create an opportunity to steer the HDV market toward greater and faster adoption of zero-emission technologies. In this paper, we analyze policy instruments that promote and encourage adoption of ZE-HDVs around the world and identify seven policy levers that can inform China's regulators as they design ZE-HDV policies.

In this paper, zero-emission heavy-duty vehicles refers to vehicles with maximum weight ratings greater than 3.5 tonnes (t) that are equipped with powertrain technologies that produce no tailpipe emissions of greenhouse gases and air pollutants. ZE-HDVs are battery-electric and hydrogen fuel-cell vehicles. This paper will cover freight-carrying heavy-duty rigid trucks and tractor-trailers. Buses are outside the scope of the analysis.

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ZE-HDV ADOPTION TARGETS AND SALES REQUIREMENTS

One policy option for promoting ZE-HDVs is to set targets that require a certain number or share of HDV sales or stock to be zero-emission. Such sales and stock targets have been implemented for light-duty vehicles (LDVs) and are documented to be effective in spurring rapid deployment of zero-emission vehicles.[3] Regulators are now broadening sales and stock targets to cover HDVs.

The path to legally binding zero-emission new sales requirements typically starts with high-level visions, established by policy makers and without enforcement mechanisms, that set a general direction for policy and that may eventually lead to a binding legislative act. Therefore, the discussion below is divided into two parts: non-binding targets for the full phase-in of ZE-HDVs, and enforceable binding regulations.[4]

Non-binding targets are political in nature, communicate the general policy of the government in power, and are relatively easy to adopt as they typically involve only the executive branch. A summary of non-binding targets that include or specify ZE-HDVs around the world is shown in Table 1.

Table 1. Examples of non-binding sales and stock targets that affect ZE-HDVs

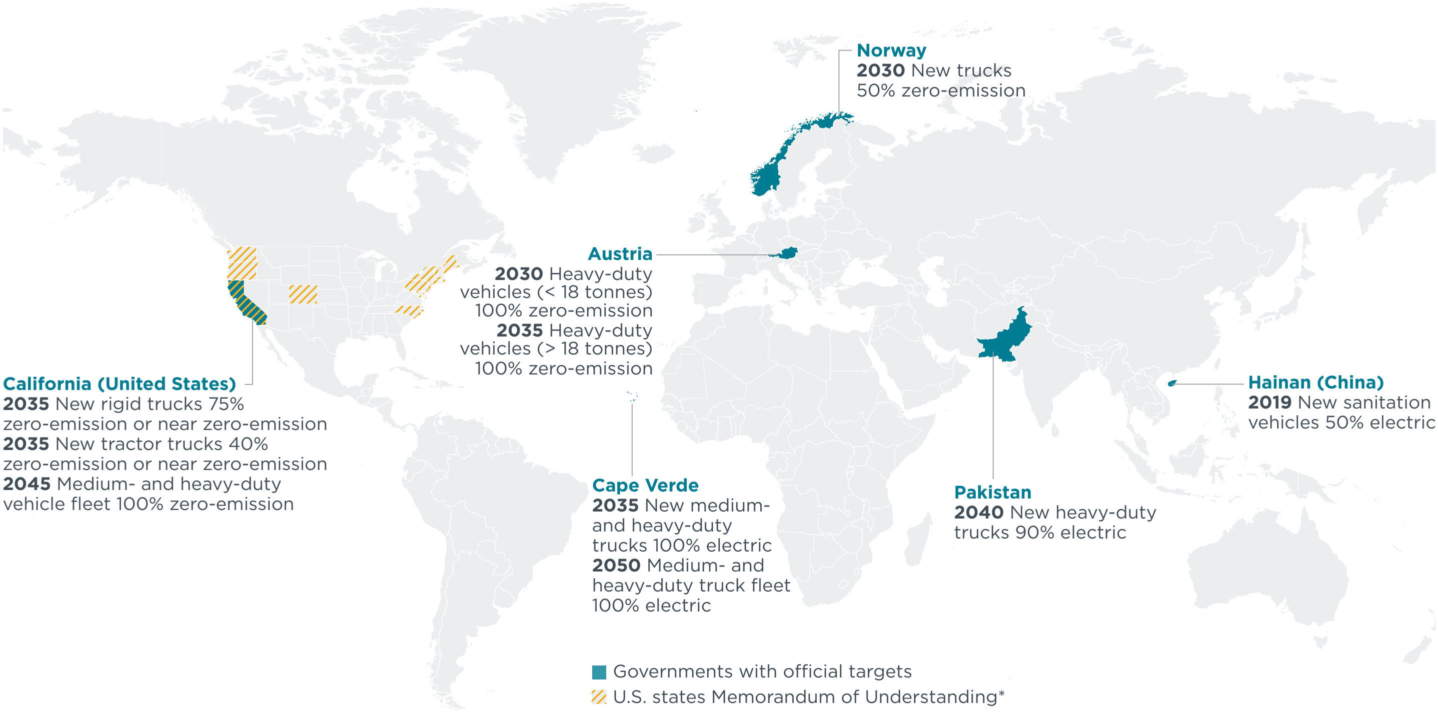
Market	Vehicle segment	Type of target	Year	Target	Source
Austria	All medium- and heavy-duty vehicles	New sales	2030	100% zero-emission buses	Government document[5]
			2032	100% zero-emission trucks under 18 t	
			2035	100% zero-emission	
Korea	Trucks	Vehicle stock	2040	40,000 fuel-cell electric trucks	Government document[6]
Netherlands	Fuel-cell electric HDVs	New sales	2025	3,000 sales	Government document[7]
Norway	Trucks	New sales	2029	50% zero-emission	Government document[8]
Pakistan	Trucks	New sales	2030	30% electric	Government document[9]
			2040	90% electric	
United Kingdom	Trucks	New sales	2035	100% zero-emission trucks under 26 t	Government document and consultation[10]
			2040	100% zero-emission	
California (U.S.)	All medium- and heavy-duty vehicles	Vehicle stock	2045	100% zero-emission	Executive order[11]
15 U.S. states[a] and the District of Columbia	All medium- and heavy-duty vehicles	New sales	2030	30% zero-emission	Government Memorandum of Understanding[12]
			2050	100% zero-emission	
Hainan (China)	Sanitation vehicles	New sales	2019	50% New Energy Vehicles (NEV)	Government document[13]

[a] California, Connecticut, Colorado, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington.

Current non-binding targets range widely in terms of scope. Canada, China, Singapore, and Sri Lanka have broad transport sector-wide electrification strategies that cover all vehicle segments, without specifying the expected contribution from zero-emission medium- and heavy-duty vehicles. With the exception of a few markets, targets apply to new vehicle sales rather than the in-use vehicle stock. Moreover, targets can be categorized in two buckets: vehicle purchase targets that regulate vehicle purchase by consumers and fleets, and vehicle sales targets which are relevant to the HDV manufacturer. Most targets today are framed as sales targets; they entail regulating manufacturers in later stages of implementation.

Figure 1 presents a summary of government ZE-HDV targets identified in this section. Targets in the United Kingdom and France are not shown, as their adoption has not yet been finalized.

Governments with targets toward phasing out sales of internal combustion engine trucks by a certain date (Status: August 2021)



U.S. states Memorandum of Understanding (MoU)
California, Colorado, Connecticut, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont and Washington and the District of Columbia
2030 New medium- and heavy-duty vehicles 30% zero-emission
2050 New medium- and heavy-duty vehicles 100% zero-emission

Note: Countries included here are those that set ZE-HDV sales targets of at least 40%.
* Not necessarily yet reflected in an official national/state policy document such as a climate or transport strategy/plan, in a law, or in a similar framework.

Figure 1. Governmental targets to phase-in ZE-HDVs.

While the targets above provide manufacturers with a clear picture that is helpful for future product planning and investment, they can only be effective if they are accompanied by legally binding policies to support the rapid deployment of ZE-HDVs. The binding sales requirements in China and California for zero-emission light-duty vehicles (ZE-LDV) provide solid evidence of the effectiveness of this policy to overcome critical barriers to large-scale electrification, such as the lack of model options and charging infrastructure.[14]

California's success with sales requirements is best seen in its ZE-LDV market share, which stands at more than four times the US average. This policy has now been extended to drive the market for ZE-HDVs. California is the only region that has adopted legally binding legislation requiring the sale of zero-emission heavy-duty vehicles. Its Advanced Clean Trucks (ACT) Regulation is the first in the world to require manufacturers to sell increasing percentages of zero-emission trucks.[15] The regulation sets sales requirements for three heavy-duty vehicle groups, defined based on the gross vehicle weight rating (GVWR), starting from model year (MY) 2024: Class 2b-3 pickup trucks and vans (GVWR from 3.8 to 6.3 t), Class 4-8 rigid trucks (GVWR greater than 6.3 t), and Class 7-8 tractor trucks (GVWR greater than 11.8 t). The gradual ramp-up of annual sales percentage requirements by vehicle group is illustrated in Figure 2.

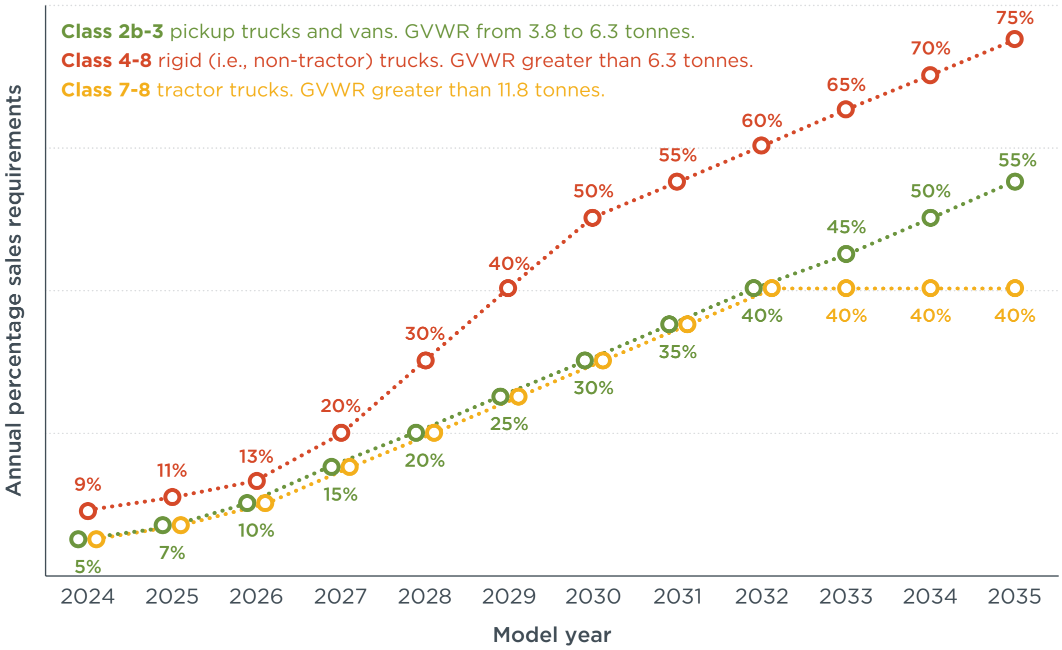


Figure 2. California Advance Clean Trucks Regulation zero-emission sales percentage schedule by vehicle group and model year

California's ACT regulation relies on a credit-deficit system. Manufacturers generate deficits based on the volume of internal combustion engine trucks sold in California. To achieve compliance, a manufacturer must offset its total deficits, for a given model year across the regulated segments, by generating credits through sales of zero-emission trucks. Deficits accrued in Class 7-8 tractor trucks can only be offset with credits from the same vehicle class. Excess credits can be traded among manufacturers.

