CALSTART | GLOBAL COMMERCIAL VEHICLE DRIVE TO ZERO | Government of the Netherlands

GLOBAL MEMORANDUM OF UNDERSTANDING

MOU SUMMIT 2 JUNE 2025

Arnhem, Netherlands

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UNLOCKING THE POTENTIAL OF SUPPLY-SIDE REGULATIONS

SESSION 2. IMPLEMENTATION

RECAP

1. What are supply-side regulations?

2. What were some of the main takeaways from the last session?

GLOBAL
MEMORANDUM OF UNDERSTANDING

UNLOCKING THE POTENTIAL OF SUPPLY-SIDE REGULATIONS
SESSION 1. IMPLEMENTATION

1. Implementing regulation: Chile's Fuel Efficiency Standards
2. Moving toward implementation: UC Davis SSR Toolkit
3. Activity: putting the first pieces in place
4. Takeaways and next steps

IMPLEMENTING REGULATION: CHILE'S FUEL EFFICIENCY STANDARDS



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MOVING TOWARD IMPLEMENTATION: UC DAVIS SSR TOOLKIT



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Supply Side Regulation (SSR)

Heavy-Duty Toolkit for Decision Makers

A guide to building supply-side regulations for heavy-duty vehicles

Presented by Lew Fulton for Global MOU conference, Arnhem Netherlands, June 2 2025

Toolkit Authors: Jacob Teter, Pierpaolo Cazzola, Roland Hwang, Aditya Ramji

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Defining SSRs

Supply side regulations, referred to as SSRs, require automotive manufacturers and their suppliers to reduce fuel consumption and/or greenhouse gas (GHG) emissions through changes in vehicle efficiency, technology or both.

The three main types of SSRs are: ZEV/EV sales requirements, GHG or CO_2 standards, and fuel economy or efficiency standards.

- **Sales standards** require manufacturers to sell a certain proportion of their fleet as alternative fuel vehicles.
- **GHG standards** require auto manufacturers to meet an average level of emissions across all vehicle sales.
- **Efficiency standards** require auto manufacturers to meet an average level of efficiency across all vehicle sales. Hybrids of the three SSR types also exist in some regions.

SSR instrument choices



ZEV / EV sales requirements (or “enabling”)

Pros

- Simpler to design and enforce (no need for compliance testing equipment, procedures, simulation tools)
- Potential alignment with other economic / industrial policy goals

Cons

- Not technology neutral, and possibly not the most efficient approach to energy savings or CO2 reduction.
- Depends on scale-up and availability of EV supply chain and of charging infrastructure
- Provides no incentive for improvements in fuel efficiency of ICEVs

Vehicle performance standards

Pros

- Properly credits and promotes all efficiency improvements, acknowledges market structures
- Encourages cost-effective technology investment

Cons

- Requires sustained investment in technical capacity building; research and design; and monitoring and enforcement (e.g. testing facilities)

*GHG standards require measurement of CO_2 / CH_4, and N_20, CO_2 standards require only monitoring of fuel consumption of the test fuel

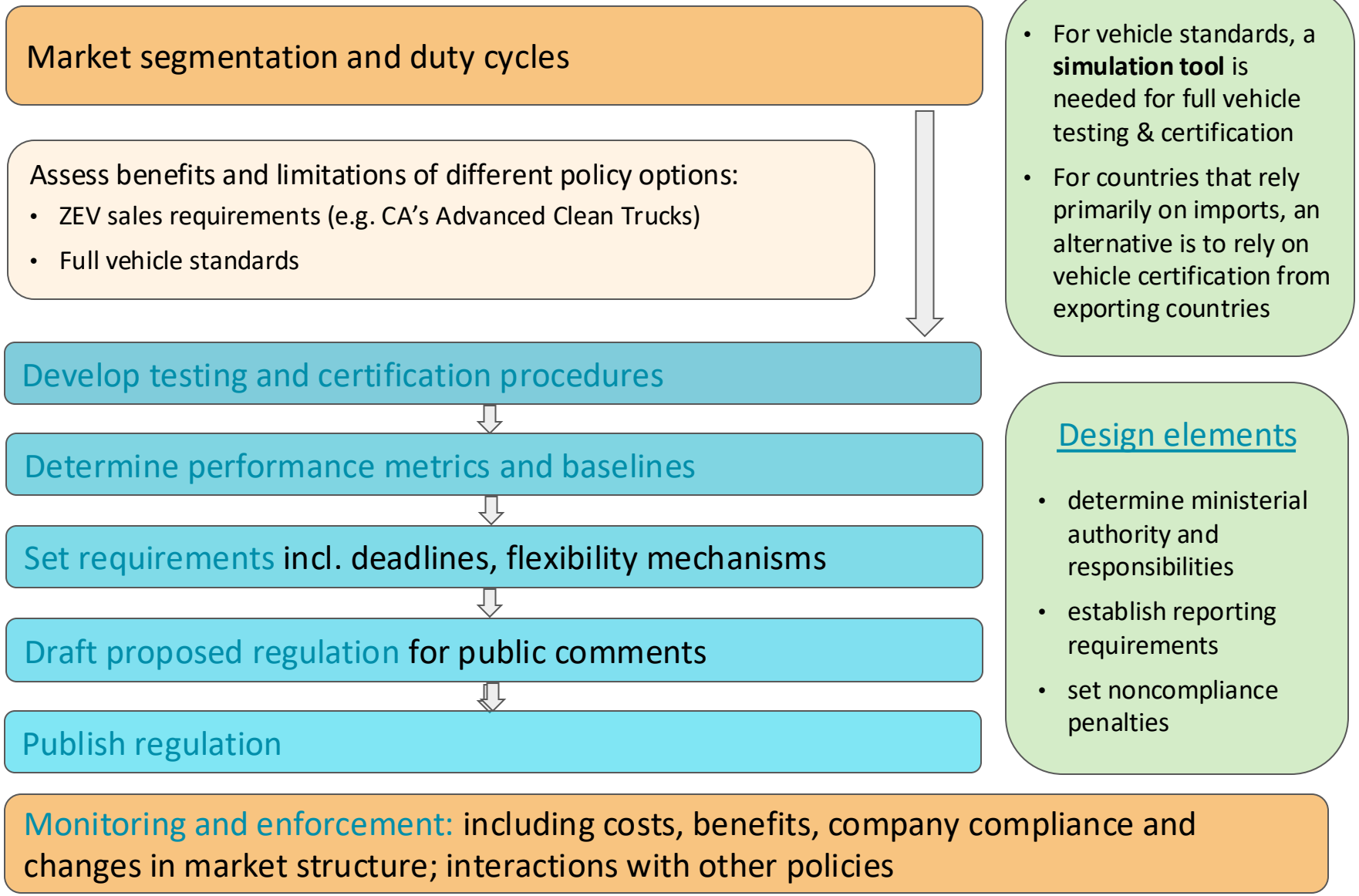
Designing SSRs for HDVs

The HDV SSR Toolkit is designed to provide guidance and resources for government decision makers including policy makers, regulatory agencies, and any supporting organizations committed to developing SSRs for the heavy-duty road vehicle sector.

By providing a summary of existing experience and best practices – as well as recommendations and guidance – on designing SSRs, as well as summaries of the key design elements of existing SSRs, the Toolkit aims to provide the resources these stakeholders need to craft effective, contextually appropriate policies.

Whether working in departments of transportation, environment, or energy, decision makers will find clear guidance on regulatory design to contribute to their own jurisdiction's key economic, industrial policy, energy security and climate goals.

Developing a fuel efficiency or GHG/CO_2 standard, and/or ZEV or EV sales requirements for M/HDV requires several steps, shown here in a simplified, idealized flow diagram.



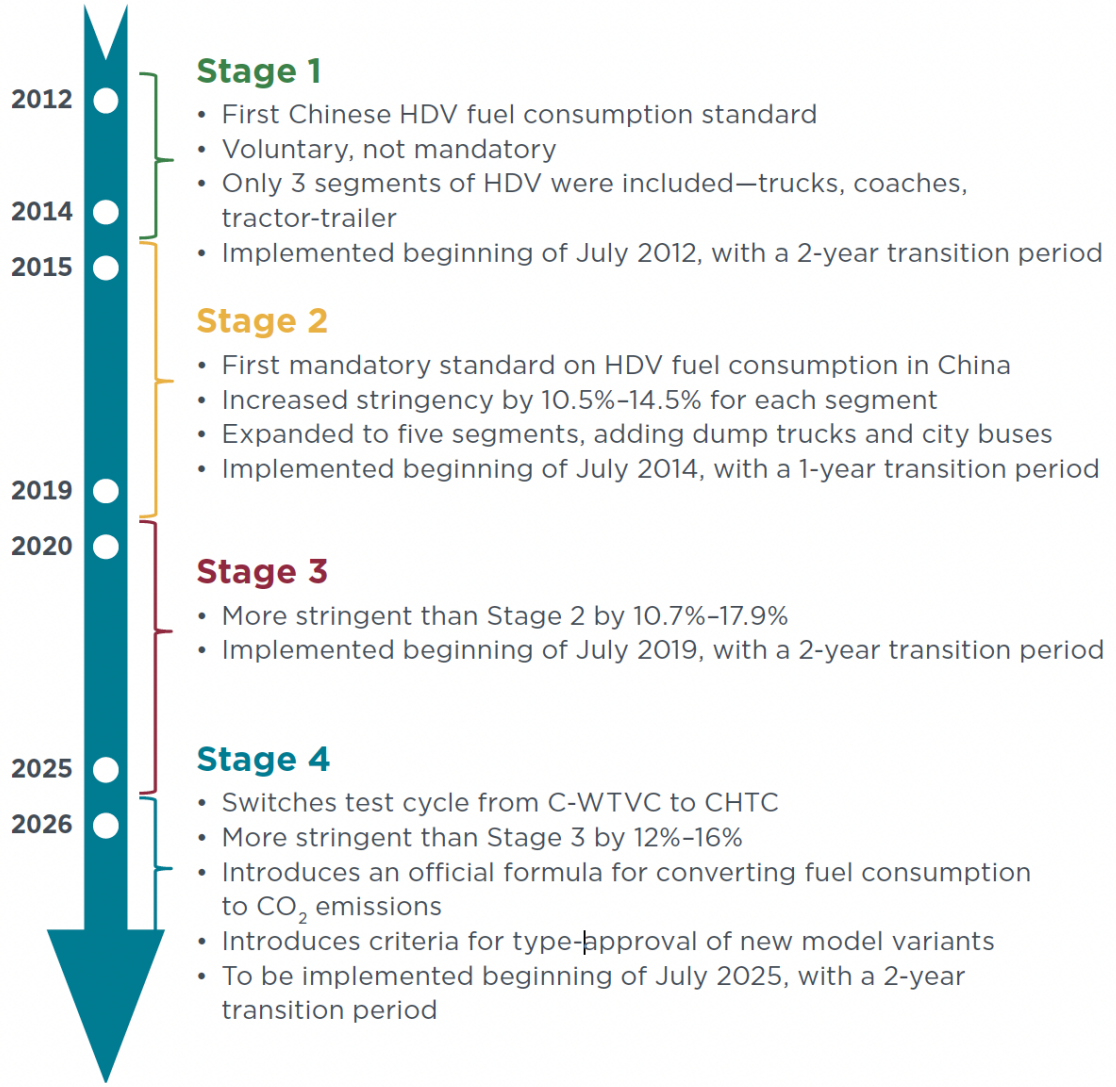
Adapted and expanded from "A Stepwise Guide to Heavy-Duty Vehicle Efficiency Standards", ICCT, 11 Nov 2020.

Setting ambitious but achievable HDV standards can be the first step in a journey toward longer-term goals

Common features of successive rounds of HDV fuel consumption standards:

- Greater coverage of segments
- Increased stringency
- Better coverage of AFVs (e.g. NGVs, hybrid-electric vehicles, including plug-ins)
- Reduced multipliers for PHEVs, BEVs, and FCEVs

Figure 14. *Timeline of China's fuel consumption standards for HDVs*



Standards can continue to be improved in successive iterations, building upon learnings from previous stages. Notifying, implementing, and enforcing standards that are 'good enough' provides a foundation for future improvements.

Source: China's Stage 4 fuel consumption standard for heavy-duty commercial vehicles, ICCT, 2024

Flexibility mechanisms

The three most common flexibility mechanisms are credit banking, trading, and averaging.

To ensure that these don't compromise the effectiveness of the standard (including deployment of efficiency technologies, fuel savings, and CO_2 emission cuts), flexibility mechanisms are often designed to be subject to constraints or caps.

Credit Banking

Deficits and credits are accrued each year, and can be used to enable manufacturers that don't meet the standard in a given to comply by overperforming in subsequent years.

- **Time limits** (e.g. in the US GHG standard, deficits must be balanced within 3 years and credits must be used within 5 years; in the EU CO_2 standard, credits must be used within 7 years, can banking is fully phased out by 2040)
- **Interest rates** (effectively reducing the value of credits for each year they are not used, and 'banked')

Flexibility mechanisms

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Credit Averaging

Averaging allows a manufacturer to apply credits (overcompliance) in one segment to deficits (undercompliance) in another segment. Examples:

- In the US GHG standard, averaging is possible within each of the weight class-based averaging sets: (i) Light HDV (Class 2b through Class 5), (ii) Medium HDV (Class 6 to Class 7), (iii) Heavy HDV (Class 8).
- Making credit averaging only possible within each weight class prevents transferring credits from lighter segments where compliance is easier (lower cost) to heavier segments, where compliance costs are higher. It therefore ensures technology progress across all segments.
- In the EU CO_2 standard, the manufacturer-specific emissions target in a given year is based on the composition of that manufacturers' sales and on the reference CO_2 emissions of each vehicle sub-group (which are common to all manufacturers). This means that undercompliance in one vehicle sub-group can be offset by overcompliance in another sub-group, with the tonne-kms in each subgroup used to weight the potential for averaging across sub-groups.

Flexibility mechanisms

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Credit Trading

Trading allows manufacturers to buy and sell credits from among one another. These are often subject to caps and/or constraints.

- The 2024 revision of the EU HDV CO_2 emission standard introduced trading
- Other flexibility mechanisms may include credits to reward manufacturers that overperform on standards in the years proceeding their implementation (e.g. early emissions credits in the EU from 2019-2024, and early credits in California's ACT for manufacturers selling ZEVs and NZEVs from MY 2021 to MY 2023)

Policies options for HDVs

Supply-side
(impact vehicle production & tech availability)

Demand-side
(impact buyer choices, operating behaviour)

Regulatory
- GHG/fuel economy standards
- ZEV sales requirements
- Low/zero-emission zones
- Clean fleet mandates

Fiscal Policies
- Manufacturer incentives / R&D funding
- Purchase subsidies/tax credits
- Fuel/carbon taxes
- Charging infrastructure investments
- Government procurement

Informational Policies
- Efficiency labelling / fleet benchmarks
- Training programs

Many policies impact all three goals simultaneously:

- ZEV mandates, subsidies, and infrastructure investments reduce fuel use, emissions, and promote electric HDVs.
- Carbon pricing drives down emissions and fuel consumption while indirectly encouraging electrification by raising fossil fuel costs.
- Fuel economy/GHG standards primarily target emissions and fuel use, but can also push OEMs toward electrification for compliance.

Table 1. *Policies to reduce GHG emissions and fuel use, and to accelerate MHDV electrification*

Policy	GHG Reduction	Fuel Use Reduction	Accelerate electrification	Type
Fuel economy/GHG emissions standards	✅	✅	🟡	Regulatory
Zero-emission vehicle (ZEV) mandates	✅	✅	✅	Regulatory
Vehicle purchase subsidies/incentives	✅	✅	✅	Fiscal
Carbon pricing (fuel taxes or carbon tax)	✅	✅	✅ (indirectly)	Fiscal
Low-emission/zero-emission zones	✅	✅	✅	Regulatory
Charging/refuelling infrastructure investment	✅	✅	✅	Fiscal
Research & development grants	✅	✅	✅	Fiscal
Public procurement of electric buses/trucks	✅	✅	✅	Fiscal/Regulatory
Labelling and efficiency information (fleet benchmarking)	🟡	🟡	⛔	Informational
Training and operational best practices for fleets	🟡	🟡	⛔	Informational

An effective strategy is to combine regulations (to set direction), fiscal tools (to ease the transition), and informational policies (to improve decision-making), across both supply and demand.

