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Turning the Wheel: Fuel Efficiency Standards for a Low-Carbon Trucking Future in India

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Executive Summary

Building upon the institutional, technical, and policy learning that India has cultivated over the past decade, policy makers in the Bureau of Energy Efficiency (BEE) Ministry of Power are empowered to frame ambitious but achievable fuel economy standards in the coming few years. The standard that they eventually design will then be notified and implemented by the Ministry of Transport and Highways (MoRTH).

The benefits of fuel economy standards are multipronged and aligns with several national policy priorities like electric vehicle policy, and contribute to key energy security, environmental, industrial policy, economic, and public health goals:

1. **Energy security and fuel savings**: reduced diesel consumption through 2050 is estimated to range from around 660-1,090 million tonnes, cutting cumulative fuel consumption by medium- and heavy-duty trucks (MHDTs) by around 30%-50%, and resulting in an estimated savings from now to 2050 of around USD 838-1385 billion (or USD 34-55 billion annually, on average) at current diesel fuel prices.
2. **CO_2 reductions**: well-to-wheel (WTW) CO_2 emissions[1] from MHDTs are projected to fall in rough proportion to fuel savings, with well-to-wheel emissions of battery electric trucks contributing only 6.8%-14.1% of cumulative emissions across all scenarios considered. (WTW) CO_2 emissions cuts estimated to range from around 2.3 to 3.6 Gt CO_2 through 2050. When monetized according to OECD estimates of the social cost of carbon, this translates to savings of around USD 315-500 billion.
3. **Industrial policy**: Cumulative battery demand by 2035 can reach 146 GWh in the ambitious fuel efficiency standards scenario, and 71 GWh in the base fuel efficiency standards scenario. Electric vehicles, and the battery value chains that enable electric mobility, are recognised as among the pivotal emerging high-value industries of the 21st Century. Fuel economy norms are an important part of a portfolio of policies that can provide market certainty and accelerating the adoption of electric trucks. India's leading truck manufacturers are well-positioned to carve out competitive niches in the global electric truck market, but, as with other stakeholders along the EV value chain, they require a coherent national policy framework to seize this opportunity.
4. **Economic benefits**: Reduced fuel costs and higher efficiency road freight translate to lower costs for the freight sector overall, lowering the cost of delivered cargo. These reduced costs translate to lower prices on materials and final consumer goods, bolstering macroeconomic productivity.
5. **Cleaner air and reduced health impacts**: By accelerating the adoption of electric trucks, fuel economy norms can reduce local air pollution in densely populated regions near ports, industrial clusters, and busy road freight corridors.

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[1] Well-to-wheel emissions include the emissions associated with producing and refining oil to diesel and emissions associated with electricity generation, transmission, and distribution (and including charging losses).

Key findings

In the long-term, benefits of both proposed standards exceed the costs of expensive technologies by an order of magnitude.

From 2026 to 2050, the cumulative benefits of reduced fuel consumption and CO_2 emissions savings (without accounting for health and other benefits of reduced local air pollution) are estimated to range from around USD 1,200-1,900 billion. Meanwhile, conservative estimates of the cumulative additional costs of efficiency technologies such as more efficient engines, transmissions, tyres and aerodynamic devices used in conventional ICE trucks, plus the costs of accelerated adoption of battery electric trucks (BETs), as compared with ICE trucks, are estimated to range from around USD 70-185 billion.

Available estimates suggest that the additional purchase price of conventional ICE trucks meeting ambitious yet attainable fuel consumption standards for N2/N3 trucks could be recovered within 2.5-7 years. After this delay in initial payback, truck owners and operators will derive net benefits from reduced fuel consumption. The additional incremental costs of fuel/energy efficiency technologies promoted by fuel consumption standards that phase in from 2028 can be expected to decline in subsequent years, as the standards incentivize competition and product differentiation among OEMs and their suppliers. Cost reductions are projected to be particularly pronounced for technologies that have only begun to reach commercial scale in the medium- and heavy-duty truck segments, such as LFP batteries, and, to a lesser extent, electric motors.