To facilitate and reward early compliance, credit accrual may begin three years before the first sales requirements enter into force. Early credits accrued from MY 2021 through 2023 will have a longer lifespan and can be banked until the end of MY 2030. Credits generated from MY 2024 onwards have a shorter lifespan, expiring in only five years.

The credit-deficit accounting in California's ACT rule distinguishes between trucks of different vehicle groups. The distinctions recognize different emission footprints for vehicles in different segments and help stimulate adoption of zero-emission vehicles in the segments that, while responsible for the greatest share of emissions, require a targeted regulatory pull to promote their development and deployment. Some key differentiations are:

» **Deficits are generated separately for each truck group.** To account for emission differences across the regulated groups, the regulation introduces a weight class multiplier. For example, Class 7-8 tractor trucks that are over 11.8 tons have the greatest weight class multiplier (2.5) to reflect their large emission footprint.

» **The value of credits is adjusted by the same set of weight class multipliers for each regulated group.** As the heaviest vehicles with the largest greenhouse gas emissions footprint, Class 7-8 tractors receive the most credits (2.5).

» **Tractor trucks are a class of their own in terms of credit and debit accounting.** Annual deficits accrued in the Class 7-8 tractor truck vehicle group can only be met with Class 7-8 tractor credits.

To encourage full ZEV technology development, the ACT regulation places several limitations on plug-in hybrid trucks. The credits generated by plug-in hybrid trucks are always less than an equivalent ZEV and are downscaled by multiplying the full ZEV credit value by the all-electric range, then by 0.01, up to a maximum of 75 miles of range. That is, the credits are capped at 75% of a regular zero-emission credit. Furthermore, the credits from plug-in hybrid trucks can only be used to offset up to half of annual deficits from the overall sales and will be phased out at the end of MY 2035.

Non-compliance with the ACT regulation is treated as any other failure to comply with emission standards or test procedures adopted by the California Air Resources Board (CARB). Manufacturers who fail to offset their deficits or fail to retire their credits under the ACT regulation are charged a civil penalty up to $37,500, in accordance with California Health and Safety Code section 43212. Fees from penalties assessed for non-compliance are deposited to the California Air Pollution Control Fund. A diagrammatic summary of the credit-deficit mechanism is shown in Figure 3.

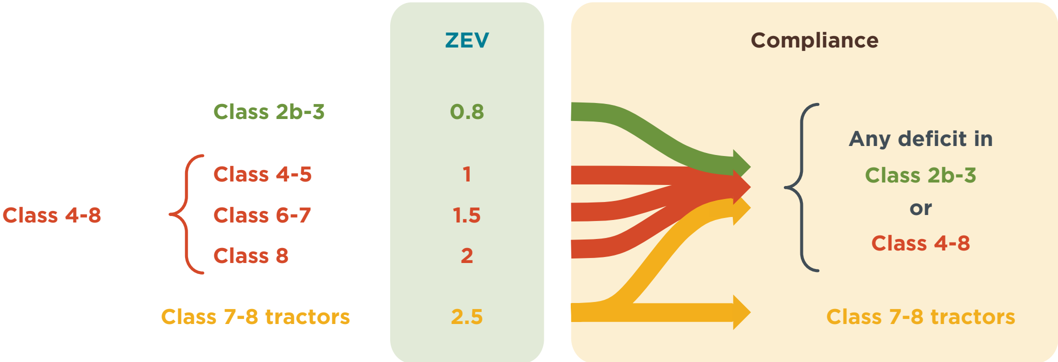


Figure 3. Yearly credit values, deficit calculation, and regulatory compliance for a manufacturer under California ACT

Chinese officials are developing a regulation that would require the sale of zero-emission new-energy commercial vehicles. This new set of rules will complement China's existing light-duty vehicle NEV mandate, commonly known as the dual-credit policy.[16] While the commercial vehicle credit policy is still under discussion, it is expected that annual requirements will be set for manufacturers to generate credits—which are then used for compliance—through the production or import of new-energy commercial vehicles. It is not clear yet whether credit trading between HDV fuel economy standards and NEV targets, the so called dual-credit policy used in the light-duty sector, would be applied to HDVs.

IMPLICATIONS AND SUGGESTIONS FOR CHINESE POLICY

California's pioneering ACT regulation features several elements that can be evaluated for adoption in China's new-energy HDV regulation. We recommend that Chinese regulators:

- **Set ambitious sales requirements for ZE-HDVs in the near term.** This ensures a robust supply of ZE-HDVs, which in turn drives infrastructure deployment and a reduction in manufacturing costs. Such sales requirements must include adequate penalties and enforcement provisions to ensure their effectiveness. California provides a best practice example of setting ambitious yet achievable targets, requiring 11% of new heavy rigid trucks to be zero-emission by 2025 and 50% by 2030. For tractor-trailers the zero-emission sales requirements are 5% and 30% by 2025 and 2030, respectively.
- **Set long-term targets for the full phase-in of ZE-HDVs, providing manufacturers with a clear picture for future product planning and investment.** Full phase-in targets complement near-term binding sales requirements and vehicle regulations. While the latter ensures the immediate kick-start of the needed supply chains, the former provides the certainty that the investments made will have long-term relevance.
- **Design policies that are application-specific, but technology-neutral:** Policies must target the deployment of zero-emission vehicles in segments with the highest CO_2 emissions, such as tractor-trailers. At the same time, they should aim for a level playing field between battery electric and fuel cell trucks, to favor the most cost-effective technological pathway in the long-term. California's ACT regulation is technology-neutral, assigning multipliers based only on weight and body type to reflect the higher emission footprints of larger trucks and their high costs and greater technical challenges of production. This means neither battery-electric nor hydrogen fuel cell is favored as a technological pathway. Furthermore, California's sales requirements apply to broad segments of the entire HDT market, including the heaviest Class 7-8 rigid and tractor trucks. All heavy-duty trucks are covered under the regulation.
- **Create provisions to facilitate compliance for manufacturers, including credit banking and trading, early credit generation, and partial credits for plug-in hybrid vehicles.** These flexibilities, coupled with a gradual ramp-up of sales targets, give manufacturers lead time to prepare ZE-HDV products, allow regulators to set more ambitious targets, and make compliance more feasible.

FUEL CONSUMPTION, CO_2 AND GHG STANDARDS AS A TOOL FOR ZE-HDV DEPLOYMENT

Demanding performance standards that cannot be met through improvements to existing technologies can spur development of new, cost-effective technologies, and they can do so while remaining technology-neutral. In the context of ZE-HDVs, stringent performance standards governing fuel consumption, CO_2, and other GHGs can draw ZE-HDVs into the market. Governments can build on a demonstrated zero-emissions track record of performance standards in other vehicle segments. For example, to meet the stringent European light-duty vehicle CO_2 standards that entered into force in 2020, manufacturers turned increasingly to electric vehicles, driving electrics' share of the market from 3% to 11% in a single year, 2020.[17]

While the elements of the regulatory design of these standards—including the technology baselines, testing methodologies, test cycles, allowed payloads, and evaluated metrics, among others—vary widely across the different regions, it is still possible to compare the improvements that would be driven by the standards in key vehicle segments. Figure 4 shows the relative stringency of different long-haul standards with respect to a baseline defined when the standards were introduced.

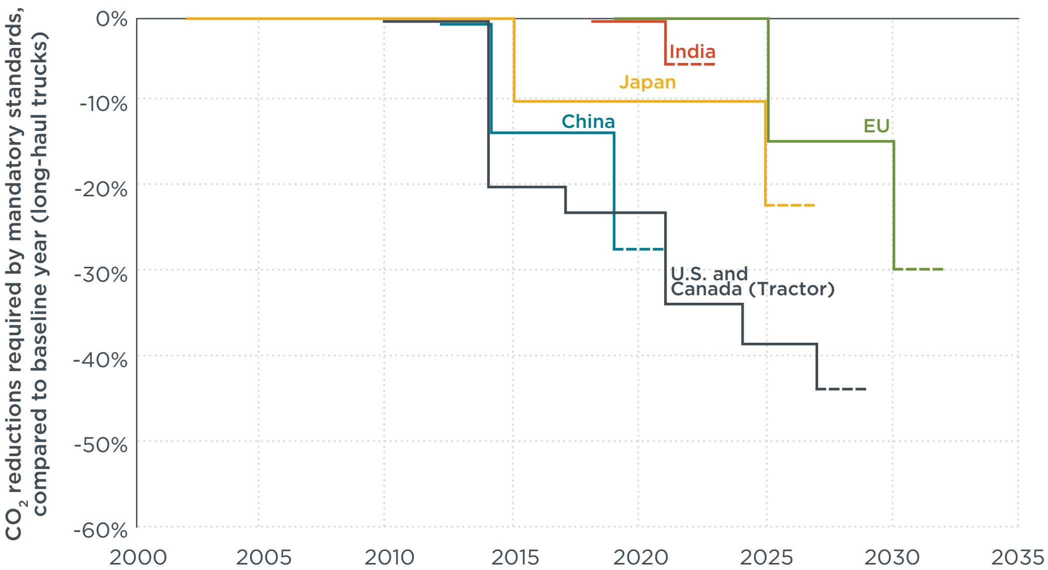


Figure 4. Long-haul truck emissions reduction requirements under new mandatory standards, various countries. The 0% horizontal line represents the baseline year for each country's standard.

The European Union, the United States, Canada, China, Japan, and India have performance standards in place regulating fuel consumption of HDVs or their emissions of CO_2 and GHGs. While standards summarized above have not yet been proven to drive the deployment of ZE-HDVs, there are clear indications that some of them will. For example, while the EU mandate to reduce CO_2 30% by 2030 is possible through improvements to combustion engine trucks, this is not the most cost-effective way to ensure compliance and reduce future risk. Therefore, European truck manufacturers have set ambitious targets for deploying ZE-HDVs by 2030, with the goal of being fossil fuel free by 2040.[18]

Table 2 presents a summary of the key elements of these performance standards.