Sources: elaboration based on data from ICCT, 2025, ICCT, 2024a, ICCT, 2024b, ICCT, 2024c, IEA, 2024, Calstart, ACEA, 2025

ACTIVITY: PUTTING THE FIRST PIECES IN PLACE

1. Split up into four groups
2. Groups work separately with discussion leads to answer worksheet questions as applicable ***for their own country***
3. After 15 min, switch to another discussion lead, and repeat
4. End after all participants have discussed with all leads

REGULATORY OPTIONS

Ethan Elkind, CLEE, UC Berkeley

TARGETS, TIMELINES AND FLEXIBILITIES

Lew Fulton, ITS-UC Davis / Stephanie Kodish, CALSTART/Drive to Zero

STAKEHOLDER ENGAGEMENT

Ricardo García, CALSTART/Drive to Zero

POLICY ECOSYSTEM

Stef Cornelis, T&E / Anna Murphy, S-Curve Economics

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TAKEAWAYS

NEXT STEPS

APPLY FOR FREE TECHNICAL ASSISTANCE TO DEVELOP SUPPLY-SIDE REGULATIONS

ZEV TRANSITION COUNCIL

ZERO-EMISSION VEHICLE
RAPID RESPONSE FACILITY

REQUEST FORM

CALSTART | GLOBAL COMMERCIAL VEHICLE DRIVE TO ZERO | Government of the Netherlands

FOR MORE INFORMATION, VISIT: HTTPS://GLOBALDRIVETOZERO.ORG/MOU/

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Additional slides:
More details and resources

ZEV and other advanced technology super-credit multipliers

In early stages of market adoption, ZEV credit multipliers can serve as a powerful incentive to accelerate technology adoption.

The main risk is of setting high credit multipliers is that they can dilute efficiency / CO_2 standards, making actual improvements more difficult to project, and less reliable. Caps or conditions can help to limit this potential effect.

As battery costs decline, and with increasing market shares of battery electric trucks, the value of multipliers will diminish.

The most mature regulations have been designed to phase out multipliers by the early 2030s, anticipating the economic competitiveness of electric technologies will provide sufficient incentives for manufacturers to transition to them.

In the European Union:

The original 2019 CO_2 emission standards for HDVs (Regulation (EU) 2019/1242) incentivized **zero- and low-emission vehicles (ZLEVs)**, defined as those that emit less than half of the average of their vehicle sub-group, by:

- ***allowing regulated entities to double count CO_2 emission savings of ZLEVs (in g CO_2/tkm), up to 2025***.
- ***defining ZEVs as vehicles with emissions of less than 1 g CO2/kWh***
- ***counting contributions toward CO_2 targets from ZEV sales beyond directly regulated vehicle categories*** (e.g. lorries with less than 16 t of maximum permissible maximum laden mass).

These multipliers were subject to caps:

- CO_2 emission savings (in g CO_2/tkm) generated by ZLEV sales were capped at 3%,
- Contributions from ZEV categories that weren't directly regulated were capped at 1.5%.

The same 2019 regulation also sets a **2% minimum benchmark of ZLEV sales** for the period 2025-2030 under which the super-credit would not apply.

The 2024 updates to the CO_2 emission standards for HDVs (Regulation (EU) 2024/1610):

- ***revised the double-counting for ZLEVs from the years 2025 onwards:*** Credits for eligible ZLEVs (e.g. PHEVs) range from 1 (for vehicles with emissions of exactly half of the average emissions of vehicles in their sub-group), to 2 (for ZEVs), with a linear scale for vehicles with specific emissions of less than half the average emissions of vehicles in their sub-group.
- ***removed ZEV credit multipliers from 2030 onwards,***
- ***removed the contributions from unregulated vehicle categories beyond 2025,***
- ***maintained both the 2% benchmark for 2025-2030 and the 3% cap for CO_2 emissions credits that can be generated by ZLEVs.***

The updates also ***redefined ZEVs*** to trucks emitting less than 3 g CO_2/tkm for trucks and buses emitting less than 1 g CO_2/pkm. This revision allows mono-fuel and dual-fuel hydrogen combustion engines to qualify as ZEVs.

Trailers equipped with a device that actively supports their propulsion without an internal combustion engine or with an internal combustion engine that directly emits less than 1 g CO_2/kWh (based on the Euro 5 or Euro 6 emission regulations) also qualify as ZEVs, including for ZEV trading, even if trailers cannot report their emissions as 0 g CO_2/tkm.

In the United States:

The Phase 3 standards enable vehicle manufacturers to ***generate advanced technology multiplier credits through MY 2027*** of:

- ***3.5 for plug-in hybrid electric vehicles (PHEVs),***
- ***4.5 for battery electric vehicles (BEVs),***
- ***and fuel cell electric vehicles (FCEVs).***

To prevent credits generated by the multipliers from diluting the effective stringency of the GHG limit values, the use of credits generated by the multipliers is restricted to MYs 2027-29 and then phased out in MY 2030. For MYs 2027-29, manufacturers are required to prioritize the use of available base credits (credits before any multipliers are applied) before using multiplier credits.

Recommendations

Leverage existing methodologies and expertise

Prioritise capacity building, while recognizing capacity constraints

Prioritise low-hanging fruit, and stage standards for maximum effectiveness

Leverage existing methodologies and international expertise

- Standardized component testing methods exist to measure tyre rolling resistance, aerodynamic drag, and engine efficiency (e.g. UNECE, ISO, EU and U.S.)
- Vehicle simulation methods that have been developed in VECTO and GEM that can be adapted to apply to national context
- Existing driving cycles can be adapted to avoid developing new ones, as has been done China, India, and elsewhere
- Lessons can be learned from countries that have implemented multiple stages of regulations, including on what mistakes that can be avoided and how

Prioritise capacity building, while recognizing capacity constraints

- Allocate sufficient resources to cultivating technical knowledge (e.g. within relevant ministry, or jointly with domestic technical partners) and infrastructure (testing facilities and equipment)
- Countries that import MHDVs and without testing capacity could build regulations based on component and vehicle certifications from vehicle exporting countries (Assuming that certification schemes can be compared or harmonized, third-party international entities can provide the necessary validation, so these certificates don't require further verification)

Prioritise low-hanging fruit, and stage standards for maximum effectiveness

- The regulator can develop the testing/certification methods, but require manufacturers to provide the data needed for the baseline (e.g. in the following year), thereby both expediting the implementation and avoiding critique of a flawed baseline. When the regulator takes charge of defining the baseline, such baseline is always "imperfect" and subject to industry attacks (e.g. that the cycle used is not representative, that too small a sample of trucks was sampled and that it is statistically significant, …); onstead of taking that time intensive task, the regulatory entities can pass the task to the OEMs (as was done by the EU).
- Implement ambitious but achievable standards, that focus on the main fuel consuming segments and on conventional technologies
- Simple standards that come into force quickly and mandate near-term improvements can be improved in subsequent phases
- ZEV sales requirements are simple to design and enforce; in segments where ZEV sales requirements are politically, economically, and technically viable, ZEVs standards can be designed and implemented quickly, and with far fewer administrative and technical resources than are needed for vehicle efficiency / CO_2/GHG standards.

Table 2. *Comparison of SSR types*

Regulation aspect	ZEV sales requirement	GHG / CO_2 standard	Efficiency standard
Primary goal	Increase alternative energy vehicle sales	Reduce vehicle CO_2 emission	Increase vehicle energy / fuel efficiency
Metric	Percentage of new vehicle sales / registrations	***gCO_2/ton-mile***, gCO_2/tonne-km (engines: gCO_2/hp-hr)	***gal/ton-mile***, ***litres/tkm***, litres/vehicle-km (India)
Primary regulated entity	Vehicle manufacturers	Vehicle and/or engine / component manufacturers	Vehicle and/or engine / component manufacturers
Fuel types/ technology	BEVs, FCEVs, (PHEVs and H-ICEVs)	All fuel types	All fuel types
Technology neutral	No	Yes*	Yes*
Targets	ZEVs or EVs sold as a share of total vehicles sold	Average specific emissions, (per v-km or tonne-km), across all vehicles sold	Average energy efficiency, (per v-km or tonne-km), across all vehicles sold
Counting zero tailpipe emission vehicles	BEVs, FCEVs, and PHEVs counted as 1 or >1	BEVs/ FCEVs generally counted as 0 gCO_2/tonne-km	Alternative energy vehicles energy consumption can be calculated based on diesel-equivalence**

* In practice, such standards are often not, strictly speaking, technology neutral, insofar as as they incorporate credit multipliers or other off-cycle credits for particular powertrain or efficiency technologies.

** A regulator might decide to assign a value of 0 to ZEVs as well, to promote EVs in the first phases of the regulation, and to give the regulator time to develop the BEV certification methodologies etc.

Data requirements for market segmentation of HDVs

Data required to enable a segmentation of the heavy-duty vehicle market is far more complex than for LDVs, given the great heterogeneity in vehicle configurations, operations, and duty-cycles.

Historical/current data

- New sales / registrations, including time trends over 5-10 years
- Top-selling vehicle models within each segment
- Manufacturer market shares (by vehicle size and type) - e.g. segmentation by GVW, axle configuration, engine capacity / power rating
- Similar analysis for major Tier 1 suppliers (e.g. engines and transmissions, chassis, tractors bodies, trailers, tires, etc.)
- Consideration of domestic manufacturing versus imports (including consideration of CND versus CBU imports)

Technology

- Most common engines, transmissions, tyres, chassis, axle configuration, trailers
- Baseline / benchmark efficiency and costs (e.g. power, efficiency, sticker price, engine mapping of top-selling engine models within each segment)

Operations

- Speed profile (cruising speeds, acceleration / deceleration, average daily mileage and times of stops (including overnight), loads (representative full load, empty running / return journey backhaul), power requirements
- Fuel / energy consumption estimates

Projections

- Segments and powertrains where market has grown over past decade (identify policy or structural drivers), and techno-economic assessments of cost reductions and comparative TCO (e.g. for BEVs)
- Economic and population growth projections (demand for cargo transport and other light/heavy industrial activities)
- Near-term (i.e. 5-10 years) and long-term (i.e. to 2050, and potentially beyond) projections

Determine performance metrics and baseline efficiency levels

Market and fuel economy assessments (Baseline analysis) inform the baseline fuel efficiency / CO_2 emissions levels and the stringency of the standards, within each regulated segment.

Fuel efficiency / CO_2 /GHG standards for trucks can be designated in either units of distance (e.g. litres per 100 km) or of distance-payload (e.g. litres per tonne-km).

- The former approach is based on estimating each segment's specific fuel consumption (litres/100 km or gCO_2/km), as estimated at representative payload (or as a weighted average of representative loads)
- The latter approach is preferable if credit averaging is allowed among segments, as it enables explicit consideration of the efficiency of trucks of different categories to provide their relevant service (i.e. to haul cargo, as measured by its weight).

Fuel efficiency testing and compliance has generally been established using a simulation tool, such as GEM (in the United States) or VECTO (in the EU).

Adapting/adopting a simulation tool requires investing substantial resources, but the approach has several advantages over full vehicle testing:

- The ability to isolate and certify fuel efficiency improvements of components and vehicles
- Long-term cost savings in verification and enforcement

Use of a simulation tool requires validation with other measurement approaches:

1. portable emissions measurement systems (PEMS) testing and/or
2. chassis dynamometer testing

Market Segmentation and Duty Cycles



The baseline analysis for HDVs includes two key elements:

- **Market segmentation**: collect data on new truck sales/registrations, including:

(1) Technical data – engine capacity/power, gross vehicle weight, axle configuration, and more

(2) Market/price data (e.g. shares of tier 1 suppliers, engine, vehicle manufacturers; and manufacturer suggested retail prices [MSRP] and sales prices).
Data on the concentration of major manufacturers, top-selling models, and shares of domestic versus imported components and vehicles (incl. CBU and CKD) can help to inform segmentation and subsequent steps.

(3) Operations information on representative daily mileage, loads, speed profiles, power requirements), need to be paired with estimates of fuel consumption.

- Together, (1), (2), and (3) enable an initial market segmentation, based on major categories of trucks that share key technology and operational characteristics. ***Representative duty cycles*** can then be defined for each major segment.

As with LDVs, the baseline analysis can help decision makers determine which SSR is the best fit for their region, and which design elements may be necessary for inclusion in the regulation.

The baseline analysis is intended to assist decision makers in creating a context specific SSR, ensuring that they address the most impactful areas of the supply chain. By examining similar efforts in other regions, the baseline analysis offers a foundation for decision makers to build upon, helping to create contextually appropriate and sustainable regulatory frameworks.

This section is composed of three subsections:

1. Data requirements
2. Stakeholder engagement and coordination
3. Market segmentation

Stakeholder engagement and coordination

The agency or agencies spearheading SSR development should establish and convene one or several working groups comprising the relevant subsets of stakeholders, and involve other stakeholders as required in specific steps of the process.

Key stakeholders should be identified and consulted early in the regulatory design process.

Expert working groups should be convened to inform and ensure buy-in during every stage. Key stakeholders at the stage of baseline analysis include:

- Market data vendors (Vehicle and Tier 1)
- Vehicle, engine, & component manufacturers
- Industry associations (HDV manufacturers, road freight [shippers, carriers, 3POs] and commercial bus operators)
- All relevant government ministries (including Energy, Environment, Industry, Trade, Finance, etc.)
- Research and technical experts (e.g. universities, NGOs, companies)
- Relevant public interest groups / civil society

Collecting the data needed for the market segmentation requires engaging a broad set of stakeholders:

- Vehicle market data vendors
- Vehicle, engine, and component manufacturers
- Industry Associations (including vehicle and component manufacturers and associations of road freight haulers / cargo companies)
- Government agencies responsible for tracking vehicle sales / registrations / production (including import of CBU / CKD vehicles)

Example of India:

- **Vehicle / Tier 1 market data vendors**: Segment Y, JMK Research, EV Volumes, Marklines
  Vehicle, engine, and component manufacturers: Tata, Ashok Leyland, Eicher, BharatBenz, Force, Mahindra, others
  Engines: Cummins, Greaves, Weichai India, Mahindra & Mahindra, Kirloskar Oil Engines Ltd.
  Tyres: MRF, Apollo Tyre, CEAT tyre
  Trailers: VEM, Tata, Ashok Leyland, Isuzu (the major truck OEMs are also the major tailer makers)
- **Industry associations:**
  SIAM – Society of Indian Automobile Manufacturers
- **Government agencies responsible for tracking vehicle sales**:
  Ministry of Road Transport and Highways (MoRTH) – Vahan dashboard, Ministry of Heavy Industries

- **Testing Agencies**: ARAI - Automotive Research Association of India,
  ICAT - International Centre for Automotive Technology,
  ACMA - Automotive Component Manufacturers Association of India

Beyond reducing GHG emissions, there are many strong rationale for HDV SSRs

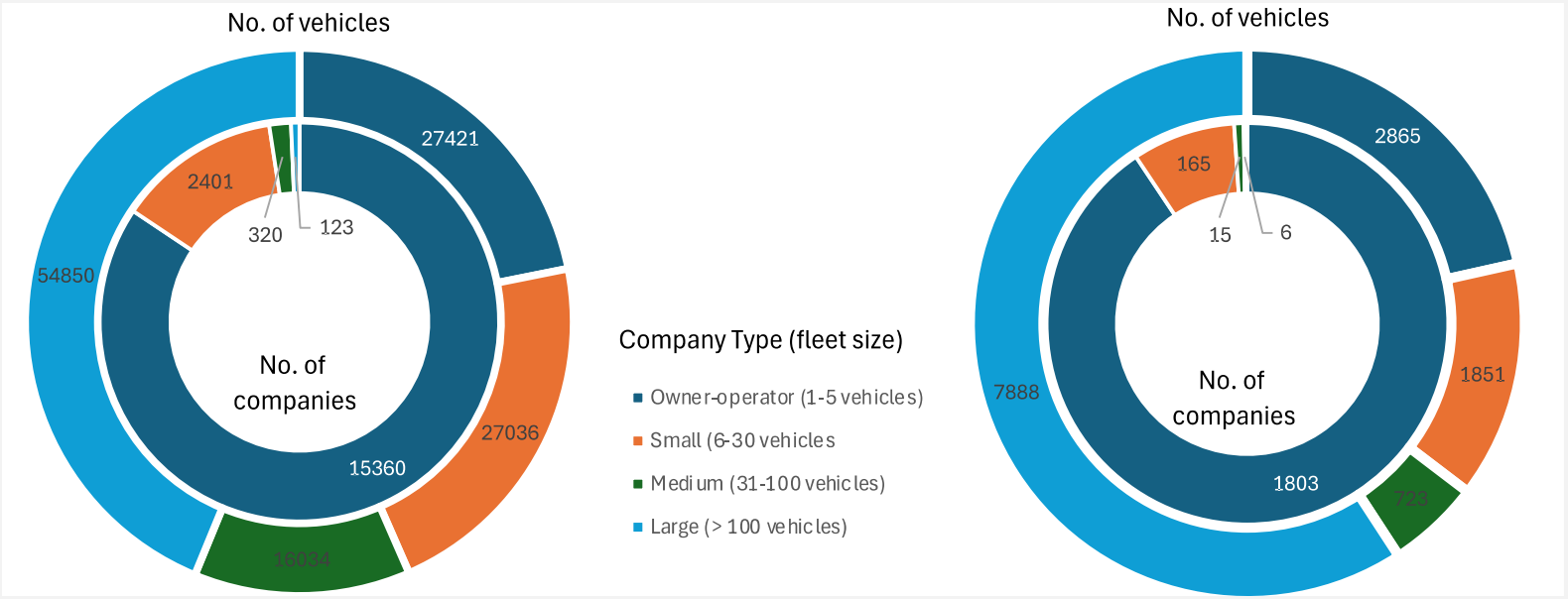
One might expect that, in a competitive market (road freight and passenger services), profit maximizing entities would minimize ownership and operational total costs by adopting fuel/energy efficiency technologies.