Table 2. HDV fuel efficiency, CO_2 or GHG standards around the globe

	United States[19] and Canada[20]	European Union[21]	China[22]	Japan[23]	India[24]
Type	Fleet average	Fleet average	Individual vehicle	Fleet average	Individual vehicle
Regulated metric	CO_2 (g/ton-mile)[a] Separate standards for CH_4 and N_2O.	CO_2 (g/tonne-km)	Fuel consumption (L/100 km)	Fuel economy (km/L)	Fuel economy (km/L)
Vehicle scope	GVW > 3.85 tonnes 19 sub-categories	GVW >16 tonnes 9 sub-categories	GVW > 3.5 tonnes 66 sub-categories	GVW > 3.5t 25 sub-categories	GVW > 12 tonnes 10 sub-categories
Year of first implementation	Phase 1: 2014, 2017 Phase 2: 2021, 2024, 2027	2025 and 2030	Stage 1: 2012 Stage 2: 2014 Stage 3: 2019	Phase 1: 2015 Phase 2: 2025	Phase 1: 2018 Phase 2: 2021
Mandated improvement[b]	Phase 1: 5% to 23% Phase 2: 10% to 27%	15% by 2025 30% by 2030	Stage 1: None Stage 2: 10% to 14% Stage 3: 12% to 16%	Phase 1: 1% to 12% Phase 2: 3% to 16%	Phase 1: None Phase 2: 5% to 16%

[a] In the United States, the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) sets equivalent fuel consumption standards in gallons/1,000 ton-mile, based on a conversion factor of 10,180 gram CO2 per gallon diesel

[b] Values presented as ranges indicate the minimum and maximum reduction mandated in the separate regulated sub-categories

To incentivize deployment of ZE-HDVs through CO_2 and GHG standards, regulations need to have the right policy design. Four elements are key: 1) fleet average standards (in contrast to vehicle-based standards), which introduce stringent targets that boost adoption of ZE-HDVs without prescribing them; 2) technology-forcing standards that set performance requirements at a level too high to be achieved cost-effectively by further improvement of current technologies; 3) ZE-HDV incentives, often in the form of performance credits, that reduce the cost of meeting the standards with a new technology; and 4) consideration of differential freight characteristics like payload, annual distance travelled, and useful life of the different vehicle segments.

The details of ZE-HDV integration into the CO_2 or GHGs standards in the United States and the EU are described in Table 3.

Table 3. ZE-HDV provisions in fuel economy and GHG standards in the U.S. and EU

Market	Item	Description
United States[25]	**Fleet averaging**	The U.S. has an averaging, banking, and trading (ABT) credit program. Compliance is assessed based on the sum of ABT credits. A "zero" credit balance or a surplus is required within an averaging set of vehicles or engines. All electric vehicles are deemed to have zero emissions of CO_2, CH_4, and N_2O. No emission testing is required.
	Technology forcing	Stringency of the standards is set on the technology feasibility of combustion engine HDVs and were not designed to drive ZE-HDVs into the market in large numbers. Efficiency improvements from Phases 1 and 2 together deliver CO_2 reductions of about 20%–30% for heavy-duty pickups and vans, 20% for rigid trucks, and 30% to 45% for tractor-trailers, compared with MY 2010 technology.
	ZE-HDV incentives	Advanced Technology Multipliers are used for ZE-HDVs: 3.5 for plug-in hybrid electric, 4.5 for battery-electric, and 5.5 for fuel-cell electric trucks. Advanced Technology Multipliers will sunset in MY 2027.
	Consideration of freight activity	There are four averaging sets: 1) Complete pickups and vans; 2) Light heavy-duty vehicles (Classes 2b–5); 3) Medium heavy-duty vehicles (Class 6–7); and 4) Heavy heavy-duty vehicles (Class 8). Each averaging set has a useful life—in thousands of miles—associated with it. The credit generation is directly proportional to the useful life. Averaging, banking, and trading can only occur within an averaging set.
EU[26]	**Fleet averaging**	The CO_2 emissions are regulated on a fleet-wide basis through a metric dubbed average specific CO_2 emissions, expressed in gCO_2/t-km. The is a banking and borrowing scheme in which manufacturers are allowed to accumulate CO_2 emission credits and debits during specific periods of time. ZE-HDVs are certified with 0 g CO_2/km.
	Technology forcing	Stringency of the standards is set on the technology feasibility of combustion engine HDVs and were not designed to drive ZE-HDVs into the market in large numbers. Compared to the baseline in 2019/2020, manufacturers must demonstrate by 2025 a 15% reduction in average CO_2 emissions, and a 30% reduction by 2030.
	ZE-HDV incentives	ZE-HDVs are incentivized through the Zero and Low Emission Vehicle (ZLEV) factor, with a technology-neutral policy design. The ZLEV factor, which depends on the number of ZE-HDVs sold, multiplies the average CO_2 emissions of a manufacturer. From 2019 to 2024, ZE-HDVs are counted more than once in the average CO_2 emissions of a manufacturer. From 2025 onwards, a minimum benchmark of 2% must be met to benefit from the ZLEV factor. The minimum value of ZLEV factor is 0.97, which means ZLEV incentives can only reduce the average emissions of a manufacturer by a maximum of 3%.
	Consideration of freight activity	Mileage and payload weighting (MPW) factors to account for the differences in freight activity between the vehicle sub-groups in the fleet average calculation. However, the ZLEV factor (presented above) does not capture such differences. Thus, the freight activity of ZE-HDV is only partially captured in the regulation.

Certification and type-approval procedures are a related policy instrument for more targeted promotion of ZE-HDVs. Most major HDV markets currently do not have a certification methodology designed specifically for ZE-HDVs (see Table 4).

Table 4. ZE-HDV certification developments

Market	Description	Status of policy
EU[27]	Timeline for ZE-HDV certification and type approval laid out in the 2019 HDV CO2 regulation	By 31 December 2021, the European Commission will adopt "a methodology for determining the zero-emission driving range and electricity consumption," and by 2022, the European Commission will submit a report "towards a possible differentiation by zero-emission driving range and vehicle sub-group, combined with mileage and payload weighting factors."
China	Energy Consumption and Range Test Procedure for Electric Vehicles	GB/T 18386-2017 is the current testing standard, which is primarily based on LDVs. The revised standards that specifically apply to HDVs (GB/T 18386.2—XXXX) are currently in the public comment phase and will create a dedicated test procedure for HD-ZEV certification.
Japan	Japan's Phase 2 HDV fuel economy standards do not currently cover hybrid, alternative fuel and zero-emission vehicles	Japan's Ministry of Land, Infrastructure, Transport and Tourism would develop a measurement method for heavy-duty electric vehicles and would explore efficiency standards incorporating these and other types of advanced technology trucks and buses.

Despite wide variations in application and performance, ZE-HDVs are undifferentiated by their zero-emission driving range and payload. The certification of energy consumption and electric driving range will enable establishing incentives targeted at deploying ZE-trucks in the highest emitting categories. The European Union, China, and Japan have identified this limitation and are designing policy interventions to overcome it.

IMPLICATIONS AND SUGGESTIONS FOR CHINESE POLICY

The current fuel consumption standards for HDVs in China are not conducive to the integration of ZE-HDVs. Performance-based standards are an important policy tool to ensure the deployment of ZE-HDVs. Such standards can be rolled out in combination and harmonized with sales requirements. However, to take advantage of this policy tool in China, a restructuring of the HDV efficiency standards is required. We recommend that policymakers:

» **Set fleet average standards.** Provisions in greenhouse gas regulations are built around a fleet average credit systems in the United States and EU. The Chinese HDV efficiency rule is vehicle-based and not manufacturer fleet-based. To drive the scale adoption of ZE-HDVs through performance-based standards, it is necessary that China move toward a fleet average approach.

» **Set technology-forcing standards.** Long-term, stringent standards that cannot be met cost-effectively with a continuous improvement of combustion engine vehicles are an effective tool for driving ZE-HDV deployment.

» **Set crediting schemes to incentivize ZE-HDVs that are well-designed and limited in scope and duration.** ZE-HDV incentives should strike a balance between incentivizing ZE-HDVs and the dilution of the benefits from GHG and fuel economy standards.[1] Regulators should especially avoid rewarding vehicle segments and classes that are already undergoing rapid electrification with high super-credits or multipliers. The latter need to be carefully designed to have the desired short-term impact and have clear sunset provisions.

» **Consider the freight activity of the various vehicle segments in the regulation.** Crediting systems should take into account the payload, annual distance travelled, and useful life of the different vehicle segments. In that way credits accrued through the sale of ZE-HDVs are proportional to the emissions mitigated by the vehicle. For example, zero-emission long-haul trucks must receive more credits for emission reductions due to their larger CO_2 footprints. Vehicle certification standards and procedures for ZE-HDVs will help with this fairer allocation.

PURCHASE INCENTIVES FOR ZE-HDVS

Purchase incentives for ZE-HDVs are a common policy instrument found in European and North American auto markets, to reduce the gap in price with conventional technologies, since the higher price of ZEVs is a barrier to their purchase. While some subsidy schemes are not explicitly targeted at ZE-HDVs, they provide funding to support cleaner on- and off-road vehicles, engines and equipment in general; zero-emission technologies are often eligible to receive the greatest amount of funding under these schemes.

Table 5 summarizes purchase incentives offered in major vehicle markets.

1 An ICCT study in 2017 found that due to super-credit provisions and zero-upstream emission accounting, a 23% penetration of electric vehicles results in a 26% loss in the U.S. regulatory program's CO_2 benefits. In Europe, electric vehicle penetration rate at 28% of new vehicle sales would erase 41% of European passenger vehicles GHG regulations' intended CO_2 benefit. See Lutsey, Nic, "Integrating Electric Vehicles within U.S. and European Efficiency Regulations," The International Council on Clean Transportation, June 22, 2017. https://theicct.org/sites/default/files/publications/Integrating-EVs-US-EU_ICCT_Working-Paper_22062017_vF.pdf.

Table 5. Purchase incentives for ZE-HDVs in various countries

Market	Policy	Responsible agency	Funding source	Eligibility	Incentive amount
California	**Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)[28]**	California Air Resources Board and CALSTART	Cap and trade revenues	Purchase of buses and trucks. Not to be combined with Carl Moyer Program, except for transit buses.	Up to $315,000 per vehicle, with additional modifiers
	Carl Moyer Memorial Air Quality Standards Attainment Program[29]	California Air Resources Board and 35 local Air Districts in California	Smog fee and registration surcharge in 19 air districts	Replacement and repower of truck and buses.	Up to $200,000 per vehicle. Up to 80% of vehicle cost for fleets smaller than 10 vehicles. Up to 50% of vehicle cost for larger fleets.
	California VW Mitigation Trust Zero-Emission Class 8 Freight and Port Drayage Trucks Category[30]	South Coast Air Quality Management District	Volkswagen Environmental Mitigation Trust	Scrappage and replacement of Class 8 freight trucks older than MY 2012.	Up to $200,000 per vehicle. Up to 100% of cost for government-owned vehicles. Up to 75% for non-government vehicles.
China	**2021 Notice on Further Optimizing Fiscal Subsidies for Promoting New Energy Vehicles[31]**	3 Ministries (Finance; Industry and Information Technology; Science and Technology) and National Development and Reform Commission (NDRC)	Central government funding	Sale of trucks and vocational vehicles	Up to CNY 49,500 per vehicle for public battery-electric trucks (> 12 tonnes). Up to CNY 40,000 for private battery-electric trucks. Subsidies depend on battery capacity. Prior to April 2020, fuel-cell trucks received up to CNY 400,000. A new program has been initiated[32] whose subsidy amounts are not yet known.
France	**Ministerial decree[33]**	Ministry of the Ecological Transition	National budget	Purchase of HDVs that use electricity, hydrogen or a combination of the two as exclusive source of energy	40% of purchase cost of ZE-HDV and up to 50.000 EUR.
Germany	**Directive on the Promotion of Commercial Vehicles with Climate-friendly Drives[34]**	Federal Ministry of Transport and Digital Infrastructure	Federal budget	Purchase of commercial vehicles with electric drive	Up to 80% of price differential between ZE-HDV and Euro VI diesel equivalent.
Italy	**Ministerial decree[35]**	Ministry of Infrastructure and Transport	National budget	Purchase of new "alternative" powertrains including gas, hybrid, and full-electric	Up to 20,000 EUR for full-electric trucks over 7 tonnes.
Spain	**MOVES II Program[36]**	Ministry for the Ecological Transition and the Demographic Challenge	National budget	Purchase of new ZE-HDVs	Up to 15,000 EUR for pure-electric and hydrogen fuel-cell trucks.
United Kingdom	**Plug-in vehicle grant scheme[37]**	Office for Zero Emission Vehicles. Department for Transport and Department for Business, Energy & Industrial Strategy	National budget	5 preapproved ZE truck models with GVW between 3.5 tonnes and 12 tonnes with at least 100 km range. Limited to 10 trucks per customer	Subsidy covers 20% of the purchase price, up to a maximum of £16,000, for first 250 orders.

Values of purchase incentives show great variation, from a few thousand US dollars to more than three hundred thousand US dollars, depending on vehicle type, load factor, original vehicle price, and technical specifications including range, battery size and energy efficiency, and vehicle market.

While some programs, like the California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), provide subsidies directly to consumers, other programs provide subsidies to manufacturers who pass the cost savings to customers. The subsidy scheme implemented in China is an example of the latter approach.[38]

An important element in incentive schemes is a reporting and verification mechanism. In China, since NEV subsidies are a significant source of revenue for vehicle manufacturers, Chinese regulators have taken steps to ensure subsidized vehicles meet the technical eligibility requirements and are put to actual use and thus generating real-world emission savings.[39] In California, consumers who benefit from California HVIP funding are similarly obliged to maintain at least three years' worth of HVIP-related reports, and are subject to evaluations and fiscal audits from CARB and other state agencies.[40] Reporting in California's HVIP program is also designed to track the service of subsidized vehicles in disadvantaged and low-income communities through onboard telematics systems.

IMPLICATIONS AND SUGGESTIONS FOR CHINESE POLICY

The Chinese NEV subsidy scheme has gone through almost a decade of iterations and revisions. China has put in place monitoring and evaluation mechanisms to avoid fraudulent subsidy claims, and with each policy update, sets progressively tighter technical requirements on range and energy consumption for manufacturers to qualify for subsidies. Based on policies and experience from other markets, future Chinese purchase incentives should bear in mind the following realities:

» **Subsidies help to incentivize the purchase of ZE-HDV in the near term.** Purchase incentives are a powerful policy tool to help close the cost gap between diesel HDVs and ZE-HDVs, creating the right conditions to accelerate adoption of ZE-HDVs. Given that subsidies are not fiscally sustainable in the long term, they must be limited in duration and scope to generate sufficient demand during market ramp-up and can be phased out as manufacturing costs drop through economies of scale.

» **To finance programs offering purchase incentives for ZE-HDVs in the long-term, fiscally sustainable alternatives must be considered.** Financing ZE-HDV deployment at scale can require hundreds of millions of dollars. A malus component in ZE-HDV subsidy schemes helps manage the fiscal sustainability of long-term subsidy programs, while disincentivizing vehicles and activities that emit greenhouse gases and/or air pollutants. The revenue raised from taxing the sale of combustion engine HDVs to better capture their externalities can be used to finance purchase incentive programs for ZE-HDVs. California's HVIP and VW Mitigation Trust are good examples of the "polluter pays principle" where funding streams for ZE-HDV purchase incentives come from the emissions cap-and-trade revenues and VW's fines from the excess nitrogen oxide (NO_x) emissions caused by VW's use of illegal emissions testing defeat devices.

» **Subsidies should aim to cover the cost difference between a zero-emission truck and an internal combustion engine equivalent.** After the conclusion of fuel-cell electric HDV subsidies in April 2020, the 2021 subsidies from the Chinese central government are capped at CNY 49,500 per vehicle for the heaviest NEV trucks and vocational vehicles in public service sectors, regardless of drivetrain technology. For some applications where high ZE-HDV costs are expected—e.g., battery electric tractor-trailers, with large batteries—this amount is insufficient to have a measurable impact on the current cost gap between diesel HDVs and ZE-HDVs. A more reasonable subsidy amount should aim to cover the cost difference between a zero-emission truck and an internal combustion engine equivalent. Higher subsidies will particularly help the heavier vehicle segments with long range requirements and, consequently, high battery costs.

» **More targeted purchase incentives for ZE-HDVs based on vehicle parameters.** Adding more eligibility criteria such as vehicle load factors, powertrain technology and energy consumption can help differentiate performance of vehicles and allocate subsidies more effectively. The expected publication of new test procedures and standards for heavy-duty NEVs will enable a more granular and efficient incentive program.

IN-USE FLEET INCENTIVES

Over the lifetime of a long-haul truck, operational costs—including fueling and road tolls—are responsible for the largest portion of the total cost of owning a heavy-duty vehicle. Thus, lowering the cost of operations of ZE-HDVs relative to combustion-powered HDVs is a viable option to make them more cost-competitive. Regulators around the world are developing regulations targeting the operational costs of ZE-HDVs; below we present two key examples targeting fuel cost in California and road tolls in Europe.

California's Low Carbon Fuel Standard (LCFS) is a market-based mechanism to increase the use of low-carbon transportation fuels in California.[41] Fleets that invest in, own, and operate charging and hydrogen refueling infrastructure generate credits based on the amount of fuel they use. LCFS credits can be sold and used for revenue that can eliminate, or nearly eliminate, the electricity costs of charging battery electric trucks. CARB estimates that a battery-electric powered Class 8 (>14,969 kg) short-haul tractor purchased in 2024 can have total LCFS revenues worth more than $120,000 over a 12-year service life.[42] LCFS revenues can cut the operational and other costs associated with the vehicle by half, making a battery-electric truck much more competitive with a diesel equivalent. In relative terms, the cost of dispensed hydrogen can be reduced by 4 to 16%.[43]

In California's LCFS policy design, the credit revenue drops over time as the program standards tighten, decreasing the magnitude of the policy support over time and enabling the development of a robust ZE-HDV market.[44] This in turn will have a positive impact on vehicle costs, and consequently on the total cost of ownership.

In some European countries, ZE-HDVs enjoy discounts and even exemptions on road-use tolls and charges. A revision of the Eurovignette Directive, which lays out the rules and procedures that EU member states must follow when charging trucks for their infrastructure usage, is currently underway. While the regulatory text has not been finalized, clear elements have already emerged from the negotiations among the EU institutions. From 2023, EU member states will have to vary the road tolls they charge truck operators based on the CO_2 emission performance of their vehicles. Member states would be allowed to keep full road toll exemptions for ZE-HDVs until 2025. Thereafter, the road toll reduction would be between 50 and 75% compared to combustion-engine trucks. Table 6 outlines key elements of current road-toll programs in some European countries and the ongoing revisions to the Eurovignette Directive.

Table 6. Toll discounts and exemptions for ZE-HDVs, various jurisdictions

Market	Tolls and fees	Exemptions/discounts for ZE-HDVs
EU	The Eurovignette Directive is the legal framework for levying road-use charges on trucks in the EU. The current Directive allows, but does not oblige, Member States to set tolls at levels required to maintain and replace infrastructure, and also authorizes the inclusion of an "external cost charge" which reflects the cost of air pollution and of noise. The European Commission put forward a proposal to revise the Eurovignette Directive in 2017.[45] A provisional agreement among legislators was reached in June 2021. Formal adoption of the regulation is pending but is considered a matter of course.	Reduces road tolls by up to 75% for ZE-HDVs. Includes a CO_2 provision to increase the road toll for internal combustion engine vehicles by up to €0.16 per kilometer for a tractor-trailer.
Austria	The toll for tractor-trailers is more than €0.40 per kilometer.	50% discount, which the government plans to increase to 75%.[46] [47]
Germany	All trucks with GVW above 7.5 tons are tolled on highways. The amount depends on the pollutant emission standard certification of vehicles, the number of axles, and the distance the vehicle travels on the tolled road segment. A Euro VI tractor-trailer would be tolled €0.19 per kilometer, representing around 15% of all operational costs, or about €20,000 per year.[48]	Fully exempt from road tolls and charges.[49]
Switzerland	A 40-tonne truck is charged more than €0.80 per kilometer for road tolls.[50]	Exempt from road tolls.

IMPLICATIONS AND SUGGESTIONS FOR CHINESE POLICY

In-use incentives can reduce operating costs. Cost savings from road tolls and fueling reduce the total cost of ownership of ZE-HDVs and attract HDV operators conscious of the economics of fleet operations. Regulators in China should bear in mind that:

» **Incentives through crediting mechanisms, such as low-carbon fuel standards, can lower the energy costs of ZE-HDVs and improve the total cost of ownership comparison**. In California, the LCFS not only provides subsidies to fleet owners that use electricity and hydrogen, but also charges a premium on the use of fossil fuels like diesel.

» **Road toll discount or exemptions for ZE-HDVs are another angle to incentivize in-use ZE-HDVs.** According to a report from Bain & Company, road and bridge tolls accounted for 30.7% of total costs in China's highway freight transport operations in 2017.[51] Lowering this number for eligible ZE-HDVs means a wider profit margin for fleet owners and operators and may help manage the safety risks caused by rampant overloading on Chinese highways.

INFRASTRUCTURE PROGRAMS AND INCENTIVES FOR ZE-HDVS

Infrastructure is identified in government policies around the world as an important component of successful ZEV deployment. Details of some infrastructure incentives and programs are shown in Table 7.