But evidence shows that efficiency technology adoption is very limited in regions without SSRs. This is likely explained by market failures and other barriers to competition in these markets (ICCT 2016; ICCT, 2017; ICCT and NACFE, 2021).

To address market failures and barriers

- **Capital constraints** – high shares of trucks and buses are owned by small businesses (owner-operators)
- **Incomplete information** – the economic payback of fuel savings technology is uncertain and difficult to calculate
- **Principal-agent problem** – the entity that buys the vehicle (e.g. leasing company) might not be the same as the person paying for fuel (driver). (Vernon & Meier, 2012)

***Figure 2**. Mexico - ownership, by type, of trucks (left) and buses (right)*



Source: Gobierno de Mexico, 2023

To reduce fuel consumption

To strengthen industry competitiveness

Acronyms & definitions

BEV	A **battery electric vehicle** is a vehicle that runs entirely off an electric motor and battery.
EV	An **electric vehicle** is a vehicle that partially or wholly runs off an electric motor and battery. This includes BEVs, PHEVs, and FCEVs.
FCEV	A **fuel cell electric vehicle** is a vehicle that uses hydrogen fuel to generate electricity, powering the vehicle.
GHG	**Greenhouse gas emissions** are a class of molecules with the ability to trap heat in the atmosphere.
ICEV	An **internal combustion engine vehicle** is a vehicle that combusts fuel (usually gasoline or diesel) in an engine to create power.
M/HDV	**Medium and heavy duty vehicles** are vehicles that have a gross vehicle weight rating above a certain threshold. For countries that are contracting parties of the UNECE Contracting Party to the 1958 UNECE agreement regarding harmonized technical regulations for wheeled vehicles, passenger vehicles (M2/M3) exceed 5 tonnes of weight; and for freight, N2 ("medium-duty") vehicles are between 3.5-12 tonnes of gross vehicle weight (GVW), and N3 ("heavy-duty") vehicles exceed 12 tonnes GVW.
NDC	**Nationally Determined Contributions** are targets reported by countries that are members of the Paris Agreement treaty.
OEM	An **original equipment manufacturer** is the original producer of a vehicle's components.
PHEV	A **plug-in hybrid electric vehicle** is a vehicle that uses battery packs to power a motor, as well as gasoline or diesel fuel that is combusted in an engine.
SHV	**Second hand vehicles** are vehicles that have had at least one previous owner.
SSR	**Supply-side regulations** require automotive manufacturers to meet minimum requirements in the new vehicles that they sell or produce. Requirements may be *performance-based standards*, and apply to the fuel efficiency, and/or CO_2 or GHG emissions, or they may be *sales share requirements* for a particular powertrain technology, e.g. zero-tailpipe emission vehicles, or ZEVs (which include BEVs and FCEVs, and may also include PHEVs at partial credits, under certain conditions), or simply Electric Vehicles (EV) sales requirements.
Utility factor	Regarding plug-in hybrid electric vehicles, a **utility factor** denotes the proportion of a vehicle's range that runs on electricity.

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04 Design elements

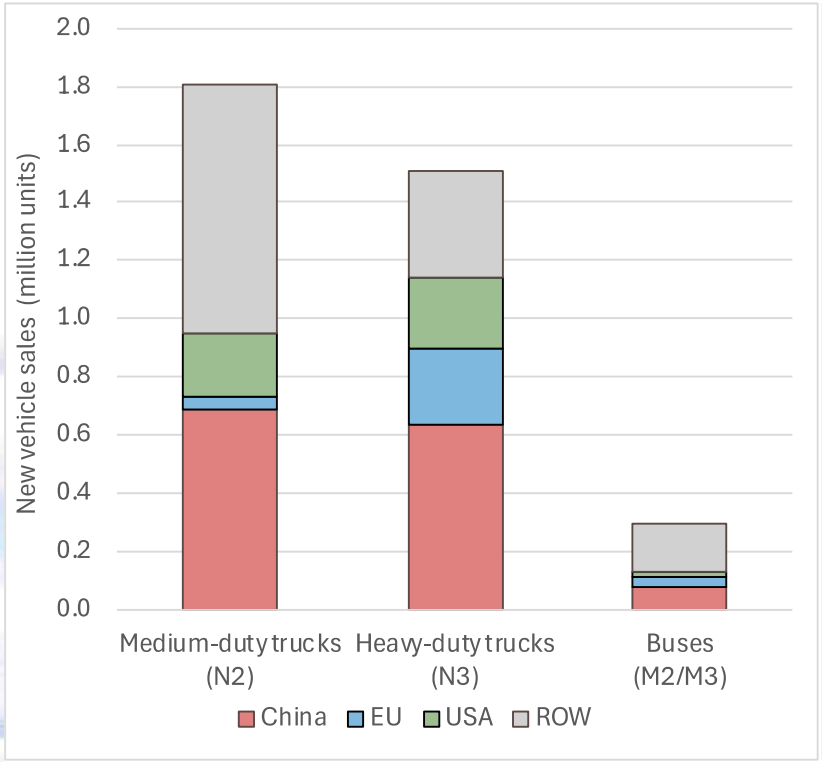
05 Cross-cutting themes

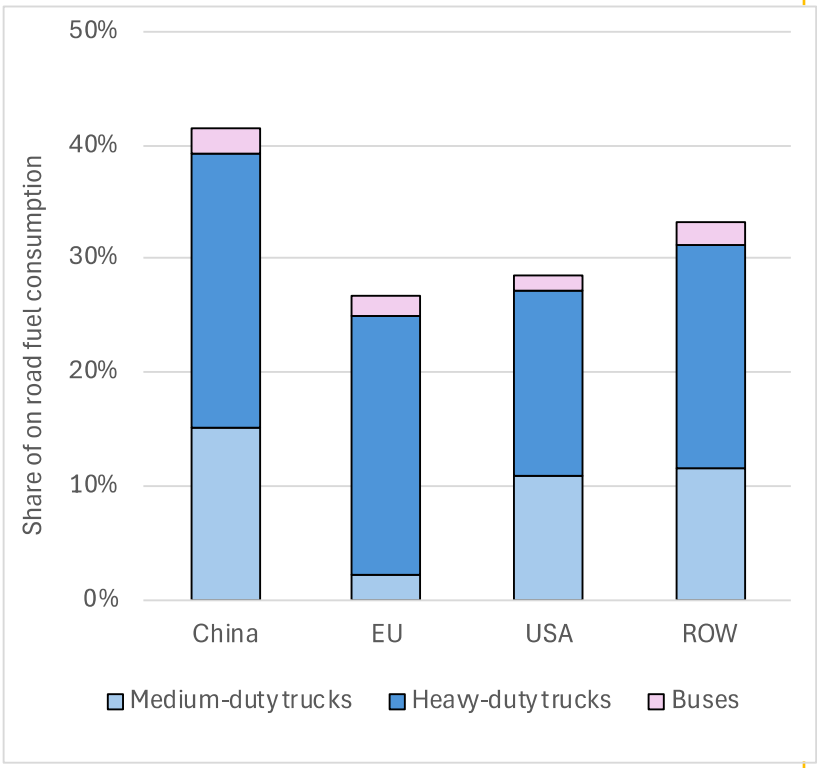
06 Technical notes & further resources

Introduction



Figure 1. *Medium- and heavy-duty vehicles: New vehicle sales and share of road sector fuel consumption in 2024*





- Globally, annual medium- and heavy-duty vehicle (MHDV) sales total ~3.6 million (this compares with about 80-90 million annual LDV sales)
- More than 90% of sales are trucks (bus sales are difficult to estimate)
- Collectively, China, EU and US account for around 60% of global truck sales
- Medium- and heavy-duty vehicles account for around one-quarter of road sector fuel consumption in the EU, up to as high as more than 40% in China

Sources: elaboration based on data from ICCT, 2025, ICCT, 2024a, ICCT, 2024b, ICCT, 2024c, IEA, 2024, Calstart, ACEA, 2025

Beyond reducing GHG emissions, there are many strong rationale for HDV SSRs

SSRs are key part of a policy portfolio needed to address equity, energy security and access, industrial policy and economic challenges and opportunities

To address market failures and barriers

To reduce fuel consumption

- **Oil (and product) import dependence (energy security**) – national economies are vulnerable to oil price shocks and supply disruptions, which are not factored into private decision-making

To strengthen industry competitiveness

- Components / vehicles manufacturers in countries with SSRs can produce products that meet higher efficiency requirements
- SSRs can be used to promote and attract domestic production / assembly of advanced technologies (including EV batteries and electric powertrains)
- Reduced fuel/energy costs improve the competitiveness of road freight and passenger transport services; some share (30%-80%) of cost reductions are passed on to consumers of shipped cargo, depending on the competitiveness of the road freight sector (ICCT, 2016)
- Reduced oil (product) imports, lower fuel costs and potential for new industries (e.g. in electric vehicles) can have positive macroeconomic impacts and provide new job opportunities

Efficiency technologies provide fuel savings with a high benefit-to-cost ratio

Assessments of the cost-effectiveness of fuel efficiency / GHG/CO_2 standards consistently find that the that benefits outweigh costs:

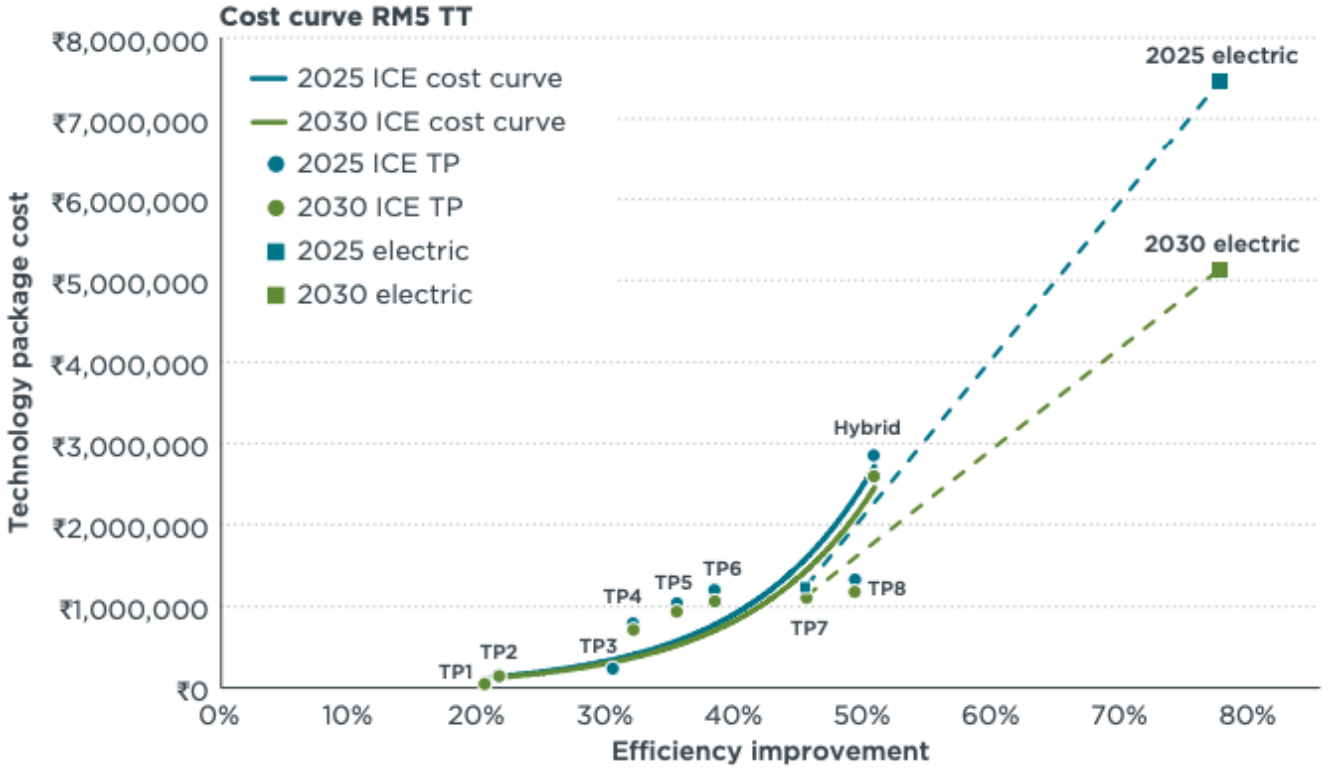
Benefits:

- CO_2 emission reductions (based on SCC)
- Reduced fuel/energy expenditures (accruing to vehicle operators)
- Reduced air pollutant emissions (coming from a switch to ZEVs)

Costs:

- Incremental up-front purchases component / vehicle costs
- Can be expected to decrease rapidly (through competition, economies of scale)
- *Ex-ante* cost estimates general prove to be higher than *post-facto* analyses (i.e. systemic over-estimation of costs)