Table 7. Infrastructure incentives and programs for ZE-HDVs, various jurisdictions

Market	Policy	Description
California	**Low Carbon Fuel Standard (LCSF)**	LCFS regulations provide infrastructure credits for eligible hydrogen refueling and direct current (DC) fast chargers based on their designed capacity. Those investing in recharging and refueling infrastructure will receive financial benefits even before the investments reach full utilization.[52] LCFS allows renewable electricity generated off-site to be used in EV charging and hydrogen production by electrolysis.
	California Energy Commission's Clean Transportation Program	California Energy Commission is California's energy policy and planning agency. CEC will invest $129.8 million of the Clean Transportation Program funds in the MD/HD ZEV Infrastructure from FY 2020-2023.[53]
	California Public Utilities Commission (CPUC) investments in Medium/ Heavy Duty charging infrastructure	CPUC, the regulatory agency for California's utility companies, approved investments by major utility companies in California to support electric M/HDV infrastructure. Pacific Gas & Electricity (PG&E) will invest $236 million to install make-ready infrastructure at more than 700 sites to support the electrification of at least 6,500 M/HDVs. Southern California Edison (SCE) will invest $343 million to install make-ready infrastructure at more than 870 sites to support the electrification of at least 8,490 M/HDVs.[54] Both utility companies are in the early stages of materializing the investments.
	Zero-Emission Vehicle Electricity Rate Programs[55]	SCE has three commercial electricity rates based on charging demands for fleet operators. Similarly, PG&E has two subscription-based commercial EV rate plans. A third major utility company, San Diego Gas and Electricity (SDG&E) is also applying for a commercial EV charging rate plan.
China	**Subsidies for charging infrastructure capital investments and operations**	During the 13th Five Year Plan (FYP) period (2016-2020), the central government provided subsidies for charging infrastructure investments. Subsidy amounts were provided to provinces and cities based on air pollution control priority. The subsidy cap and qualifying requirements tightened from 2016 to 2020.[56] Local governments have taken a more proactive role in infrastructure subsidies, including operating subsidies.[57] A detailed national subsidy scheme during the 14th FYP is yet to be announced.
EU	**Proposed Alternative Fuels Infrastructure Regulation**[58]	In July 2021, the European Commission published a proposal to revise and repeal the Alternative Fuels Infrastructure Directive (AFID), Directive 2014/94/EU. The new regulation builds on national plans (national policy frameworks, NPFs) from AFID and sets infrastructural targets to support ZE-HDVs. Targets include building publicly accessible recharging infrastructure for HDVs every 60 km along the TEN-T core network, and every 100 km along the TEN-T comprehensive network by 2030 with adequate levels of power output. The targets for hydrogen refueling are one 700 bar station every 150 km and one liquid hydrogen station every 450 km.
France	**ADVENIR program**[59]	The ADVENIR program provides subsidies for the first 50 charging infrastructure projects, or 1,000 charging points that serve N2 and N3 trucks. For projects with grid connection powers above 8,000 kVA, the French government subsidizes up to 960,000 EUR.
Germany	**Charging Infrastructure Masterplan**[60]	The German Federal Cabinet agreed to a *Masterplan Ladeinfrastruktur* in November 2019. The Masterplan lays out future measures for the development of truck charging infrastructure.
	Directive on the promotion of commercial vehicles with climate-friendly drives[61]	The German government funds up to 80% of the expenditure in charging or refueling infrastructure for ZE-HDVs.
Poland	**National Policy Framework for the Development of Alternative Fuel Infrastructure**[62]	The report on the implementation of the National Policy Framework for the Development of Alternative Fuel Infrastructure (Sprawozdanie z realizacji Krajowych ram polityki rozwoju infrastruktury paliw Alternatywnych), prescribes a subsidy for charging stations up to 150,000 PLN (~ $40,200), or 50% of the total cost of construction.
South Korea	**Subsidies for hydrogen fueling station construction and operations**	The Ministry of Environment's Hydrogen Vehicle Supply Project Budget in 2021 provides 508.2 billion KRW ($450 million) for construction of hydrogen charging stations that service HDVs. Each fueling station can receive at least 70 million KRW ($62,000) of operating subsidies.[63]
Spain	**MOVES II Program**[64]	Spain provides up to €100,000, or 40% of the total cost of chargers. The funding is not designed specifically for ZE-HDVs and covers private and public chargers with power ranging from less than 7 kW to more than 100 kW. The Moves II Plan is endowed in 2021 with a total of 100 million euros, which can be expanded.
UK	**Charging Infrastructure Investment Fund**[65]	The Charging Infrastructure Investment Fund aims to provide public charging at destinations, on strategic roads, and in urban areas. It has a 200 million GBP cornerstone investment by government, matched by the private sector, and is managed by the private firm Zouk Capital.

The most common form of infrastructure incentive is subsidies for capital investments. Such subsidies are sometimes part of a larger electromobility package, and do not distinguish between public charging for passenger vehicles and depot charging for commercial HDVs. California stands out as a leader in this regard, by having multiple funding streams and dedicated provisions for HDV charging.

Besides subsidizing capital investments in infrastructure, other policy tools in this category include guidelines to set up a certain number of charging/refueling facilities. The European Union's new Regulation for the deployment of alternative fuels infrastructure, announced in July 2021, is an example of infrastructural guidelines to support deployment of ZE-HDVs across the European Union's member states. The proposed new Regulation sets minimum targets for the deployment of alternative fuels infrastructure at 3 levels: (1) the trans-European network for transport (TEN-T), (2) the urban transport network, and (3) overnight parking areas. The Regulation introduces distance-based targets for recharging and refueling stations along the Core and Comprehensive TEN-T combined with minimum requirements for recharging stations power and refueling stations capacity. For urban nodes along the TEN-T—where urban nodes are defined as passengers' terminals, airports, and railway stations—the Regulation defines the minimum required recharging station power capacity that should be installed at these urban nodes. Finally, the regulation sets the minimum required number of chargers and their power capacity to be installed in secure parking areas for HDVs, mainly to serve long-haul truck journeys.

As ZE-HDV fleets enter service, another important angle of infrastructure regulations is energy pricing. A good energy pricing mechanism should allow fleet owners and operators to have stable access to energy to meet charging needs while keeping the total utility spending down; on the other hand, utility providers can manage costs and deliver service to all customers, including ZE-HDV fleets. Policymakers can support ZE-HDV owners and operators by reforming capacity-based network charges, adopting time-varying, volumetric network tariffs that reflect actual conditions of the power grid, and allowing flexible energy delivery times for ZE-HDV fleet consumers. Utility regulatory reform is beyond the scope of this paper. A detailed discussion of charging cost and heavy-duty charging energy demand illustrated in the context of European Union can be found in previous ICCT publications.[66]

IMPLICATIONS AND SUGGESTIONS FOR CHINESE POLICY

While China has invested heavily to support the rise in NEV deployments for passenger cars and buses, continued policy support for charging infrastructure is needed, with a more explicit focus on ZE-HDVs with their particular charging and refueling needs. ZE-HDVs will likely require high-power DC charging at ports, along heavily trafficked highway freight corridors, near logistics distribution centers, and in other locations. Based on policies and experience from other markets, we offer the following recommendations for China:

» **Charging infrastructure is needed to accelerate the transition to ZE-HDVs:** High-power charging infrastructure, ranging from about 100 kW for private overnight charging to 1 MW for public on-road charging, is needed for successful deployment of ZE-HDVs. Therefore, targeted policies are needed for a cost-effective roll-out of the needed infrastructure.

» **Financial support programs can dampen the impact of hardware and installation costs for ZE-HDV infrastructure:** Upfront hardware costs and installation expenditures can drive up the energy costs of ZE-HDVs, hindering their attractiveness compared to diesel HDVs. Financial support programs, such as those summarized in this section, can be effective in accelerating the early market for private and public charging infrastructure aimed at ZE-HDVs.

» **Integration of utility providers and network operators:** From a capital investment point of view, HDVs that draw high amounts of energy at high voltages can require upgrades to existing power distribution networks. Therefore, utility providers can be a key partner in providing innovative models that ensure lower operating costs in the form of low electricity prices. For example, electricity tariffs are not designed to deal with intermittent high-power consumers such as ZE-HDVs. This can translate into high energy prices. A restructuring of the network charges—for example by introducing time-varying, usage-based network fees that reflect actual conditions on the power network—can help mitigate such negative impacts on the energy price.

INCLUSION OF ZE-HDV IN POLLUTANT EMISSION STANDARDS

Like GHG and CO_2 standards, pollutant emission standards are technology-neutral and do not prescribe the use of zero-emission technologies. However, given the positive impact of ZE-HDVs in air quality—they have no tailpipe air pollutant emissions—some regulators create compliance options that integrate zero-emission technologies into what traditionally has been the arena of combustion engine regulators.

California is the only HDV market that has incorporated ZE-HDV credits in its pollutant emission standard regulations. In August 2020, CARB approved the Heavy-Duty Engine and Vehicle Omnibus Regulation and a series of amendments to exhaust emissions standards and test procedures.[67] The new regulations raise the stringency of California's HD engine emission standards, especially NO_x emissions, and other emission-related requirements relative to the US federal regulations. In its Initial Statement of Reasons, CARB states that the regulation will provide further incentives for the production of ZE-HDVs and create synergies with the ACT regulation.[68]

Since the new California standards are more stringent than federal ones, CARB proposed an averaging, banking, and trading (ABT) program specifically for California. Manufacturers can choose to produce and certify Class 4-8 ZE-HDV families (GVW > 6.3 tonnes) to generate NO_x credits in the dedicated ABT program for California between MY 2022 and MY 2026. These ZE-HDV credits can be transferred into and used for compliance with the NO_x limits in any averaging set, as shown in Figure 5.

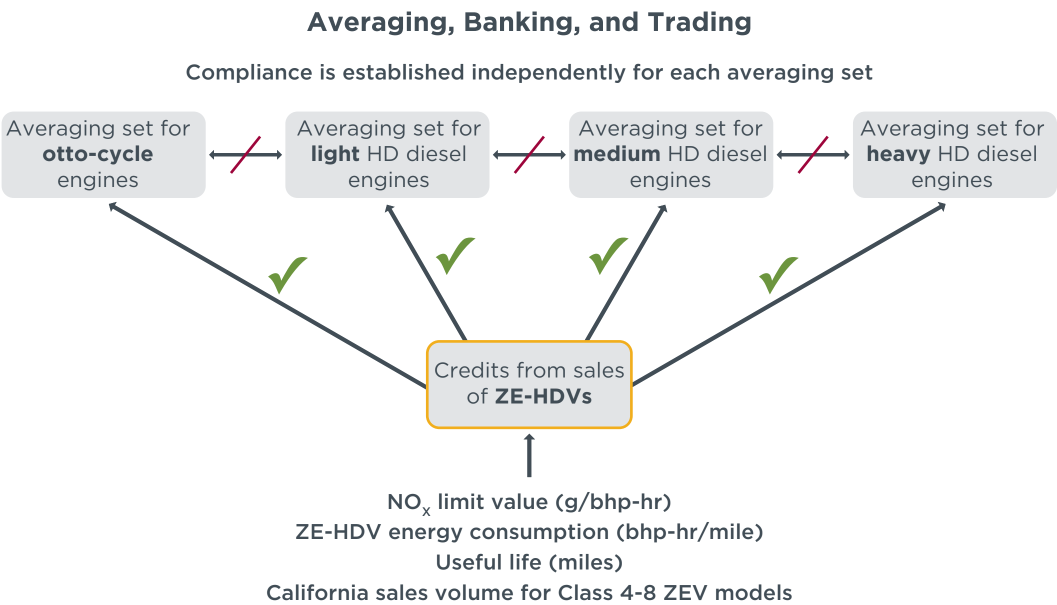


Figure 5. ZE-HDV credits and compliance for averaging sets under California ABT

These provisions would enable a manufacturer to make more ZE-HDV in lieu of certifying other engine families to more stringent standards, before the credits' expiration in MY 2027.[69] For the calculation of NO_x credits generated from the sale of ZE-HDVs, the regulation takes into consideration the applicable emissions limit for combustion engines, the energy consumption and useful life of a typical vehicle in the segment, and the share of ZE-HDVs sold.

California has set limits on the integration of ZE-HDV into the pollutant emission standards. The banked credits in this heavy-duty zero-emission averaging are set to expire in 2030, as California regulators believe that by then ZE-HDVs would reach the point of maturity where such an incentive mechanism would no longer be warranted to support their deployment. Furthermore, ZE-HDVs are not eligible for Early Compliance Credit Multipliers. These are super-credits to provide extra compliance credit to manufacturers that certify MY 2022 to MY 2030 engine and powertrain families to applicable emission standards. The credit multipliers can be as high as 2.5 for engine families in MY 2022-2023 that meet target standards nine years ahead of schedule.

IMPLICATIONS AND SUGGESTIONS FOR CHINESE POLICY

California's omnibus regulation shows that embedding ZE-HDV credits in pollutant emission standards is possible. While the effect of the regulations is yet to be known, some design elements mentioned above are worthy of consideration by Chinese regulators:

» **Any integration of ZE-HDVs into pollutant emission standards must be coordinated with any existing or planned ZE-HDVs sales requirements and CO_2 standards.** Coordinated policy measures and consistent targets are fundamental to ensuring that the integration of ZE-HDVs into pollutant standards does not dilute the benefits sought by the regulation. Setting limits on the scope and validity of pollutant emission credits gained through the sale of ZE-HDVs is necessary. As a case in point, California has set limits for the NO_x credits gained through the sale of ZE-HDVs.

» **The integration of ZE-HDVs into pollutant emission standards should strive to achieve additional benefits.** In the company of additional policy measures targeting ZE-HDV deployment—such as sales requirements and technology-forcing CO_2 standards—the integration of ZE-HDVs into pollutant emission standards should aim to provide additional health benefits on top of what parallel regulations would drive. For instance, trucks and buses operating in urban conditions are responsible for a high share of the health impacts from HDVs, but a low share of CO_2 emissions. Therefore, a well-designed integration of ZE-HDVs into pollutant emission standards can help to incentivize the electrification of such vehicle segments that escape the strong regulatory pull of other measures.

» **ZE-HDV crediting in pollutant emission standards requires a fleet average approach with a crediting mechanism.** As was the case in the CO_2 standards discussion, fleet averaging of pollutant emissions provides additional degrees of freedom in the regulatory design and enables the integration of ZE-HDVs into pollutant emission standards. Fleet-averaging, however, is linked with additional administrative and oversight efforts to ensure compliance with the set standards.

OTHER POLICIES INCENTIVIZING ZE-HDVS

Several other policies can incentivize ZE-HDV uptake. One of them is fleet requirements that dictate a minimum percentage of ZE-HDVs in new vehicle purchases. While fleet requirements have often been applied to transit buses, government vehicles, and urban service fleets, such programs have limited scale and ambition. But fleet purchase requirements are starting to emerge for trucks and other on-road freight vehicles. The European Union's Clean Vehicles Directive sets minimum requirements of "clean heavy-duty vehicles" for member states' public procurement of vehicles.[70]

Each member state has a national-level aggregate target to fulfill but can choose to distribute efforts across contracting entities. The targets range from 6% in 2021 and 9% in 2030 for countries like Romania, to more ambitious targets of 10% in 2021 and 15% in 2030 for wealthier Germany and France. The regulation defined “clean vehicles” in broad and loose terms, without specific requirements on the percentage of ZE-HDVs.[71] The Chinese central government implemented a nationwide mandate in 2014 for government agencies and public institutions to procure at least 30% NEVs in their new vehicle purchases from 2016, including sanitation and postal trucks.[72] Many cities have since surpassed this target, although the contribution of freight-carrying HDVs in the overall purchase is not known.

California’s Advanced Clean Fleets is anticipated to be the most sweeping fleet requirement that will mandate zero-emission procurements over large segments of HDV applications in California. CARB staff are exploring a regulation that would recognize differences in suitability and feasibility of HDV vehicles in achieving electrification. Targets would go into effect first for applications and vehicles that can most easily become ZE. For example, 10% of the yard truck fleets need to be ZE by 2025, 50% by 2031, and 100% by 2035. By contrast, 10% of a sleeper-cab tractor fleet would be required to become ZE by 2030, 50% by 2036, and 100% ZE by 2042. [73]

At a more local level, cities and boroughs in Europe, China and the United States have implemented, are piloting, or have set clear timelines for low-, near-zero and zero-emission zones to regulate vehicle access. Only vehicles that satisfy the environmental performance standards are granted unrestricted access in these zones. In the case of zero-emission zones, battery electric, fuel-cell electric vehicles meet the criteria. Other vehicles are either barred from entering the area or have to pay an access charge.

Zero-emission delivery zones are a subcategory of zero-emission zones that focus entirely on delivery trucks in cities. Zero-emission zones should not bar trucks altogether irrespective of their environmental performance. One way to encourage ZE-HDVs is to grant at least ZE medium-duty trucks access to these zones.[74]

In Table 8 below, we summarize zero-emission delivery zones in urban areas that have been implemented, planned and announced.

Table 8. Summary of zero-emission delivery zones in urban areas globally

Jurisdiction	Status	Implementation date	Mechanism	Vehicles affected	Areas affected	Operation hours
Rotterdam, the Netherlands[75]	Implemented	January 2015	Road access privilege	Heavy-duty trucks > 3.5 tonnes	One street	24/7
	Planned	2025		Light commercial vehicles and heavy-duty trucks	~ 22 km^2	
Shenzhen, China[76]	Implemented	July 2018	Road access privilege	Light-duty trucks (<4.5 tonnes)	22.33 km^2	24/7
Santa Monica, United States[77]	Pilot	February 2021 (11-month pilot)	Voluntary program	Light, duty and medium-duty vehicles	~ 2.5 km^2	Not specified
30-40 cities, the Netherlands[78]	Planned	2025	Not specified	Light commercial and heavy-duty trucks	Not specified	Not specified
Foshan, China[79]	Announced	Not specified	Road access privilege	Delivery trucks	Not specified	6am-10pm, daily

The establishment of zero-emission delivery zones encourages demand for light and medium ZE-HDVs. Granting access to smaller ZE vans and trucks access in these zones will be an incentive for logistics companies that operate in cities to procure zero-emission trucks. There is also an opportunity to upgrade current low emission zones to zero-emission zones, an action that Paris and Amsterdam already plan to take in 2030.[80]

IMPLICATIONS AND SUGGESTIONS FOR CHINESE POLICY

China has experience with both fleet requirements and zero-emission zones as policy instruments. Fleet purchase requirements in China can be traced back to the Government and Public Institution NEV Purchase Action Plan announced in 2014, the landmark 2015 New Energy Public Transit Bus Promotion Policy, the 100% NEV urban bus requirement in key polluting cities under the national Clean Diesel Action Plan in 2018-2020, and the most recent Green Mobility Action Plan which set a target of at least 80% NEV for new urban bus purchases.[81] Shenzhen is also one of the few cities in the world with zero-emission delivery zones in operation. Here, we provide additional suggestions to extend fleet requirements to more HDV applications, and expand zero-emission zones to wider geographical areas:

» **Public and transit fleet requirements in the past decade have made public fleets and transit operators the trailblazers in the adoption of NEVs in China.** Future regulations can make similar fleet requirements with a specific focus on other types of ZE-HDVs. Drayage trucks, refuse trucks and other vocational HDVs which follow predefined routes are ideal candidates for such fleet requirements.

» **Some Chinese city centers remain closed off to medium- and heavy-duty trucks altogether, regardless of the vehicles' environmental performance or emissions.** Establishing more zero-emission delivery zones that are open to some smaller segments of medium-duty trucks and vans in cities can offer economic and administrative incentives to fleets that run urban freight and logistics operations.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Wider adoption of ZE-HDVs in China and around the world faces several challenges: limited ZE-HDV model availability; higher overall cost, especially upfront cost compared with ICEs; lack of consumer demand; and inconvenient recharging and refueling. In this paper we have identified policy instruments that tackle one or more obstacles facing ZE-HDVs. A summary matrix of the challenges and policy instruments is shown in Table 9.

Table 9. Policy instruments to overcome barriers to ZE-HDV adoption

	Policies	Policy impacts					
		Secure OEM and supply chain investments in ZE-HDVs	Secure abundant model availability	Reduce total cost of ownership	Improve convenience of ZE-HDV use	Redcue demand for ICE usage	Create demand for ZEV usage
Manufacturing/ sales stage	Long-term vision/targets of ZE-HDVs	x					
	ZE-HDV sales requirements	x	x				
	Stringent GHG/CO2/fuel efficiency standards and ZE provisions	x	x				
	Inclusion of ZE-HDVs in pollutant emission standards	x	x				
	Purchase incentives for ZE-HDVs			x			x
	Fleet ZE-HDV procurement requirements						x
In-use stage	In-use tolls and fees incentives for ZE-HDVs			x			
	Infrastructure programs and incentives for ZE-HDVs			x	x		x
	Low- or zero-emission delivery zones					x	x

First, articulating long-term targets for ZE-HDV phase-ins sets a general direction with which other policy levers can harmonize, and gives the industry certainty that enables research and development and product planning to proceed.

The next step is to translate high-level political targets to actionable, concrete vehicle regulations that manufacturers can follow. California's ACT regulation is the first in the world to define sales requirements in specific policy terms and timelines. Its credit-deficit approach allows compliance flexibility and differentiates between vehicle segments based on emission footprints, while not elevating any single ZE-HDV technology pathway or application as an area of priority. Regulators in other markets will need to balance feasibility and ambition in sales requirements to design meaningful yet realistic policies.

Stringent HDV CO_2 and GHG standards will have the effect of stimulating the advance of ZE-HDV technologies that can meet the standards more cost effectively. The same goes for pollutant emission standards. GHG and emission standards should be coordinated with one another, along with current or planned ZE-HDV sales requirements, as is the case in California. Several HDV performance standards today are rewarding ZE-HDVs with credit multipliers. These ZE-HDV credits should not sacrifice the energy or environmental benefits of a technology-forcing standard. Credits should also reflect different freight activities and greenhouse gas emission savings and not be a one-size-fits-all calculation.

Purchase subsidies can lower the capital cost of ZE-HDVs. As prices of ZE-HDVs are projected to decrease, the key is to provide more targeted subsidies to support ZE-HDVs that cannot achieve cost parity with conventional fuel vehicles by market forces alone, and ramp down and eliminate subsidies for other segments. Bonus-malus mechanisms that charge high-polluting internal combustion vehicles and activities can improve the efficiency and financial sustainability of fiscal subsidies.

Operating cost is an area where ZE technologies hold an edge over internal combustion engine technology. Providing operational incentives, including favorable energy prices and discounted road tolls, can help ZE-HDVs extend this lead and improve ZE-HDVs' total cost of ownership advantage.

While countries have announced zero-emission infrastructure investment packages, policies and provisions that address specific needs of ZE-HDVs, including high-power charging and hydrogen refueling that will be necessary for ZE-HDV mass adoption are still rare. Development of infrastructural support policies will need to occur in tandem with vehicle policies to make deployment at a massive scale possible.

Finally, other important policy instruments include purchase requirements for fleets, which are already in place for transit buses in markets like California, China, and Colombia. Fleet requirements provide a push for ZE-HDV adoption from the demand side and complement vehicle regulations and sales requirements. Zero-emission delivery zones grant special privileges to ZE-HDVs that are otherwise shut off from urban areas and can attract logistics companies.