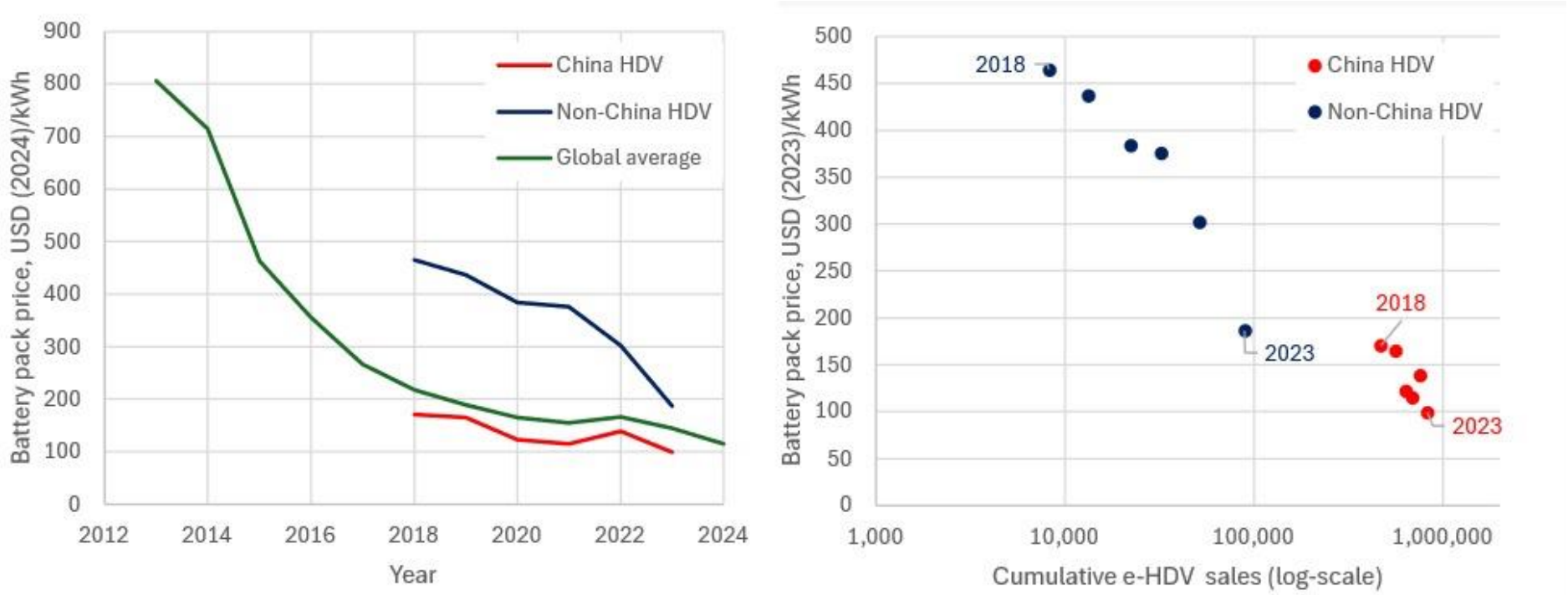
Figure 3. *Incremental costs and efficiency improvements for technology packages for tractor trailers in India*



- Each technology package (TP) combines different levels of efficiency improvements across the engine, transmission, driveline, tyre rolling resistance, aerodynamics, and accessories
- Costs of hybridization and electrification powertrain options are also assessed
- Costs of all technology options decline with technology innovation and scale

Source: Heavy-Duty Trucks in India: Technology Potential And Cost-Effectiveness Of Fuel-Efficiency Technologies In the 2025–2030 Time Frame, ICCT, 2023

Figure 4. *Li-ion battery pack prices for commercial HDVs*



There are strong prospects for market adoption of battery electric HDVs

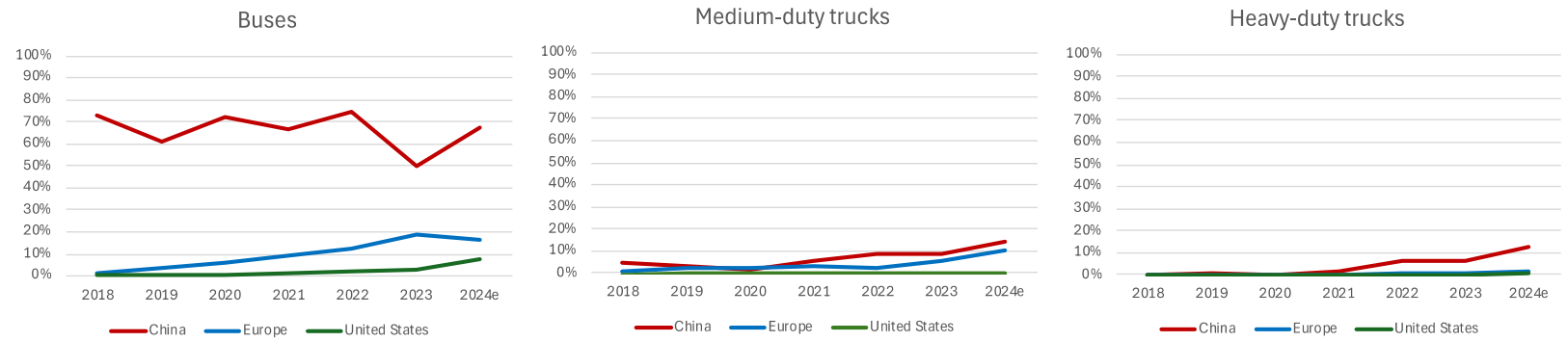
There are structural reasons to expect continued progress on battery technologies, and cost reductions

Sources: elaboration based on data from BNEF, 2024 and EV-Volumes, 2024

There are strong prospects for market adoption of battery electric HDVs

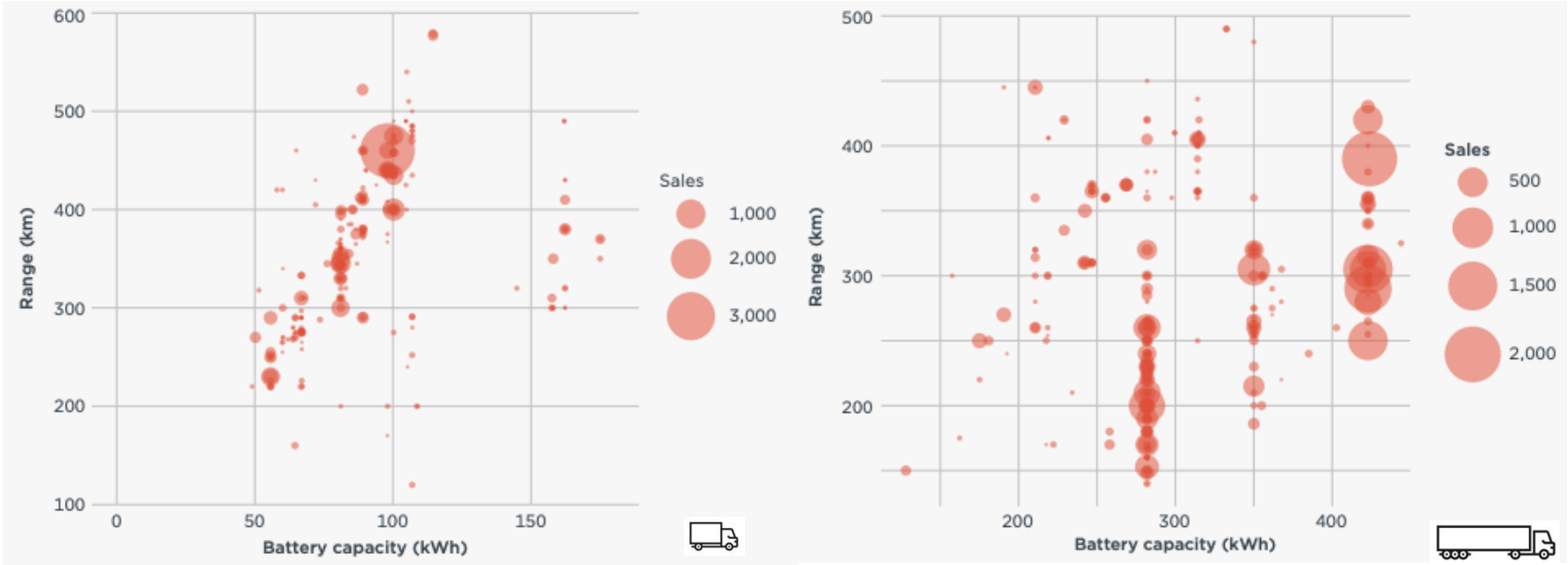
- Certain segments (e.g. urban buses) have comparatively high BEV sales shares
- Increased market adoption is happening, based on costs, and supported by policy
- Vehicle ranges are already in the hundreds of km, and will continue to improve

Figure 5. BEV sales shares in medium- and heavy-duty vehicles



Sources: elaboration based on data from ICCT, 2025, ICCT, 2024a, ICCT, 2024b, ICCT, 2024c, IEA, 2024, Calstart, ACEA, 2025, BCG, 2022, McKinsey, 2022 and McKinsey, 2023

Figure 6. Battery capacity and declared range of medium- and heavy-duty trucks in China with an LFP battery, 2024



Source of Figure 6: Zero-Emission Medium- And Heavy-Duty Vehicle Market in China, 2024, ICCT, 2024

HDV SSR analysis

To inform the creation of the HDV SSR Toolkit, a content analysis was conducted to assess and compare existing vehicle SSRs. In addition to a comparative summary of existing HDV SSRs (**Table 2**), three focus regulations were chosen for inclusion in the toolkit: One ZEV sales requirement (California's Advanced Clean Trucks), and two GHG/CO2 standards (the European and the United States).

Of the HDV SSRs adopted to date:

- All require market segmentation to design appropriate performance metrics for highly heterogeneous vehicle types and operations
- Many (USA, CA, EU, Japan, Canada, China) build on previous standards
- Most rely on component testing and vehicle simulation for compliance. Exceptions are California's ACT (volumes of HDV sales by powertrain), China (option to use a chassis dyno), & India (constant speed fuel consumption testing)
- Many contain flexibilities, such as credits for low- or zero-emission vehicles, and credit trading, averaging, and banking
- Few (CA, EU for urban buses) directly require increasing ZEV sales shares

Table 3. *Eight jurisdictions have adopted SSRs representing one or more of the three SSR types*

Region	SSR type	Policy name and link	Segments	Years
California	ZEV Sales requirement	Advanced Clean Trucks (ACT) Regulation	I. Class 2b-3 II. 4-8 rigid III. 7-8 tractors	Model years (MY) 2024-2035
California*	GHG / CO_2 standard	California Phase 2 GHG Emissions Standards for Medium- and Heavy-Duty Vehicles and Engines	**28**: type/duty cycle + GVW	MY 2014-2027
European Union		CO_2 standards for HDVs	Covers nearly 92% of sales	Calendar year (CY) 2025, 30, 35, 40
United Kingdom		The New HDV (CO_2 Emission Performance Standards) Regulations 2025	Covers ~65% of HDV sales	CY 2025, 2030, 2035
Japan		2025 Phase 2 Fuel Economy Standards	**25**: type + GVW	From MY 2025 onward
Canada		Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations	**34**: type/duty cycle + GVW	MY 2014-2027
United States*	GHG + Fuel efficiency	Phase 3 Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles	**28**: type/duty cycle + GVW	**Phase 1**: MY 2014-17; **2**: MY 2021-27; **3**: MY 2027-32
China	Fuel consumption	Stage 4 fuel consumption standard for heavy-duty commercial vehicles	**66**: type/duty cycle + GVW	from 7/2025 type approvals; and 7/2027 - all sales
India	Fuel consumption	Fuel economy norms for medium- and heavy-duty vehicles	**14**: axle #, type, and GVW	2018 - testing, 2022 - standards

* The United States and California both have separate fuel consumption / GHG emissions standards on heavy-duty engines

Other national-level ZEV purchase or sales requirements

National legislation across many countries has targeted urban buses and municipal, public service, and government fleets (**Table 3**).

More broadly, a growing number of subnational jurisdictions have adopted ZEV sales or fleet purchase requirements – the later being examples of demand-side regulations (DSRs) – for urban buses, or government or municipal bus and/or truck fleets

Table 4. *National legislation mandating ZEV adoption in selected vehicle categories*

Country	Scope	Policy link (year adopted)	Year and shares
Colombia	New public service vehicle and city buses	Minimum EV purchase quota of 30% for public service fleets by 2025 (2019) City bus fleets must ensure that 10% of new buses are EVs in 2025, rising every two years up to to 100% by 2035 (2019)	Public service vehicles: 2025 - 30% City buses: 2025 - 10% ; 2035 – 100%
Ecuador	Public transport	100% of new public transport fleet to be electric by 2025 (2019)	2025 – 100%
France	Public buses and coaches	100% of public buses & coaches to be low-emissions from 2025. In large towns/cities, at least 50% of buses to be very low-emission from 2022 (2019)	2022 – 50% 2025 – 100%
Israel	New municipal buses	Ministry of Environmental Protection (2022)	2024 – 30% 2025 – 50% 2026 – 100%
Poland	New public service vehicle and city buses	30% ZEV (or biomethane) buses in public transport from 2028, 30% share of ZEVs in local government LDV fleets by 2025 Central government l LDV fleet target of 50% by 2025 (2018)	City buses: 2028 - 30% Public vehicles: 2025 - 30% (local) and 50% (national)

Sources: IEA Global EV Policy Explorer, IEA 2024, ZEV Transition Council Phase-out targets, trucks, ZEVTC, 2024

In addition to these ZEV or low-emission vehicle sales shares mandated by legislation, many other subnational governments have adopted similar legislation, and many national and subnational governments provide incentives to support the purchase of ZE buses and/or public service vehicles.

Challenges to designing and implementing fuel efficiency / GHG/CO_2 standards for MHDVs

HDV manufacturing tends to be a highly consolidated market (typically fewer than 5 brands cover more than 80% of the market).

Designing HDV regulations requires constructive engagement and close collaboration with incumbent engine, component, and vehicle manufacturers, as they share the data for the development of the simulation tools.

This gives manufacturers significant leverage to influence the pace of regulatory developments and introduces a risk of regulatory capture.

On the other hand, easier to deal with a few regulated entities (through an SSR) than aiming to work with the many truck operators.

The heterogeneity of designs and operations of medium and heavy-duty vehicles makes regulating them more complex than for light-duty vehicles.

MHDVs are built as **customised combinations of components** (engine, drivetrain, chassis, axles, cab, etc.) with different configurations, each of which has **significantly different technical potential and costs for efficiency improvement**.

As a result, countries have developed a mixture of approaches, which typically involve a combination of **component testing** and **vehicle simulation models**.

Countries designing fuel efficiency / GHG/CO2 standards can adapt existing simulation tools (e.g. VECTO, GEM), focusing on the main efficiency technologies that are most relevant based on domestic MHDV operations.

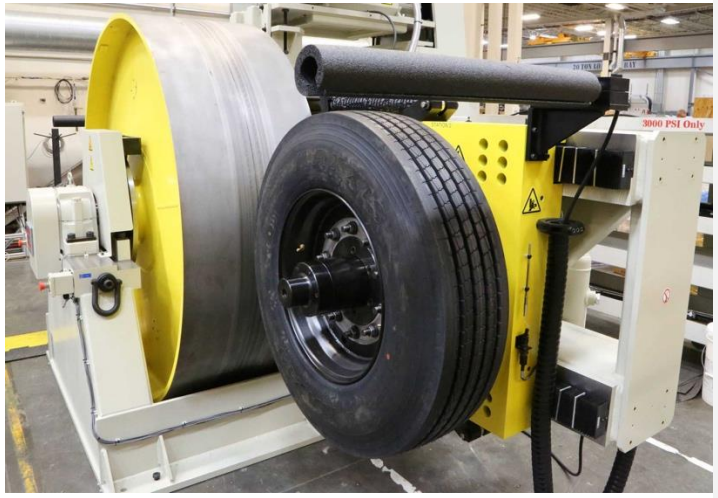
Even if existing tools are adapted, gathering the market, technology performance, and operational data needed to develop vehicle technology baselines, as well as the improvement potential and costs, for every segment, is **time and resource intensive**.

In certain contexts, there may be ways to simplify or bypass certain steps (such as relying on foreign certification, or implementing ZEV sales requirements), as well as to expedite implementation (such as setting percent reduction targets based on a market baseline that hasn't been already determined, as was done by the EU).



Testing

Whole vehicle and component testing



Whole vehicle testing

Chassis dynamometer – fixed rollers with motors are used to recreate real-world road conditions (and test cycles) in a controlled environment

- Requires road load data inputs from test track measurements (coastdown or constant speed)
- Can be used to validate and calibrate simulation models

Test track – closed test course; typically, circular or oval track with banked corners

Portable Emissions Measurement Systems (PEMS) – a small measuring device that can be installed inside / behind a vehicle, enabling on-road emissions measurements

Components testing

Certified physical component testing can be used to: (1) set data inputs for simulation tools
(2) test compliance for stand-alone standards (e.g. engine standard, tyre rolling resistance)

Aerodynamics

Test track - for coastdown testing, a straight, level track with low wind conditions is ideal

Wind tunnel / physical model (computational fluid dynamics): used to measure the coefficient of aerodynamic drag (CdA)

Tyre rolling resistance

- Test track / on-road measurements – a tyre is mounted on an axle and is pressed against a smooth steel drum, of known diameter, at a specified pressure and vertical load
- Laboratory drum test - a tyre is mounted on an axle and is pressed against a smooth steel drum, of known diameter, at a specified pressure and with a vertical load applied

Engine, powertrain, and driveline

- Engine dynamometer – measures the power and torque generated from the crankshaft of an engine. Engine ”dynos” can be passive (if they can only absorb and measure power generated by an engine) or active (when they can also generate power)
- Powertrain dynamometer – connects at the transmission output shaft, rather than the crankshaft, and measures the power/torque of the combined engine and drivetrain (but must be capable of accommodating the rotational inertia of a transmission)

Links to selected relevant standardised test procedures from the UNECE / ISO are given in the annex.