Taking all available policy instruments into consideration, California is arguably the world leader in ZE-HDV regulations, enacting policies that cover sales targets, performance standards and fiscal and in-use incentives. California's Advanced Clean Fleets rule, which is still under development, will add a powerful demand-side push to electrification by placing requirements on fleets to procure ZE-HDVs.[2] California's experience highlights the need for a series of policies that work together to serve a common goal.

Another overarching lesson is regular, timely reviews of ZE-HDV targets and policies. The market for ZE-HDVs is still in early stages of development with limited product choices and consumer confidence. Given the uncertainties that surround ZE-HDVs, targets and policies need constant evaluation and adjustment to reflect the changing landscape of ZE-HDV demand and supply.

With China rolling out its commercial vehicle New Energy Vehicle policy, the European Union working on Euro VII emission standards, and California finalizing its Advanced Clean Fleets Regulation, major markets have important policy windows that can introduce innovative and meaningful regulations to accelerate ZE-HDVs adoption and lower emissions from heavy-duty freight transport. We hope policymakers in China and elsewhere explore policy instruments from multiple angles to accelerate this crucial step towards transport decarbonization.

2 California Air Resources Board. "Advanced Clean Fleets Regulation Workshop." March 2, 2021. https://ww2.arb.ca.gov/sites/default/files/2021-02/210302acfpres_ADA.pdf.

ENDNOTES

1 Ministry of Ecology and Environment of the People's Republic of China (2020). "China Mobile Source Environmental Management Annual Report." https://www.mee.gov.cn/hjzl/sthjzk/ydyhjgl/202008/P020200811521365906550.pdf

2 Government of China (2020a). "2020年上半年全国机动车保有量达3.6亿辆" ["Total motor vehicle population reaches 360 million in first half of 2020"]. http://www.gov.cn/xinwen/2020-07/18/content_5528056.htm

3 ICCT and EV100. "Driving a Green Future: A Retrospective Review of China's Electric Vehicle Development." (Washington, D.C.: International Council on Clean Transportation, January 2021). https://theicct.org/publications/china-green-future-ev-jan2021

4 Wappelhorst, Sandra. "The End of the Road? An Overview of Combustion-Engine Car Phase-out Announcements across Europe." Washington, D.C.: International Council on Clean Transportation, May 10, 2020. https://theicct.org/publications/combustion-engine-car-phase-out-EU

5 Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie. "Mobilitätsmasterplan 2030 Für Österreich." Austria, July 2021. https://www.bmk.gv.at/themen/mobilitaet/mobilitaetsmasterplan/mmp2030.html

6 Ministry of Trade, Industry and Energy. "Hydrogen Economy Roadmap of Korea." Accessed June 29, 2021. https://docs.wixstatic.com/ugd/45185a_fc2f37727595437590891a3c7ca0d025.pdf

7 Government of the Netherlands (2019). "Climate Agreement." The Hague. https://www.government.nl/binaries/government/documents/reports/2019/06/28/climate-agreement/Climate+Agreement.pdf

8 Norwegian Ministry of Transport and Communications. "National Transport Plan 2018-2029." (2017). https://www.regjeringen.no/contentassets/7c52fd2938ca42209e4286fe86bb28bd/en-gb/pdfs/stm201620170033000engpdfs.pdf

9 Uddin, Moaz. "Pakistan's National Electric Vehicle Policy: Charging towards the Future." International Council on Clean Transportation (blog), January 10, 2020. https://theicct.org/blog/staff/pakistan%E2%80%99s-national-electric-vehicle-policy-charging-towards-future

10 Department for Transport. "Heavy Goods Vehicles: Ending the Sale of New Non-Zero Emission Models." Open consultation. United Kingdom, July 14, 2021. https://www.gov.uk/government/consultations/heavy-goods-vehicles-ending-the-sale-of-new-non-zero-emission-models

11 State of California. "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change." California Office of Governor, September 23, 2020. https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/

12 NESCAUM. "15 States and the District of Columbia Join Forces to Accelerate Bus and Truck Electrification, Sign Memorandum of Understanding – Pledge to Develop Action Plan to Eradicate Toxic Diesel Emissions by 2050," (July 14, 2020). https://www.nescaum.org/documents/multistate-truck-zev-governors-mou-20200714.pdf/

13 Hainan Provincial People's Government. 海南省清洁能源汽车发展规划 [Development Plan of Clean Energy Vehicle in Hainan Province]. https://www.hainan.gov.cn/hainan/xnyzcwj/201907/cb9368c30a0f42e7a4cae7dad6651a09.shtml

14 Shikha Rokadiya and Zifei Yang. "Overview of Global Zero-Emission Vehicle Mandate Programs" (Washington, D.C.: International Council on Clean Transportation, April 24, 2019), https://theicct.org/publications/global-zero-emission-vehicle-mandate-program

15 California Air Resources Board. "Advance Clean Trucks Regulation Final Regulation Order." January 29, 2021. https://ww3.arb.ca.gov/regact/2019/act2019/fro2.pdf

16 Cui, Hongyang. "China's New Energy Vehicle Mandate Policy (Final Rule)." Washington, D.C.: International Council on Clean Transportation, January 11, 2018. https://theicct.org/publications/china-nev-mandate-final-policy-update-20180111

17 Peter Mock. "Europe's Lost Decade: About the Importance of Interim Targets." *ICCT Staff Blog* (blog), May 9, 2021. https://theicct.org/blog/staff/interim-targets-europe-may2021

18 European Automobile Manufacturers' Association and Potsdam Institute for Climate Impact Research. "The Transition to Zero-Emission Road Freight Transport." December 15, 2020. https://www.acea.auto/files/acea-pik-joint-statement-the-transition-to-zero-emission-road-freight-trans.pdf

19 Ben Sharpe et al. "United States Efficiency and Greenhouse Gas Emission Regulations for Model Year 2018-2027 Heavy-Duty Vehicles, Engines, and Trailers" (International Council on Clean Transportation, August 25, 2016). http://www.theicct.org/US-phase2-HDV-efficiency-GHG-regulations-FRM

20 Benjamin Sharpe. “Final Second-Phase Greenhouse Gas Emissions Standards for Heavy-Duty Engines and Vehicles in Canada.” (Washington, D.C.: International Council on Clean Transportation, September 21, 2018), https://theicct.org/publications/second-ghg-standards-hdv-Canada

21 Felipe Rodríguez. “CO2 Standards for Heavy-Duty Vehicles in the European Union” (Washington, D.C.: International Council on Clean Transportation, April 16, 2019). https://theicct.org/publications/co2-stds-hdv-eu-20190416

22 Oscar Delgado. “Stage 3 China Fuel Consumption Standard for Commercial Heavy-Duty Vehicles” (Washington, D.C.: International Council on Clean Transportation, July 8, 2016). https://theicct.org/publications/stage-3-china-fuel-consumption-standard-commercial-heavy-duty-vehicles

23 Benjamin Sharpe. “Second-Phase Fuel Economy Standards for on-Road Heavy-Duty Vehicles in Japan.” (Washington, D.C.: International Council on Clean Transportation, January 28, 2019). https://theicct.org/publications/second-phase-fuel-economy-standards-road-heavy-duty-vehicles-japan

24 Mehul Garg and Benjamin Sharpe. “Fuel Consumption Standards for Heavy-Duty Vehicles in India.” (Washington, D.C.: International Council on Clean Transportation, December 7, 2017). https://theicct.org/publications/fuel-consumption-stds-hdvs-india-update-201712

25 U.S. EPA and U.S. DOT. “Final Rule: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2.” Federal Register / Vol. 81, No. 206. October 25, 2016. https://www.gpo.gov/fdsys/pkg/FR-2016-10-25/pdf/2016-21203.pdf

26 European Commission. “Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 Setting CO2 Emission Performance Standards for New Heavy-Duty Vehicles and Amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and of the Council and Council Directive 96/53/EC.” *Official Journal of the European Union* L 198 (July 25, 2019). https://eur-lex.europa.eu/eli/reg/2019/1242/oj#d1e1921-202-1

27 (European Commission, 2019.)

28 California Air Resources Board. “Implementation Manual for the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP).” June 4, 2020. https://californiahvip.org/wp-content/uploads/2020/09/HVIP-FY2019-20-Implementation-Manual-1.pdf

29 California Environmental Associates, and California Air Resources Board. “The Carl Moyer Program Guidelines 2017 Revision.” April 27, 2017. https://ww2.arb.ca.gov/sites/default/files/2020-06/2017_cmpgl.pdf

30 California Air Resources Board. “Zero-Emission Class 8 Freight and Port Drayage Trucks Category.” California VW Mitigation Trust. Accessed February 27, 2021. https://xappprod.aqmd.gov/vw/zero-emission.html

31 Ministry of Finance (2020a). 关于进一步完善新能源汽车推广应用财政补贴政策的通知 [“Notice on further optimizing fiscal subsidies for promoting new energy vehicles”]. http://www.gov.cn/zhengce/zhengceku/2020-12/31/content_5575906.htm

32 Ministry of Finance (2020b). “关于开展燃料电池汽车示范应用的通知” [“Notice on initiating fuel-cell electric vehicle demonstration and application”]. http://www.gov.cn/zhengce/zhengceku/2020-10/22/content_5553246.htm

33 Ministère de la Transition écologique. “Décret N° 2021-37 Du 19 Janvier 2021 Relatif Aux Aides à l’acquisition Ou à La Location de Véhicules Peu Polluants.” 2021-37 § (2021). https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043014941

34 Bundesministerium für Verkehr und digitale Infrastruktur. “Richtlinie Über Die Förderung von Leichten Und Schweren Nutzfahrzeugen Mit Alternativen, Klimaschonenden Antrieben Und Dazugehöriger Tank- Und Ladeinfrastruktur Für Elektrisch Betriebene Nutzfahrzeuge (Reine Batterieelektrofahrzeuge, von Außen Aufladbare Hybridelektrofahrzeuge Und Brennstoffzellenfahrzeuge).” Federal Republic of Germany, August 2, 2021. https://www.bag.bund.de/DE/Foerderprogramme/KlimaschutzundMobilitaet/KSNI/KSNI.html

35 Ministero delle Infrastrutture e dei Trasporti. “Decreto Ministeriale 203.” Pub. L. No. 203 (2020). https://www.mit.gov.it/sites/default/files/media/documentazione/2020-07/DM%20203%20-%202020.pdf

36 IDAE.es. “MOVES II PLAN: Impulso a la movilidad sostenible.” 2020. https://www.idae.es/ayudas-y-financiacion/para-movilidad-y-vehiculos/plan-moves-ii

37 UK.gov. “Low-Emission Vehicles Eligible for a Plug-in Grant.” GOV.UK, 2020. https://www.gov.uk/plug-in-car-van-grants

38 Hongyang Cui and Hui He. “China Announced 2020–2022 Subsidies for New Energy Vehicles” (Washington, D.C.: International Council on Clean Transportation, July 13, 2020). https://theicct.org/publications/china-2020-22-subsidies-new-energy-vehicles-jul2020

39 Jin, Lingzhi, Hui He, Hongyang Cui, Nic Lutsey, Chuqi Wu, Yidan Chu, Jin Zhu, Ying Xiong, and Xi Liu. "Driving a Green Future: A Retrospective Review of China's Electric Vehicle Development and Outlook for the Future." Washington, D.C.: International Council on Clean Transportation, January 14, 2021. https://theicct.org/publications/china-green-future-ev-jan2021