Advantages and disadvantages of alternative testing approaches

Most countries' fuel economy standards rely on simulation modelling for compliance testing.

Table 5. *Advantages and disadvantages of of alternative testing approaches*

	Advantages	Disadvantages
Chassis dynamometer	• Can be used to test any vehicle configuration • Can be used to isolate impact of components or subsystems • Capable of including manufacturers' proprietary component / vehicle control algorithms in the testing	• High capital costs (equipment costs range from USD 300,000 – 3 million) • Testing is time and resource intensive (hence impractical across all configurations) • Coastdown or constant speed testing is needed to set road load inputs • Vehicles may be optimized for chassis testing
Test track	• Can be used to test any vehicle configuration • Can be used to isolate impact of components	• Limited accuracy and replicability • Time and resource intensive (hence impractical across all configurations)
Vehicle simulation tools	• Can evaluate a large number of vehicle configurations, or subsystems, cost-effectively and quickly • Minimizes need for dynamometer testing • Complete test-to-test repeatability	• Requires physical testing for data inputs that are the foundation of modelling. • The more representative a model is of real-world operations, the more resources are required to validate the model and ensure its fidelity
Engine dynamometer (engine test bench)	• Comparatively low capital costs (as compared with a chassis dyno. (~ 1000 USD/kW for active dynos) • Consistent with equipment (and test cycles) required for local pollutant emissions testing • High replicability, control of testing procedures (e.g. STP)	• Cannot be used to test drivetrains, nor components / vehicles • More expensive, and less common, than engine dynos for light-duty vehicles

Sources: Adapted from Table 3 of Heavy-Duty Trucks in India: Technology Potential And Cost-Effectiveness Of Fuel-Efficiency Technologies In the 2025–2030 Time Frame, ICCT, 2015 and an Overview presentation on VECTO, JRC 2018

Vehicle simulation modelling

Whole vehicle and component testing

Simulation models provide physics-based estimates of vehicle-level fuel consumption and CO_2 emissions

- Models are validated with vehicle and components testing, and are run on official test cycles
- Simulation models are widely used to test compliance with fuel efficiency / CO_2/GHG standards
- User inputs to the models focus on the main components where technology innovation can improve overall vehicle efficiency

Requirements

- Need to represent real-world operations with a reasonable degree of fidelity (but no need to be exact)
- Need to be calibrated and validated through testing (e.g. chassis dynamometer, test track, PEMS)
- For components that have less impact (e.g. auxiliaries), default values from other markets may suffice

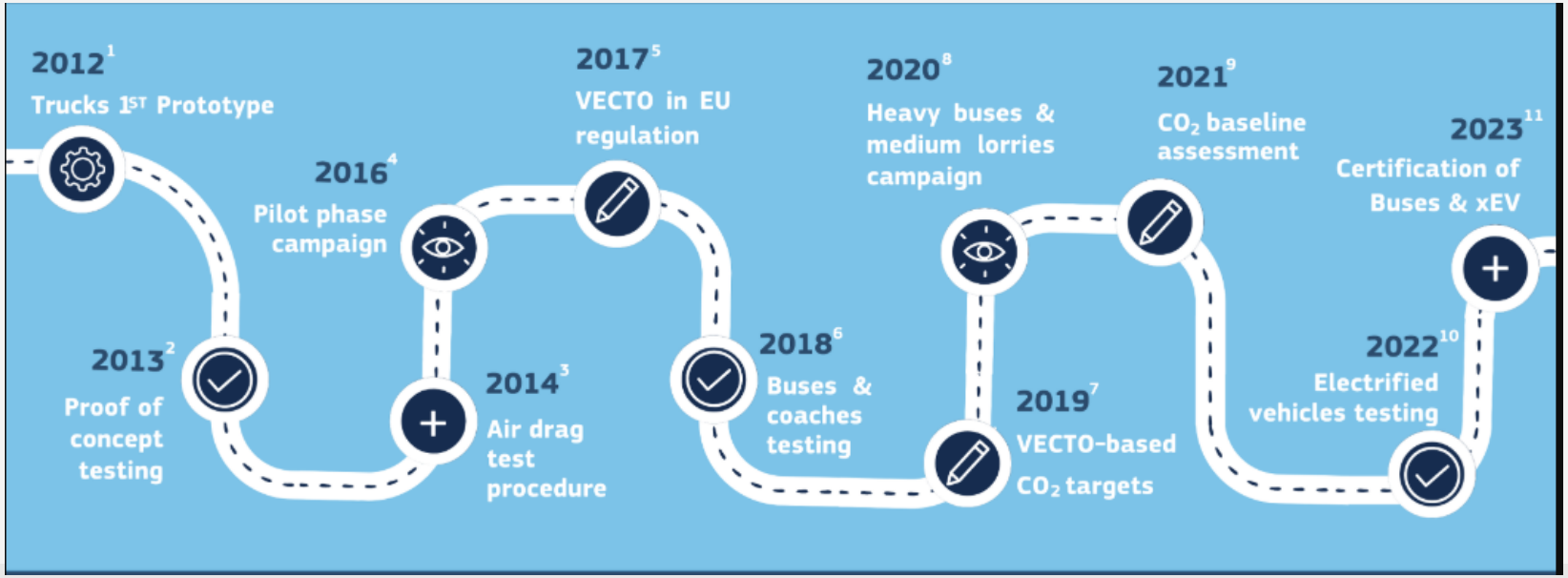
Overview of the European Union's Vehicle Energy Consumption calculation TOol (VECTO)

Given the application-specific default and user-defined **inputs**, a physical model in VECTO simulates vehicle operations to estimate fuel consumption and CO_2 emissions:

- **Tyre rolling resistance**
- **Engine performance**
- **Transmission / gearbox friction**
- **Air drag**
- **Energy consumption of auxiliaries** (e.g. air compressors, cooling fans, steering pump, air conditioning, etc.)

Energy demand / efficiencies for each operation that correspond to a specific vehicle type are then simulated to determine specific emissions (litres or gCO_2/tonne- or passenger-kilometre)

Figure 7. *VECTO Development timeline*



Component tests + vehicle simulation enable estimates of full vehicle fuel consumption.

This is cost efficient (efficiency of measured components can be applied across vehicle types), highly reproducible, and flexible, but requires regular updates to cover relevant technologies

- VECTO development preceded notification of the EU's HDV CO_2 standards by 7 years
- VECTO is used as the basis for monitoring/reporting, & certification for HDV CO_2 standards
- The tool has been further developed since the initial 2019 HDV CO_2 emissions standards to include new vehicle categories (e.g. vocational vehicles, coaches and buses), powertrains (e.g. LNG, hybrid- and pure battery electric vehicles, dual-fuel vehicles), technologies (e.g. waste heat recovery, advanced driver assistance systems), and designs (bodies, trailers)

By 2024, VECTO enables near-complete coverage of vehicle categories and mission profiles, covering > 98% of all newly registered MHDVs in the EU

Overview of the Greenhouse Gas Emission Model (GEM)

The US EPA developed multiple versions of the GEM model, first for the Phase 1 standards, and the later for the Phase 2 standards (v4.0 is the final official version)

Software

- GEM is a physical model coded in MATLAB/Simulink, for HDV (Class 2b-8) vehicle compliance
- It is open-source and free, and can be downloaded from the EPA website and operated on a single computer (since it is downloaded as an exec, the user doesn't need MATLAB/Simulink)
- The model simulates four systems: **Ambient**, **Driver**, **Powertrain**, and **Vehicle**

Certification tool

- GEM is run over three EPA drive cycles: at 55 and 65 mph (each with varying road grades), and over a transient cycle (the California Air Resources Board Highway Heavy-Duty Diesel Transient cycle CARB HHDDT)
- 16 combination tractor categories: the 10 regulatory categories shown in Slide 23, plus 6 higher gross combined weight rating categories designed for heavy-haul in Canada
- 18 vocational categories: shown in Slide 23, plus 7 trailer subcategories
- For vocational vehicles, simulates additional idle measurements: parking idling, traffic idling

Input parameters

- Each regulatory subcategory (including trailers) is assigned a set of drive cycle weightings, specific default vehicle parameters (e.g. weight, axle #, payload, aerodynamic drag area, accessory power), and technology options
- **Predefined parameters**: transmission shifting strategies and associated losses (mechanical efficiency/spin loss), engine inertia, etc. (some with optional overrides)
- **User-defined parameters**: vehicle technologies and component attributes, such as aerodynamic performance, tire rolling resistance, vehicle weight, engine fuel map, transmission gear ratio, tire radius, axle ratio

Sources: Greenhouse Gas Emissions Model (GEM) for Medium- and Heavy-Duty Vehicle Compliance v4.0 user guide, EPA 2022

Market segmentation

Determining the right number of segments requires striking a balance should between representativeness and complexity.

- Need a sufficient number of segments to create conditions for equitable competition within each segment
- Creating too many segments can increase administrative burden and complexity

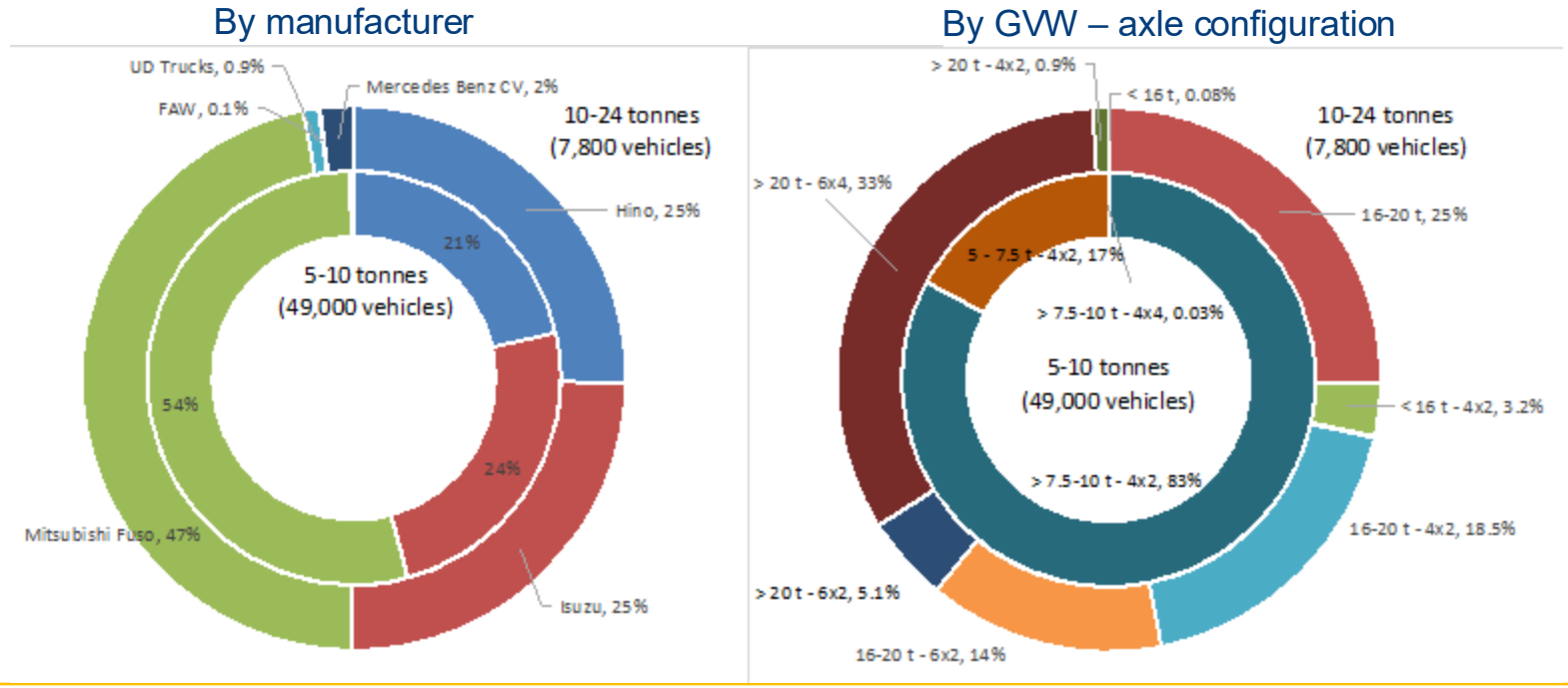
Segments should group vehicles based on:

- Similar technical characteristics
- Similar operational patterns

This enables regulations that:

- Are based on technology assessments that reflect the efficiency potential and costs of adopting more efficient technology
- Avoid leading to structural changes in the market, or compliance mechanisms that don't translate to actual efficiency improvements

Figure 8. *Medium- and heavy-duty trucks sold in Indonesia, 2023*



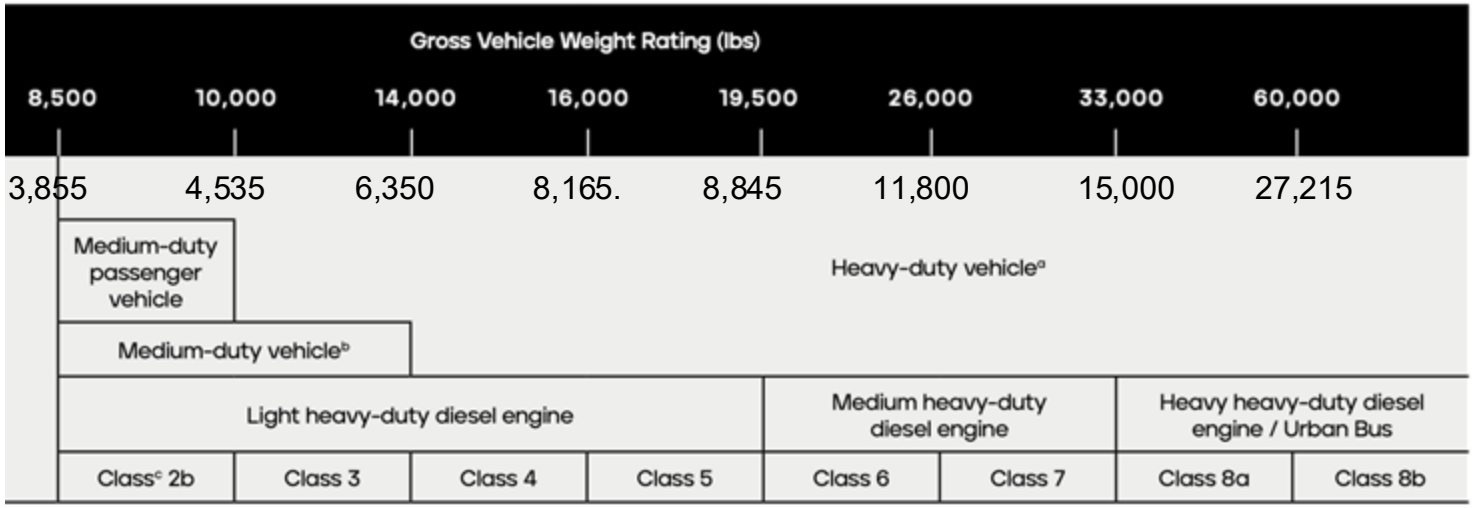
Source: Gaikindo, Wholesale data, December-January 2023

Vehicle segmentation

Segments in the United States and Canada

Figure 6. *Phase 2 and 3 CO_2 Emission Standards for vocational vehicles (top) and tractors (bottom)*





HDE Heavy-duty engine
LHDDE Light heavy-duty diesel engine
MHDDE Medium heavy-duty diesel engine
HHDDE Heavy heavy-duty diesel engine

Footnotes:

[a] Complete HD vehicles are vehicles < 14,000 lbs that have a primary load-carrying container or device attached

[b] "Medium-duty vehicle" originally only used in California until also adopted in Federal standards in 2024

[c] Truck class is used for many purposes, including vehicle category identification, defining driver's license requirements, fuel consumption standards and California zero-emission vehicles standards

Source: Phinia Worldwide emissions standards booklet, 2024 version

Weight Class	Class 2b	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Example Vehicles	  		  		  		  
GVWR	8,500 – 10,000 lb 3,856 – 4,536 kg	10,001 – 14,000 lb 4,536 – 6,350 kg	14,001 – 16,000 lb 6,351 – 7,257 kg	16,001 – 19,500 lb 7,258 – 8,845 kg	19,501 – 26,000 lb 8,846 – 11,793 kg	26,001 – 33,000 lb 11,794 – 14,969 kg	> 33,000 lb > 14,969 kg

Source: NESCAUM Multi-state medium- and heavy-duty zero-emission vehicle action plan

Vehicle segmentation

Examples of how vehicle segments are categorised in different countries / regions

The European Union segments based on GVW and axle configuration

- Vehicle bins serve as the basis for CO_2 emissions reduction timelines, on a percent reduction basis
- Further sub-groups are defined based on operations / mileage, for testing / compliance using the VECTO tool; baseline CO_2 emissions are defined for each VECTO group and are common to all manufacturers.
- The manufacturer-specific CO_2 emissions target in a given year is based on the composition of sales, and on the reference CO_2 emissions of each vehicle sub-group. This means that undercompliance in one vehicle sub-group can be offset by overcompliance in another sub-group, with the tonne-kms in each subgroup used to weight the potential for averaging across sub-groups.