40 California Air Resources Board. "Implementation Manual for the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)." June 4, 2020. https://californiahvip.org/wp-content/uploads/2020/09/HVIP-FY2019-20-Implementation-Manual-1.pdf

41 California Air Resources Board. "Low Carbon Fuel Standard." 17 CCR § 95480-95503 (2020). https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

42 *Ibid.*

43 California Air Resources Board. "Advanced Clean Trucks Total Cost of Ownership Discussion Document Preliminary Draft for Comment." February 22, 2019. https://ww3.arb.ca.gov/regact/2019/act2019/apph.pdf

44 *Ibid.*

45 European Parliament Think Tank. "Revision of the Eurovignette Directive." accessed May 11, 2021. https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI(2017)614625

46 ASFINAG. Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft. "GO Maut." 2020. https://www.asfinag.at/maut-vignette/maut-fuer-lkw-und-bus/

47 Kurier. "Regierung senkt Maut für emissionsfreie Lkw." February 24, 2021. https://kurier.at/wirtschaft/regierung-senkt-maut-fuer-emissionsfreie-lkw/401198941

48 BGL. "Modellrechnungen Zur Kostenentwicklung Im Güterkraftverkehr" (Bundesverband Güterkraftverkehr Logistik und Entsorgung. (BGL) e.V., 2018). https://www.bgl-ev.de/web/der_bgl/informationen/branchenkostenentwicklung.htm&v=2#form

49 Bundesministerium für Verkehr und digitale Infrastruktur. "Lkw-Maut." 2021. https://www.bmvi.de/SharedDocs/DE/Artikel/StV/Strassenverkehr/lkw-maut.html

50 Eidgenössische Zollverwaltung EZV. "LSVA - Allgemeines / Tarife." 2021. https://www.ezv.admin.ch/ezv/de/home/information-firmen/transport--reisedokument--strassenabgaben/schwerverkehrsabgaben--lsva-und-psva-/lsva---allgemeines---tarife.html.

51 Bain & Company, and G7. 中国公路货运市场研究报告 [Research report on China's road freight transport market"]. 2017. https://www.bain.cn/pdfs/201709180300293802.pdf

52 California Air Resources Board. "LCFS Basics." September 2020. https://ww2.arb.ca.gov/sites/default/files/2020-09/basics-notes.pdf

53 Patrick Brecht. "2020–2023 Investment Plan Update for the Clean Transportation Program." Revised Lead Commissioner Report. California Energy Commission, September 2020. https://efiling.energy.ca.gov/getdocument.aspx?tn=235226

54 California Public Utilities Commission. "CPUC Approval of Utility Projects Keeps California at Forefront of Transportation Electrification." California Public Utilities Commission, May 31, 2018. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M215/K467/215467739.PDF

55 California Public Utilities Commission. "Zero Emission Vehicle (ZEV) Rate Programs." Accessed March 7, 2021. https://www.cpuc.ca.gov/General.aspx?id=12184.

56 Ministry of Science and Technology of the People's Republic of China. (2016). "关于"十三五"新能源汽车充电基础设施奖励政策及加强新能源汽车推广应用的通知" [Notice on new energy vehicle charging infrastructure incentive policy and promotion of new energy vehicles in the 13th five-year period], http://www.most.gov.cn/tztg/201601/t20160120_123772.htm

57 People.cn. "'以奖代补' 财政部支持地方开展充电基础设施建设" ['Reward instead of subsidy', the Ministry of Finance supports local recharging infrastructure constructions], (November 3, 2020). http://auto.people.com.cn/n1/2020/1103/c1005-31917589.html

58 European Commission. "Proposal for a Regulation of the European Parliament and of the Council on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU of the European Parliament and of the Council," July 14, 2021. https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf.

59 ADVENIR. (2021). "Nouvelle prime pour les flottes poids lourds. [New premium for heavy vehicle fleets.]" Retrieved from https://advenir.mobi/2021/05/03/nouvelle-prime-flottes-poids-lourds/

60 Bundesministerium für Verkehr und digitale Infrastruktur. (n.d.) "Masterplan Ladeinfrastruktur Der Bundesregierung: Ziele Und Maßnahmen Für Den Ladeinfrastrukturaufbau Bis 2030. [Federal Government's Charging Infrastructure Master Plan: Targets and measures for the development of charging infrastructure by 2030]." Retrieved from https://www.bmvi.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur.pdf?__blob=publicationFile

61 Bundesministerium für Verkehr und digitale Infrastruktur. “Richtlinie Über Die Förderung von Leichten Und Schweren Nutzfahrzeugen Mit Alternativen, Klimaschonenden Antrieben Und Dazugehöriger Tank- Und Ladeinfrastruktur Für Elektrisch Betriebene Nutzfahrzeuge (Reine Batterieelektrofahrzeuge, von Außen Aufladbare Hybridelektrofahrzeuge Und Brennstoffzellenfahrzeuge).” Federal Republic of Germany, August 2, 2021. https://www.bag.bund.de/DE/Foerderprogramme/KlimaschutzundMobilitaet/KSNI/KSNI.html.

62 Ministry of Energy, Poland. (2019) “Poland’s National Policy Framework for the development of alternative fuels infrastructure [Sprawozdanie z realizacji Krajowych ram polityki rozwoju infrastruktury paliw Alternatywnych].” Retrieved from https://www.gov.pl/web/aktywa-panstwowe/zapraszamy-do-konsultacji-projektu-sprawozdania-z-realizacji-krajowych-ram-polityki-rozwoju-infrastruktury-paliw-alternatywnych

63 Ministry of Environment. (2021). 「2021년 수소연료전지차 수소연료전지차 보급 및 수소충전소 설치사업」 보조금 업무처리지침 [「2021 hydrogen fuel cell vehicle hydrogen fuel cell vehicle supply and hydrogen charging station installation project」 Guidelines for handling subsidies]. Retrieved from https://www.ev.or.kr/portal/board/14/8405/?

64 IDAE.es. (2020)

65 Infrastructure and Projects Authority, and HM Treasury. (2018). “Charging Infrastructure Investment Fund: Request for Proposals”. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727576/CIIF_RFP.pdf

66 Rodríguez, Felipe, Julia Hildermeier, and Andreas Jahn. “Electrifying EU City Logistics: An Analysis of Energy Demand and Charging Cost.” Washington, D.C.: International Council on Clean Transportation, November 18, 2020. https://theicct.org/publications/optimizing-charging-logistics-nov2020

67 California Air Resources Board. “Public Hearing to Consider the Proposed Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments: Proposed Amendments to the Exhaust Emissions Standards and Test Procedures for 2024 and Subsequent Model Year Heavy-Duty Engines and Vehicles, Heavy-Duty On-Board Diagnostic System Requirements, Heavy-Duty In-Use Testing Program, Emissions Warranty Period and Useful Life Requirements, Emissions Warranty Information and Reporting Requirements, and Corrective Action Procedures, In-Use Emissions Data Reporting Requirements, and Phase 2 Heavy-Duty Greenhouse Gas Regulations, and Powertrain Test Procedures. Staff Report: Initial Statement of Reasons.” Sacramento, California, June 23, 2020. https://ww3.arb.ca.gov/regact/2020/hdomnibuslownox/isor.pdf

68 *Ibid.*, pg. III-76

69 California Air Resources Board. “Proposed Amendments to the Exhaust Emissions Standards and Test Procedures for 2024 and Subsequent Model Year Heavy-Duty Engines and Vehicles, Heavy-Duty On-Board Diagnostic System Requirements, Heavy-Duty In-Use Testing Program, Emissions Warranty Period and Useful Life Requirements, Emissions Warranty Information and Reporting Requirements, and Corrective Action Procedures, In-Use Emissions Data Reporting Requirements, and Phase 2 Heavy-Duty Greenhouse Gas Regulations, and Powertrain Test Procedures,” August 27, 2020. https://ww3.arb.ca.gov/regact/2020/hdomnibuslownox/res20-23atta.pdf

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

71 The definition of “clean” HDV trucks here include vehicle categories N2 and N3 that use hydrogen, battery-electric (including plug-in hybrids), natural gas (both CNG and LNG, including biomethane), liquid biofuels, synthetic and paraffinic fuels, and liquified petrol gas (LPG).

72 National Government Offices Administration. (2014). 政府机关及公共机构购买新能源汽车实施方案 [Action plan on purchase of new energy vehicles by governments and public institutions]. Retrieved from http://www.gov.cn/xinwen/2014-07/13/content_2716565.htm

73 California Air Resources Board. “Advanced Clean Fleets Regulation Workshop.” March 2, 2021. https://ww2.arb.ca.gov/sites/default/files/2021-02/210302acfpres_ADA.pdf

74 Paris City Hall. “Zone à Faibles Emissions [Low Emission Zone].” https://www.data.gouv.fr/fr/datasets/zone-a-faibles-emissions-zfe/#:~:text=La%20Ville%20de%20Paris%20a,qualit%C3%A9%20de%20l’air

75 City of Rotterdam. “Vrachtautoverbod ’s-Gravendijkwal [Truck ban in ’s-Gravendijkwal].” https://www.rotterdam.nl/werken-leren/sgravendijkwal/

76 Shenzhen Public Security Bureau. “关于继续设置绿色物流区禁止轻型柴油货车通行的通告 [Notice on continuing Green Logistic Zones to ban the use of light-duty diesel trucks].” http://ga.sz.gov.cn/gkmlpt/content/8/8394/post_8394656.html#808

77 Los Angeles Cleantech Incubator. “Santa Monica Zero Emissions Delivery Zone Pilot”. https://laincubator.org/zedz/

78 “Climate Agreement.” The Government of the Netherlands, June 28, 2019. https://www.government.nl/documents/reports/2019/06/28/climate-agreement

79 Foshan Transportation Bureau. “佛山市城市绿色货运配送办法 (征求意见稿) [Proposal on Foshan Green Urban Delivery Rules].” http://www.foshan.gov.cn/hdjlpt/yjzj/answer/9083

80 Paris City Hall. “Zone à Faibles Emissions [Low Emission Zone].” https://www.data.gouv.fr/fr/datasets/zone-a-faibles-emissions-zfe/#:~:text=La%20Ville%20de%20Paris%20a,qualit%C3%A9%20de%20l'air

81 Ministry of Transport (2015). 交通运输部关于加快推进新能源汽车在交通运输行业推广应用的实施意见. [Ministry of Transport Guidance on accelerating the application of new energy vehicles in the transport sector]. Retrieved from http://www.gov.cn/gongbao/content/2015/content_2883248.htm.

He, Hui (2019). China's Clean Diesel Action Plan: 2018-2020. Retrieved from the International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/ICCT_China_Clean_Clean_Diesel_2018_2020_20190529.pdf

Ministry of Transport, and National Development and Reform Council (2020). 交通运输部国家发展改革委关于印发《绿色出行创建行动方案》的通知. [Ministry of Transport and National Development and Reform Council's notice on the publication of Green Mobility Action Plan]. Retrieved from http://www.gov.cn/zhengce/zhengceku/2020-07/26/content_5530095.htm