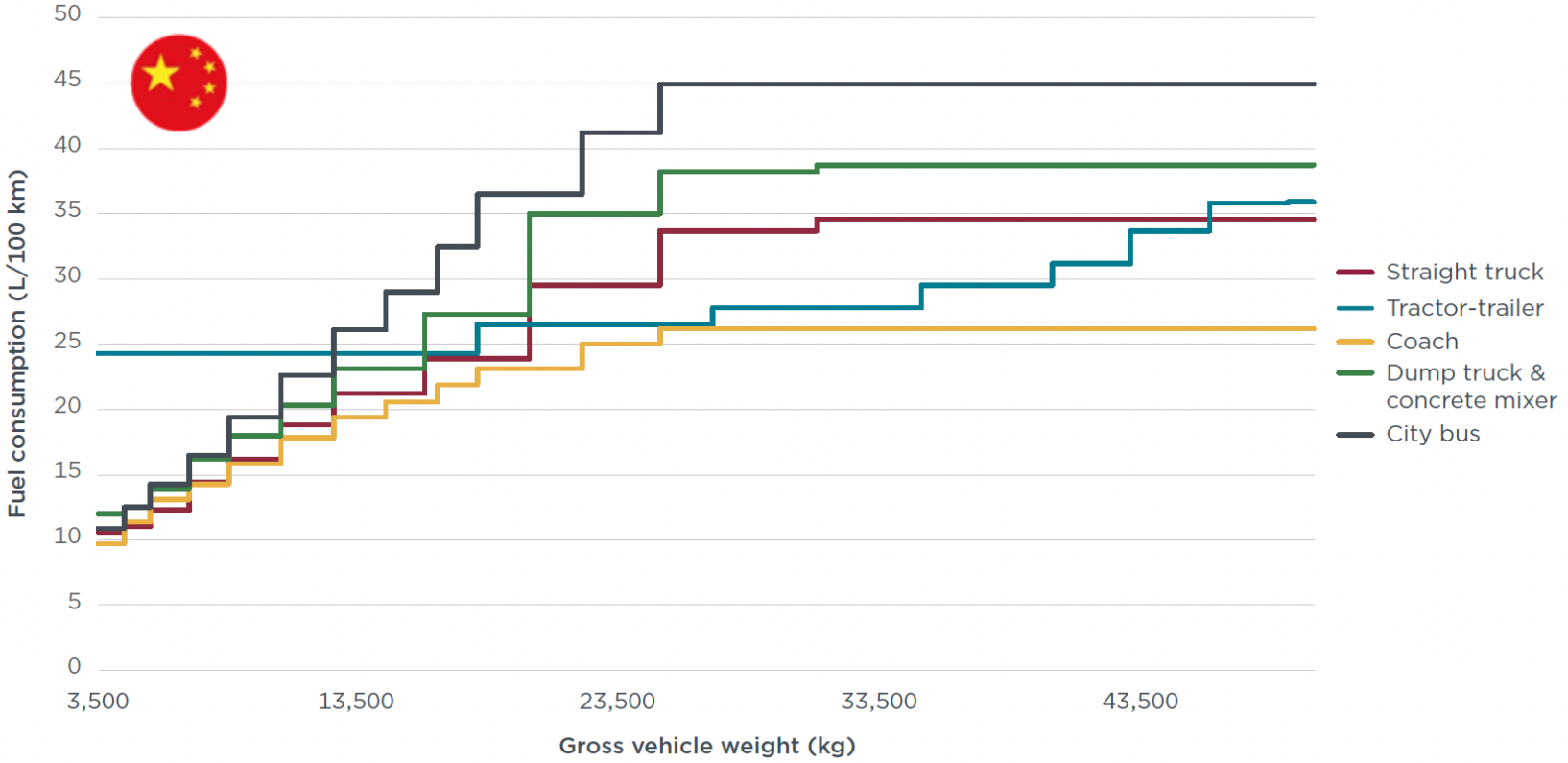
	Vehicle bins	VECTO group	Gross vehicle weight (t)	Axle configuration	2025	2030	2035	2040
Regulated in 2019 standards	Heavy lorries >16 t with a 4x2 or 6x2 axle configuration	4-UD, 4-RD, 4-LH, 5-RD, 5-LH, 9-RD, 9-LH, 10-RD, 10-LH	>16	4x2, 6x2	15%	43%	64%	90%
Newly added trucks and coaches	Medium lorries	53, 54	>5 - ≤7.4	4x2 (rear wheel drive only)	0%	43%	64%	90%
	Heavy lorries > 7.4t and ≤ 16 t	1s, 1, 2, 3	>7.4 - ≤16	4x2	0%	43%	64%	90%
	Heavy lorries with special axle configuration	11, 12, 16	All weights	6x4, 8x4	0%	43%	64%	90%
	Completed coaches	32-C2, 32-C3, 32-DD, 34-C2, 34-C3, 34-DD	>3.5	2- and 3-axles	0%	43%	64%	90%
	Primary coaches		>3.5	2- and 3-axles	0%	43%	64%	90%
Newly added trailers	Semi-trailers	Many groups: specifically all groups up to 3 axles in Table 1, 4, and all groups in Table 6 of (EU) 2022/1362.	>8	1-, 2-, and 3-axles	0%	15%	15%	15%
	Drawbar trailers		>8	1-, 2-, and 3-axles	0%	7.5%	7.5%	7.5%
Newly added buses	Urban heavy buses	31-LF, 31-L1, 31-DD, 31-LF, 33-L1, 33-DD, 35-FE, 39-FE, 31-L2, 33-L2	>3.5	2-, 3-, and 4-axles	0%	100%	100%	100%

Table source: An analysis on the revision of Europe's heavy-duty CO_2 standards, ICCT, 2023

Vehicle segmentation

Examples of how vehicle segments are categorised in different countries and regions

Figure 9. *China Stage 4 fuel consumption limits by vehicle category*



China sets fuel consumption limits based on GVW and operations / type

- Stage 4 introduces fuel consumption limits that are from 12%-16% more stringent than Stage 3
- Expands technology coverage to include hybrid electric vehicles, and vehicle types to concrete mixers
- Updates to a new test cycle – the China Heavy-duty Commercial Vehicle Test Cycle (CHTC)
- Adopts CO_2 conversion factors for diesel and 2,370 g/L for gasoline
- Revises the conformity of production and clarifies the criteria for type-approval of new model variants

Source: China's Stage 4 fuel consumption standard for heavy-duty commercial vehicles, ICCT, 2024

Assess benefits and limitations of different SSR policy options

With the baseline analysis complete, policy makers can assess the benefits and challenges of alternative regulatory approaches:

- ZEV / EV sales requirements
- Separate engine / component (e.g. tyre) / trailer standards
- Full vehicle standards

Depending on the type of SSR chosen for a region, and the design elements selected for inclusion in the regulation, additional data collection will be required beyond the variables listed here. Note that the data requirements may change depending on the SSR type being implemented.

ZEV / EV sales requirements

Data needed to assess the potential for ZEV / EV sales requirements:

- Market share of BEVs, PHEVs, HEVs (and, if wanted, H-ICEVs and FCEVs), trends over time, and projections; inc. group-brand affiliation and manufacturing base (domestic versus imports)
- Current and projected electric powertrain costs (battery, electric motor, auxiliaries, etc.)
- Battery supply chain considerations (including flexibility/transparency of suppliers' suppliers)
- Operational characteristics / charging availability and associated costs of charging (current and projected)
- Typical technology characteristics and technology baseline

Key stakeholders to consult include vehicle market data vendors, battery and EV component manufacturers, vehicle manufacturers and industry associations.

Separate engine / component (e.g. tyre) / trailer standards

Data needed to assess the benefits of separate engine / component / trailer standards:

- Component sales totals (focusing on components being installed in new vehicles, rather than the replacement market), trends over time, and projections
- Component manufacturer market shares by vehicle size and type
- Domestic manufacturing versus imports
- Top-selling component models by vehicle segment
- Typical technology characteristics and technology baseline

Key stakeholders to consult include vehicle market data vendors, component manufacturers, and industry associations.

California's Advanced Clean Truck regulation

California's Advanced Clean Trucks (ACT) regulation is currently the only existing ZEV sales requirement for MHDVs.

The ACT rule requires sales of zero-emission vehicles (ZEVs) or near zero-emission vehicles (NZEVs) from Model Years 2024 to 2035.

ACT sets ZEV sales share requirements for three separate vehicle categories:

- Class 2b-3 pickup trucks and vans (GWV 8500-14000 lb; 3856-6350 kg)
- Class 4-8 rigid trucks (GVW 14001-33000 lb; 6351-14969 kg)
- Class 7-8 tractor trucks (GVW 26001-33000 lb; 11974-14969 kg)

ACT is designed based on credits (accrued from sales of ZEVs and NZEVs) and deficits (from sales of conventional ICE MHDVs),

Scope of the ACT rule

- California (CA) alone accounts for ~9.5% of US HDV registrations
- 11 other states have adopted ACT; collectively these states + CA account for ~25% of US HDV registrations

Design of the ACT rule

- Credits: based on weight-class multipliers for each group / sub-group
- Deficits: apply these same multipliers
- Deficits from Class 2b-3 & Class 4-8 can be met by ZEV / NZEV credits from any vehicle group / sub-group
- Deficits in Class 7-8 tractors can only be met by credits from that group *
- NZEV credits capped at ½ of deficits
- Early credits: model year (MY) 2021-23, valid through MY 2030, w/ 5-yr limit

Figure 10. *ZEV sales percentage requirements by vehicle category and model year*

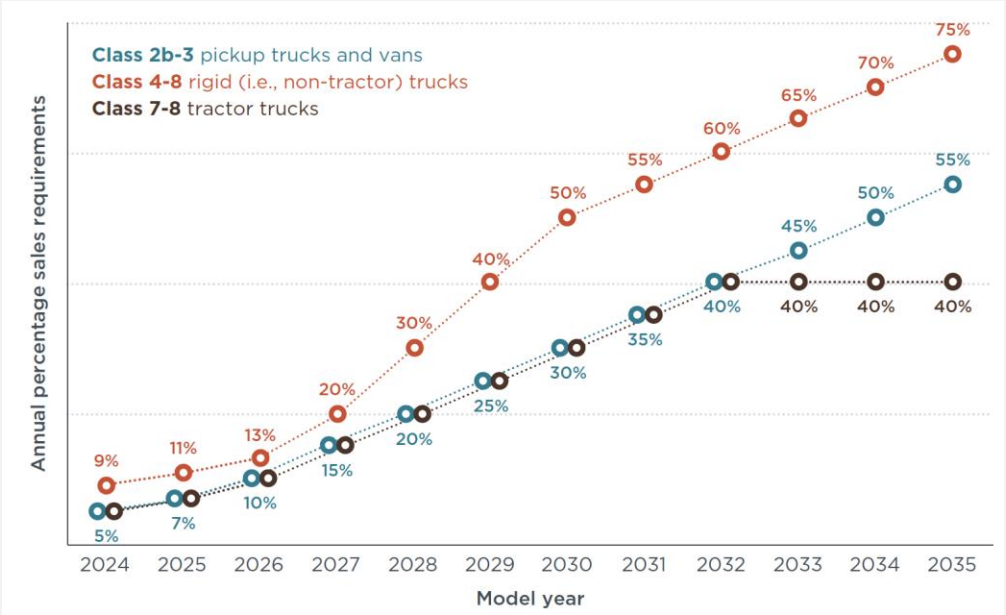
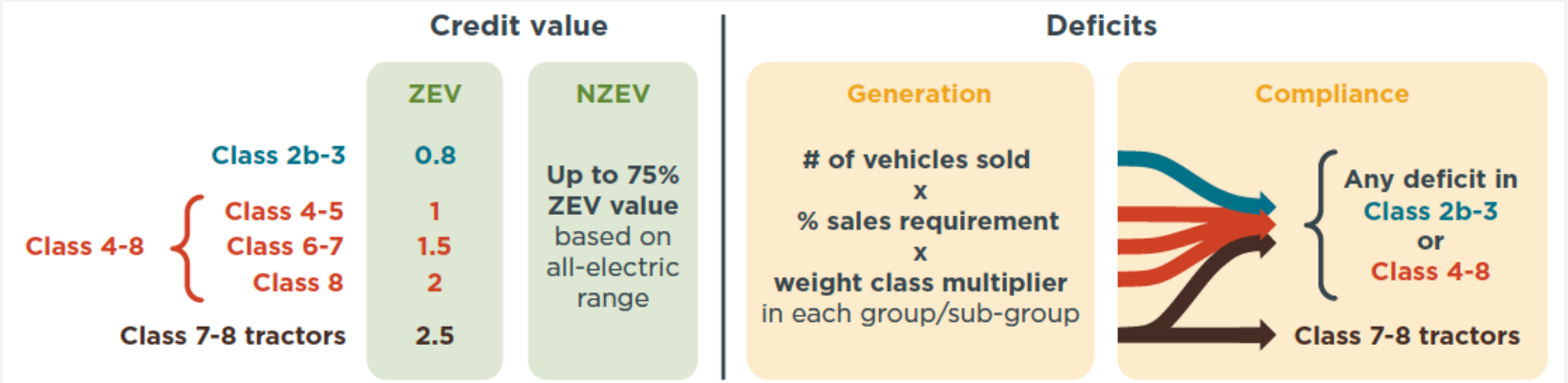


Figure 11. *Credit and deficit calculations to determine compliance in a given year*



Source of figures: California's Advanced Clean Trucks regulation: Sales requirements for zero-emission heavy-duty trucks, ICCT, 2020

* see further details on flexibility for credit trading across vehicle categories in the following slide

California's Advanced Clean Truck regulation

Compliance, Penalties, Flexibilities & Exceptions

Compliance

- Credits banked or generated in a given year must match or exceed deficits
- Manufacturers are given one model year to make up any outstanding deficits, which may only be satisfied with ZEV (and not NZEV) credits

Penalties

- Civil penalties (like penalties for non-compliance with fuel efficiency / emissions standards, or violating test procedures)
- Manufacturers are given one model year to make up any outstanding deficits, which may only be satisfied with ZEV (and not NZEV) credits

Flexibilities and exceptions

- Small-volume manufacturers (≤500 MHDVs) are exempt, but can still generate and trade, bank, or sell credits
- * Large-volume manufacturers that accrue ≤25 deficits in the Class 7-8 group can offset tractor deficits with credits from any group

California's Advanced Clean Truck regulation

Reporting

Projected costs & benefits

Reporting

Requirements for manufacturers

- Annual reporting of MHDT sales and transfer of ZEV / NZEV credits
- Documentation of vehicle delivery to California (for out-of-state purchases)

Requirements for "large entities",[1] large fleet owners,[2] brokers, and government agencies that operated MHDVs (from 2019 onwards)

- Details on MHDV operations for each vehicle group: e.g. average annual mileage, ownership, depot location, refuelling infrastructure, trailers, etc. (aim was to inform the design of Advanced Clean Fleets)
- Business practices on MHDV use and transport emission reduction goals
- Documentation of vehicle delivery to California (for out-of-state purchases)

Projected costs & benefits

- **Reduced fuel costs:** the main contributor to cost savings
- **Health benefits:** avoided premature deaths and avoided health burden
- **Emissions reductions:** NO_x, $PM_{2.5}$, and well-to-wheel greenhouse gases
- **Employment growth:** in construction and transportation
- **Net direct cost – benefit (2020-2040):** $5.9 billion
- **Benefit-to-cost ratio**: 1.5

[1] These have gross annual revenues >$50 million

[2] These operate a facility in and California, and own or dispatch ≥50 vehicles

Design elements



Once one or multiple SSR regulatory approaches have been determined, efforts can begin to design the regulation, including:

1. Develop testing and certification procedures
2. Determine performance metrics and baseline efficiency levels
3. Set performance requirements, deadlines, and flexibility mechanisms
4. Draft, revise, and finalise the regulation

Stakeholder engagement, including convening subject-specific working groups and bilateral meetings with key stakeholders, is essential throughout the design process

While advancing on the above core design features, parallel efforts are needed to:

- Determine ministerial authority and responsibilities
- Establish reporting requirements
- Set noncompliance penalties

Develop testing and certification procedures

Established procedures for testing component, engine, and vehicle efficiency enable benchmarking efficiency performance for each regulated segment.

Benchmark test cycles should be established to approximate typical operations best-selling models; but an exact match of driving cycles and payloads with any particular model is not feasible, nor is I necessarily needed.

Measurement protocols enable the regulator to develop technology assessments of key components:

i) *Engines* – "engine maps" - engine dynamometer measurements and/or simulated relationships at different combinations of output torque and engine speed – measures/estimates of fuel consumption, at torque-speed combinations that:

   (a) covers the full real-world range of torque-speed requirements and

   (b) is designed, based on the test cycle, to be representative of operations for each regulated segment.

ii) *Component performance* – including at minimum measured or modelled tyre rolling resistance and transmission torque loss.

iii) *Vehicle characteristics* – including aerodynamic drag and auxiliary load.

Inventory of existing testing facilities and testing procedures

- Includes industry-owned, private, research, and government facilities (and hybrids of these ownership / operations models, including PPPs)
- Examples: test tracks, engine dynamometers (e.g. for testing compliance with pollutant emissions standards), Portable Emissions Measurement Systems (PEMS)

Set performance requirements and deadlines

Estimated payback periods and societal benefits of reduced fuel consumption, together with considerations of the time needed to bring technology packages to market, can inform appropriately ambitious, but achievable near-, mid- and long-term fuel efficiency targets.

Flexibility mechanisms should be designed in parallel to performance requirements and deadlines

Most fuel efficiency standards are designed to regulate the corporate average fuel economy (CAFE), on a sales-, registration-, or production-weighted basis, for each manufacturer.

An alternative is to set a minimum standard that applies to all vehicles for sale in a given market, following a minimum energy performance (MEPS) design.

Both approaches can be used to set standards for each regulated vehicle segment.

Despite far higher information requirements, both for baseline analysis and enforcement (e.g. sales/region data collection for each manufacture), a CAFE regulation has many benefits over a MEPS standard design:

- **Flexibility**: **CAFE standards** allow manufacturers to plan components sourcing vehicle design, and model offer. Together with other flexibilities, this enables them to plan and optimize their strategy and investments to meet the standards in a cost-effective and competitive way.
- Under a **MEPS** approach, some industry players may face challenges in meeting the standard, risking bankruptcy, while others aren't significantly impacted or incentivized to improve their efficiency technology offer. Hence, industry laggards are likely to be left behind, resulting in industry consolidation and other unfavourable market dynamics.
- A **MEPS** approach is difficult to calibrate to changing technology costs and the impacts of innovation; if set too conservatively, it is unlikely to lead to the development and introduction of new efficiency technologies to the market; if set too stringently higher manufacturing costs across an entire segment may be passed on to truck fleets.

A simple alternative is to set near-term fuel efficiency targets based on the current best-in-class performing vehicle in each segment (like Japan's "Top Runner" approach). The main drawbacks of this approach are:

- The timeline is arbitrary
- Such standards typically don't bring any new efficiency technologies to market (instead, they accelerate adoption of already available technologies)

Stringency determination

Example of India's next potential round of medium- and heavy-duty truck fuel economy norms

Technology **potential** and cost assessment of energy/fuel efficiency components, combined into packages:

- **Baseline** using reference top-selling models, prices, modelled (Anesim) fuel consumption mimicking real-world operations (GPS+OBD)
- Engines, transmissions, GVW based on specs, other inputs estimated
- Engine map from engineering service (AVL)
- Simulation models calibrated to real-world data, then validated to be within 5% of actual fuel consumption
- Technology component detail: Engine, driveline, tyre rolling resistance, aerodynamic drag, weight reduction, auxiliary component energy efficiency
- Alternative powertrains: conventional ICEVs, hybrids, and battery-electric trucks

Figure 12. *Fuel consumption reduction potential and payback periods for rigid truck technology packages (TP)*



Tata 1212 – 21.7 lakhs (2022)



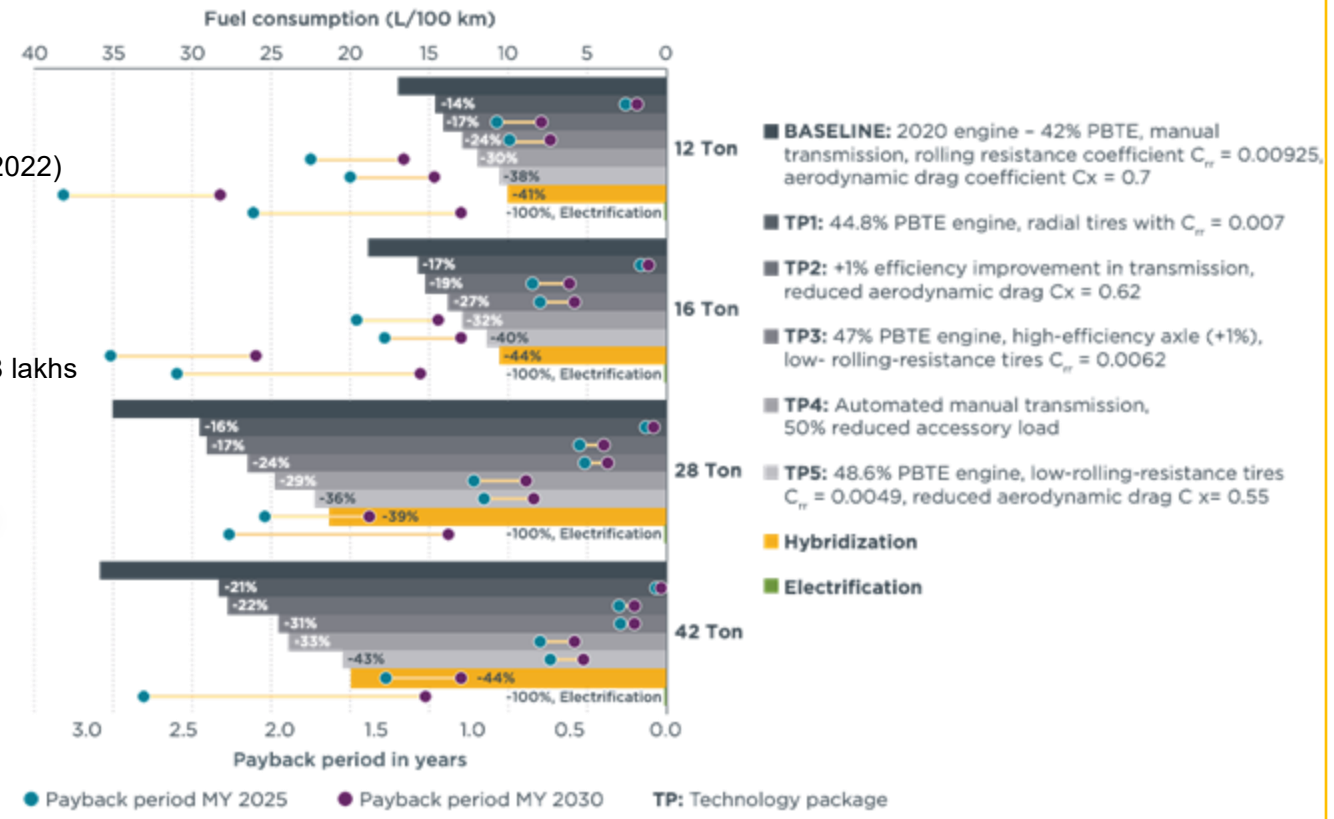
Ashok Leyland 1615– 24.8 lakhs



Tata 2818 – 31.0 lakhs



Ashok Leyland 4220- 5.7TD HM 10x2– 38.7 lakhs



TP1: Near-term, readily deployable: 14%-21% fuel consumption reduction for rigid trucks can be achieved by deploying best-in-class engines and tires already on the market

TP3: Mid-term, deployable by 2025: 24%–31% fuel consumption reduction for rigid trucks with commercialized technologies, ready for deployment

TP5: Long-term, deployable by 2030 or later: 36%-43% fuel consumption reduction for rigid trucks, with technologies are not currently commercialized but could be deployed (SuperTruck)

Source: Heavy-Duty Trucks in India: Technology Potential And Cost-Effectiveness Of Fuel-Efficiency Technologies In the 2025–2030 Time Frame, ICCT, 2023

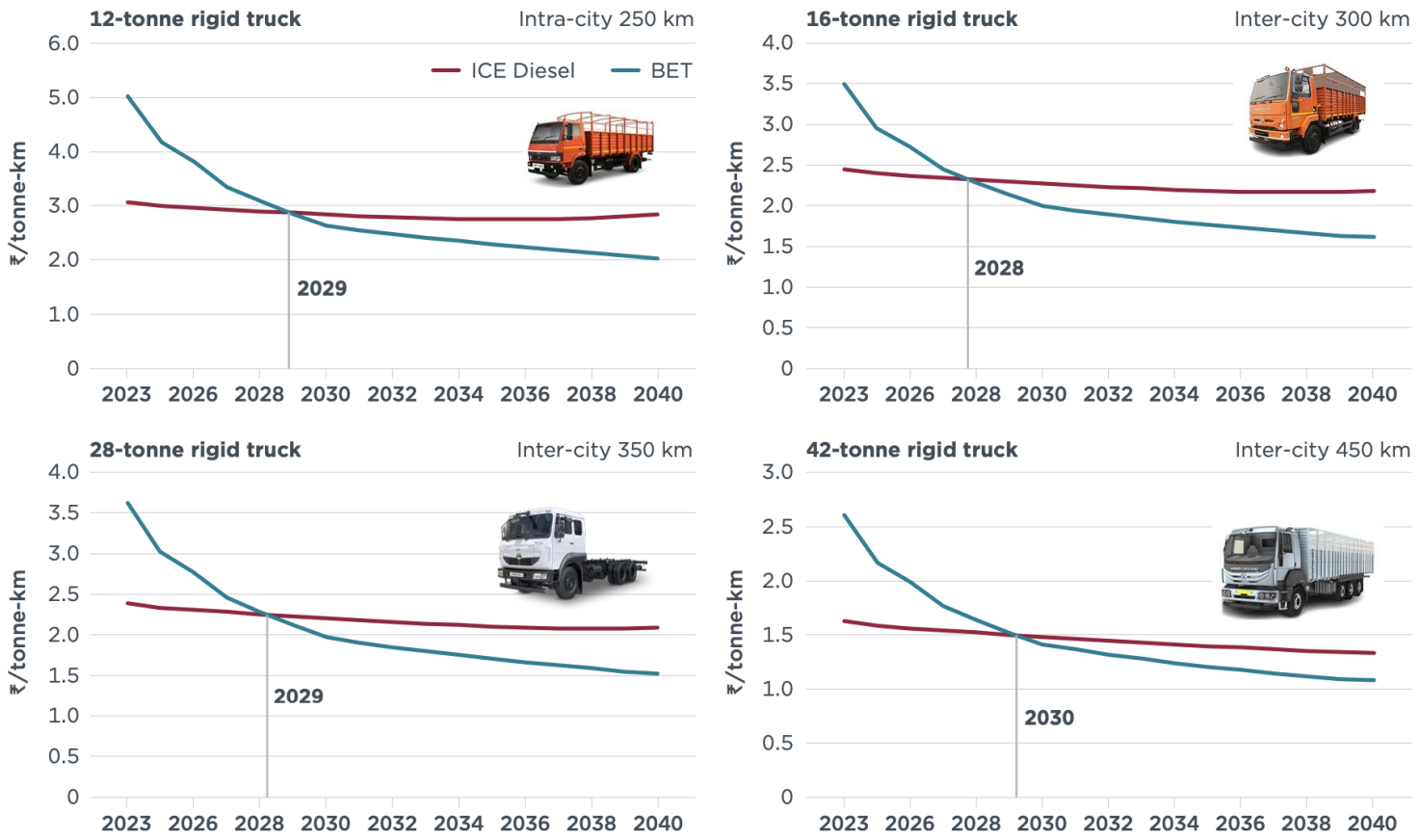
Stringency determination

Example of India's next potential round of medium- and heavy-duty truck fuel economy norms

Technology potential and cost assessment of energy/fuel efficiency components, combined into packages:

- Costs based on an assessment of technology costs in China; and US EPA regulatory impact analysis for Phase 1 and 2 standards
- Direct manufacturing costs + indirect cost multipliers (ICMs) = total costs
- ICMs are higher for less commercially mature technologies, decline with economies of scale

Figure 13. *Estimated TCO parity between battery-electric trucks and diesel trucks*



- **Battery-electric truck (BET) costs are projected to fall rapidly** (cheaper LfP batteries and higher vehicle efficiency (tyres, powertrain, aerodynamics, etc.)
- **Stringent fuel consumption standards improve the cost-effectiveness of BETs** compared to diesel trucks, pushing forward the year of TCO parity
- **Incentives can also bring TCO parity years closer**, with examples including interest rate subventions, road tax/toll waivers, and gross vehicle weight relaxation for BETs

Source: Total cost of ownership parity between battery electric trucks and diesel trucks in India, ICCT, 2024

Governance & enforcement

What role does institutional capacity play in the implementation of SSRs?

Decision makers planning to implement SSRs should carefully assess existing resources and operational capacity within their agencies and broader government.

- Effective SSRs depend on whether regulatory and enforcement bodies are adequately staffed, equipped with technology, and funded to monitor compliance and impose penalties.
- Each agency should have well-defined roles, such as designing regulation versus compliance testing and enforcement, and allocate resources accordingly.
- Enforcement agencies, in particular, need access to data systems and trained staff to effectively monitor compliance and enforce penalties.
- The roles of agencies involved in the regulating and enforcement of SSRs should be well defined within the design of regulation.
- When considering SSR adoption, governments should also assess the capacity of supporting institutions, such as customs or local authorities, to ensure consistent nationwide enforcement.

Table 6. *Scope of responsibilities for regulating and enforcing entities in the EU*

Entities	Scope of responsibilities	Legal authority
Regulating European Commission, European Environment Agency (EEA) **Enforcing** EEA, National Authorities in Member States	The European Commission designs CO_2 standards and vehicle emissions regulations, while the EEA monitors compliance by collecting and reporting emissions data. National authorities in member states are responsible for enforcing penalties, and ensuring manufacturers meet emissions targets.	Regulation (EU) 2018/956 requires EU Member States and manufacturers to report data related to heavy-duty vehicles. Member States report trucks, buses and trailers registered in their territory. Manufacturers report trucks of specific types that are subject to certification requirements. European Climate Law (Regulation (EU) 2021/1119): Binding framework for national compliance

Compliance, reporting, and penalties in the United States

U.S. EPA requires detailed reporting and adopts a multi-pronged approach to monitor compliance.

Penalties are applied based on the Clean Air Act.

Reporting

Manufacturers engines and of chassis-certified vehicles, and OEMs are each required to submit detailed data to the EPA in annual GHG reports that include results testing, as well as the total number of engines/vehicles sold by category, and including information on the engines, components (e.g. transmissions, tyres, axles, aerodynamic features, etc.) and powertrain technologies.

Reports are submitted through the EPA's Engines and Vehicles Compliance and Certification Information System (EV-CIS).

Compliance

- Pre-production certification requires that manufacturers submit applications to the EPA with emissions and fuel economy data before a vehicle or engine can be sold.
- Routine consistency reviews ensure that these certification reports are correct and complete (e.g. across reported credit balances, production data, technology adoption), and any inconsistencies or anomalous patterns are subject to further investigation.
- Manufacturers must conduct conformity of production testing to ensure that the engines/vehicles in production match those that have undergone certification,
- EPA may audit manufacturers, request test data, or perform independent testing to verify production conformity.
- EPA also conducts selective enforcement audits – random or targeted inspections of manufacturer facilities and vehicles – on production engines and vehicles. Finally, in-use testing and surveillance includes direct requests to manufacturers for in-use data, especially for plug-in hybrids and electric vehicles), audits of telematics or onboard diagnostics when these are available, and targeted investigations of real-world performance modelling or field evaluations.

Penalties

Under the Clean Air Act, EPA may seek civil penalties and/or injunctive relief (including remediation of the violations and projects to offset excess emissions) for violations of the Act and regulations and may bring cases in federal district court or through an administrative process.

Enforcement actions include cases against a variety of parties, including manufacturers, importers, distributors, and consultants. Violators are subject to civil penalties up to 45,268 USD per noncompliant vehicle or engine, 4,527 USD per tampering event or sale of defeat device, and 45,268 USD per day for reporting and recordkeeping violations. The EPA often uses the Mobile Source Civil Penalty Policy to arrive at an appropriate civil penalty for vehicle and engine enforcement settlements.

Compliance, reporting, and penalties in the European Union

The European Union CO_2 emission standards for heavy-duty vehicles (HDVs) are enforced through a combination of regulatory oversight, monitoring and reporting obligations, penalties for non-compliance, and transparency measures.

Mandatory Reporting and Certification

- **Manufacturers** must report CO_2 emissions and fuel consumption data, as determined by VECTO, for each new HDV sold in the EU. Reporting periods are annual and run from 1st July to 30 June the following year. (An exception was the first reporting which covered 1st January 2019 to 30 June 2020, in the initial year that the standard went into effect).
- The data is certified by **national approval authorities** as part of the vehicle type-approval process.

Compliance Checks

- The **European Commission** verifies whether manufacturers comply with the fleet-wide CO_2 reduction targets.
- The compliance is assessed based on the average CO_2 emissions of a manufacturer's fleet of newly registered vehicles within a reporting period (e.g., 2025, 2030).

Penalties for Non-Compliance

- If a manufacturer exceeds its CO_2 emission target for a given year, it must pay an excess emission premium.
- As of the 2025 targets, the penalty is **€4,250 per gram of CO_2 per tonne-kilometre over the target, multiplied by the number of vehicles sold**.
- These fines can amount to millions of euros, acting as a strong deterrent: the estimated penalty for the median-sized heavy-duty vehicle manufacturer has been estimated at EUR 90 million for a deviation by 1% from their g CO2/tkm target (Mulholland, 2024).

Independent Verification and Audits

- The Commission may **audit** data and conduct **independent verification** of compliance information. If discrepancies are found, corrective actions or further penalties may be imposed

Public Transparency

- Emission data and compliance information for each manufacturer is **published annually**.
- This allows for **public and stakeholder scrutiny**, enhancing pressure for compliance.

Support for Monitoring In-Service Emissions (Future Development)

- There are plans to introduce **in-service monitoring** and better tracking of **real-world emissions** to close any gaps between certified and actual performance.



Penalties for non-compliance

Financial penalties should be set at a level that makes compliance the clear least cost option to manufacturers.

Regulations that lack penalties are not recommended:

- Penalties create a financial disincentive for automakers to ignore or fall short of fuel economy requirements. Without penalties, there's little motivation for manufacturers to invest in fuel-efficient technologies or redesign vehicles to meet environmental goals.
- If some automakers were allowed to ignore standards without consequences, they could produce cheaper, less efficient vehicles and undercut competitors who invest in compliance. Penalties help maintain fairness across the industry.

Penalties often take the form of fines, but alternatives or additional measures can also be considered:

- Revoking incentives, grants, or exemptions (e.g. production incentives or sales EV tax credits, exemption on import duties or VAT)
- Delaying, applying conditions on, or revoking type approval for certain / all vehicles produced by a non-compliant manufacturer
- Public disclosure or reputational penalties (as in Japan's 'Top Runner' approach)
- Litigation or legal action
- Mandatory corrective actions (e.g. recall or retrofit, offsetting excess CO_2 emissions)

Monitoring the impact of SSRs

Assessing the impact of FES enables the evaluation of policy effectiveness, including both the measurement of real-world benefits, estimation of the impacts on vehicle prices and market dynamics.

These assessments, together with a continuing understanding of how technologies and markets are evolving, can inform improvements to existing standards and ensure that future standards are optimally designed to anticipate and address any challenges or shortcomings of the initial standards.

Measure benefits…

- **Reduced fuel consumption** – both at a segment level and for the HDV sector as a whole, and including both regulated and unregulated segments
- **Reduced greenhouse gas (CO_2) emissions** – direct combustion emissions, and "upstream" (well-to-tank) emissions (e.g. oil production, transport and refining; electricity generation, transmission, and distribution – including losses associated with charging)
- **Health benefits of local pollutant emissions cuts –** primarily NOx and $PM_{2.5}$
- **Reduced energy/fuel and operations costs** – electric MHDVs typically cost less, in many cases substantially less, to fuel, on a per km (or per tonne-km) basis. They also can cost less to maintain, provided the capacity and infrastructure for servicing electric vehicles is sufficiently mature.
- **Broader evaluations** of societal, economic, and infrastructure deployment implications, including truck driver wages, experience of driving, and jobs in the power sector (including grids and charging infrastructure installations and maintenance), construction (e.g. new/upgraded manufacturing / assembly), and manufacturing.

…as well as costs…

- **Increased technology costs, leading to higher vehicle purchase prices** – requires tracking the evolution of component, engine, and vehicle costs both before and after the implementation of FES enables analysis of impacts on manufacturing costs.
- **Industry dynamics may also be impacted** by the standards (for instance, if the stringency in a given segment is considerably more or less stringent than in other regulated segments, sales shares may shift, or sales shares in unregulated segments may increase). – these effects can be reduced in subsequent phases of regulation.
- **Tracking technology trends within and across segments** (including non-regulated segments) can help to inform updates or standards revisions.

Cross-cutting themes



Many of the broader issues and barriers associated with designing, implementing, and enforcing SSRs in light-duty vehicles also apply to SSRs for medium- and heavy-duty vehicles.

These include interactions between different design elements; the impact of design flexibilities on the stringency and simplicity of the regulation; potential stakeholder responses to the regulation; and the potential for stakeholders to shape the regulation.

Additional considerations that merit further consideration for MHDVs include:

1. Improving on and expanding the scope of existing standards in stages
2. How SSRs can fit into a a broader policy framework
    - Fiscal policies (e.g. differentiated incentives, tolls)
    - Infrastructure deployment
    - Supply-side policies (fleet procurement)

Policies to address equity & financing challenges

Lessons from the light duty vehicle sector suggest that supply side regulations, alone, may lead – especially during the transition – to a market offer that is particularly skewed towards vehicles with high margins, for suppliers, exacerbating issues faced by stakeholders (e.g. small and medium enterprises) that face capital availability constraints or higher borrowing costs

Pro-active policies aiming to prevent this can help ensuring that SSRs are progressive, and not regressive, from economic and equity standpoints

Prioritize the early electrification/ZEV adoption for large fleet owners by requiring early transition for fleets belonging to large logistic companies (e.g. through demand-side policies such as clean fleet mandates)

- Policies targeting adoption of efficient / electric MHDVs by large fleets make the vehicles more widely available through the second-hand vehicle market, at more affordable cost points

Require large fleets to establish dedicated funds to support service providers to which they outsource deliveries

- This funding can help foster a broader and more equitable transition to higher cost, more energy efficient, vehicle technologies (and battery electric MHDVs, in particular)

Use public funding to support partial credit guarantees to commercial lenders for electric MHDV adoption

- Blended capital helps to de-risk financial support for the transition of SMEs, e.g. through liquidity facilities that help offering low interest rates on electric MHDVs for capital-constrained economic actors

Promote business models such as electric truck leasing and charging- / trucking-as-a-service programs

- These pay-per-use models, with usage-based fees, help to reduce capital costs, taking advantage of the lower operating costs of battery electric MHDVs (see, start-ups like Juna or Pragmacharge)

Policies to accelerate the deployment of charging infrastructure

As in the case of vehicles, specific policy tools to address equity-related challenges. Priority actions include:

- investing in grids,
- easing of permitting (streamlining) of new charging installation and grid connections (e.g. depots, later also opportunity and destination charging)

A combination of regulation, public funding, and fiscal policy is needed to promote rapid and equitable charging infrastructure deployment:

- Regulations requiring minimum infrastructure roll-out (like the European Union's Alternative Fuel Infrastructure Regulation – AFIR)
- In parallel with policies mobilizing public funding to stimulate deployment

Integrate projections of MHDV charging needs in grid planning

- Target both *highly industrialized regions with major road freight corridors* (where public funds can crowd-in private investment),
- as well as *areas with a less clear near-term commercial viability for charging* (and that risk being subject to structural under-investments), to guarantee charging access (where public funds can ensure minimum charging availability)
- Also use public funds to support and/or finance grid investments

Set requirements for local authorities to deploy minimum capacity (MW) of EV chargers, based on national plans

- Requirements should build on the assessment developed to integrate MHDV charging in grid planning, based on geographical access needs and linked with the (projected) number of electric MHDVs in circulation

Design bundled public competitive concession tenders that include multiple locations

- This design allows charging point operators (CPOs) to cross-subsidize chargers in locations with lower utilization with revenues from highly utilized chargers

Support infrastructure investments in disadvantaged areas to de-risk investments in charging infrastructure with public funding

- Public funding using financial instruments such as partial credit guarantees maintains the role of commercial lenders in financing CPOs
- Revenues can come from carbon pricing or general taxation
- Partial credit guarantees or other financial instruments can also be used to encourage truck-as-a-service business models that include charging access

Technical policies to accelerate the deployment and improve the performance of electric trucks

Ensure that e-trucks meet the need of operators:

- Battery durability (calendar and cycle life) standards, to ensure that batteries retain most of their original capacity over the first-owner usage lifetime (and ideally, beyond this)
- Harmonized high power recharging infrastructure and communication
- Customer-friendly and comparable charging speed information

UN GTR on heavy-duty vehicle battery durability

- Provides harmonized way to measure battery degradation over the years
- Included in Euro 7 proposal
- Harmonized performance requirements for HDV still tbd
    - For LDV, battery should last for at least 8 years and 16,000 km and not lose more than 30% of original capacity
- Formal vote on the proposal in November 2025

Ensure harmonized connectors and communication protocols for high power charging

- Trucks will require high power charging, in the range of 0.5 – 3 Megawatts
- CharIn develops the Megawatt charging system (MCS)
- US/EU agreement on the use of MCS

Charging speed metric for HDV

- UNECE working on the development of harmonized methodology to measure charge speed of EVs
- Part of the fast & smart charging cluster (F&SC), chaired by the Netherlands
- LDV the primary focus, HDV to come in 2026
- Provides customer friendly, comparable information on how fast can EV charge
- Key for e-truck operators

Policies to secure battery supply and to develop domestic industrial capacity/ value-add in EV/battery value chains

Policy making requires striking a balance across multiple objectives:

- Securing access to low-emission technologies at lower cost
- Managing risks of de-industrialization and overdependency
- Seizing opportunities for a more diversified and equitable global development of EV value chains
- Economic risks

This is relevant for the job creation, economic/industrial development, social stability and also from the security standpoint (especially for dual-use technologies)

- Policy choices need to enable competition, stimulate innovation, ensure access to raw materials, secure diversity in trade partnerships for mineral-rich economies, offer development opportunities for a globally diversified technological supply, and at the same time ensure resilience (e.g. to supply chain disruptions)
- Trade-related choices are very relevant, in this context: alignment with open trade and multilateral governance principles are far more likely to lead to stability for each individual trade partner
- Choices by mineral-rich countries may include conditional access to the resources, aiming to attract investments that retain more domestic value-added (e.g. mineral processing, and not only extraction, and other downstream steps of the battery/EV value chains)
- Options that may help to manage de-industrialization and social instability risks in wealthy, but mineral-poor countries may include negotiated price undertakings, use of ESG-related parameters to allocate public funding for research, public procurement and incentives for demand creation, and even conditional access to consumers, also aiming to attract investments allowing to retain more value (e.g. battery manufacturing and upstream steps of the battery/EV value chains)
- Intergovernmental dialogue is important to manage these complex trade issues, especially considering the existence of both major opportunities and very significant risks

A compendium of relevant technical regulations and standards enabling different aspects of the SSR development for heavy vehicles

UN Global Technical Regulations (GTRs) - 1998 Agreement

- UN GTR 4 and amendments 1 (+ corrigenda 1 and 2) 2, 3 and 4 - Test procedure for compression ignition (C.I.) engines and positive-ignition (P.I.) engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG) with regard to the emission of pollutants (WHDC)
    - The most recent version includes references to ISO standards on the measurement of fuel flows and other region-specific and technical standards regarding reference fuels (in its Annex 2: ISO, EN, CEC, ASTM, ICS and HPLC)
- UN GTR on electric vehicle safety
    - Includes a list of relevant ISO and other international standards for Electric Vehicle Safety and on hazards associated with toxicity, corrosiveness and flammability of gases emitted from batteries
- UN GTR on hydrogen fuel cell vehicles and following admendment/corrigenda 1 and 2
    - Includes a list of relevant national and international standards on hydrogen fuel specifications, on refuelling connection devices and on fuel cell vehicle safety specifications

UN Regulations - 1958 Agreement on mutual recognition of type approvals

- 49 - Emissions of C.I. and P.I. engines
- 100 - Electric power trained vehicles
- 134 - Hydrogen and fuel cell vehicles (HFCV)
- 143 - Heavy Duty Dual-Fuel Engine Retrofit Systems (HDDF-ERS)

Further resources



On heavy-duty vehicle SSR design

- ICCT A stepwise guide to HDV fuel efficiency standards, Nov. 2020
- ICCT Deep-dive presentations on HDV fuel efficiency standards, Transport Coordination Group, Nov. 2020 (presentations on HDV fuel efficiency standards at the bottom of the website)
- ICCT Supply-side regulations to accelerate the market for zero-emission heavy vehicles: Best practices from major policies, Feb. 2025

On heavy-duty vehicle electrification

- BloombergNEF's Zero-Emission Commercial Vehicles: The Time Is Now, Sept. 2024
- Smart Freight Centre's Fleet Electrification Coalition
- CALSTART's Zeroing in on Zero-Emission Trucks, Jan. 2025
- CALSTART's Global Drive to Zero Programme
- CALSTART's Global Green Road Corridors, May 2024

On testing and vehicle simulation

- ICCT Testing methods for heavy-duty vehicle fuel efficiency: Trends from regulatory programs around the world and implications for India, 2015
- ICCT Comparison of Aerodynamic Drag Determination Procedures for HDV CO_2 Certification, 2019
- ICCT Adapting the Vehicle Energy Consumption Calculation Tool (VECTO) for use in India and other countries, 2019

On existing supply-side regulations

- ICCT China's Stage 4 fuel consumption standard for heavy-duty commercial vehicles, Dec. 2024
- ICCT U.S. EPA Phase 3 greenhouse gas emission standards for heavy-duty vehicles, Sept. 2024
- ICCT The revised CO2 standards for heavy-duty vehicles in the European Union, May 2024
- ICCT California's Advanced Clean Trucks regulation: Sales requirements for zero-emission heavy-duty trucks, July 2020