Table ES.1 shows the estimated benefits and costs resulting from two alternative stringency levels of fuel economy standards. Both standards require linear reductions in specific fuel consumption from 2028-2033, and both incorporate credit multipliers to stimulate the near-term adoption of battery electric trucks. In both cases, credit multipliers are gradually reduced to 1 by 2033, ensuring that the long-term stringency and effectiveness of the standards to reduce fuel consumption is maintained.

Table ES 1. Estimated cumulative benefits and costs, from 2026 through 2050 (billion USD)

	Benefits		Costs	
Fuel consumption standard scenario	Fuel savings (billion USD)	WTW CO_2 cuts (billion USD)	Incremental purchase costs (ICE trucks)	Incremental purchase costs (BETs)
Baseline	838	316	39	34
Ambitious	1,385	502	112	75

Note: estimated benefits are from reduced fuel expenditures and CO_2 emission reductions, and costs estimates include incremental technology costs that are reflected in higher purchase prices of conventional ICE trucks, as well as the incremental costs of additional BETs promoted by the fuel economy standard.

Opportunities for India to leverage international experiences and best practices

1. *Sloped standards, which increase gradually in stringency, are preferable to step-functions*. Comparison across existing standards suggests that sloped standards (like in the US), with sufficient flexibilities (e.g. credit trading, averaging, and banking), are a better option than the 5-year step functions adopted by India in its light-duty vehicle fuel economy norms, as well as by the EU (in CO_2 emissions standards for both LDVs and HDVs).
2. *Baselines can be set using established methods and relying on industry provided data for a future year (e.g. 2026), to avoid industry critiques and to streamline notification*. The European Union's success in designing CO_2 emissions standards for HDVs that require aggressive percentage reductions by 2025, 2030, 2035 and 2040 from a 2019 baseline year, without requiring that the market average emissions performance in that year be determined in advance, offers a promising example of one way to circumvent industry objections (e.g. of picking a baseline that is not representative or is deficient in other ways), and to expedite the design and implementation of standards, without sacrificing stringency or making the perfect the enemy of the good.
3. *Consider adopting credit multipliers for zero-emission trucks to promote the market adoption of battery electric trucks but embed a ramp down and phase out by the end of the standards*. Credit multipliers of no more than 5 should decline predictably, down to 1 by the final year of the standards (2033, in this analysis).
4. *Embed ZET sales requirements into fuel consumption standards, as the EU has done in the case of urban transit buses*. Based on analysis of the domestic market and operations, India could identify segments where electric truck supply could scale rapidly, and where the economic and operational cases (at least for certain operators) is most conducive to rapid electric truck adoption.
5. *Continue research and capacity-building to adapt VECTO, but do not wait for VECTO-based baselines and stringency determination to notify and implement fuel consumption standards.* In the mid-to long-term, testing and compliance based on simulation modelling is the gold standard practice to ensure that fuel consumption standards translate into real-world fuel savings, that the standards are well calibrated and fair across all industry players, and that stringency levels across vehicle segments coherent. However, there is no need to wait for VECTO to be completed to notify and implement the next stage of fuel economy norms for medium- and heavy-duty trucks. Instead, ensuring that efficiency technologies are adopted soon, and that India can promote truck electrification calls for designing and implementing standards based on current testing and compliance methods (i.e. Constant Speed Fuel Consumption), despite the shortcomings of this method.

1. Introduction

India is currently exploring the development of updated fuel economy standards (FES) for its heavy-duty trucks. These regulations are critical for advancing clean transportation. In fact, well-designed and timely implementation of fuel economy regulations can contribute substantially to many of India's key policy priorities. Fuel economy standards can not only reduce the country's dependence on oil imports, but also support India's net-zero goals for 2070, accelerate the electrification of the road freight sector, promote economic development and job creation, and provide long-term policy signals to key domestic industries.

To fully realize these benefits, the regulations must be phased in as swiftly as feasible, while also ensuring that the standards are sufficiently stringent to drive adoption not only of fuel efficiency technologies in conventional ICE trucks running on diesel, but also to accelerate market penetration of zero-emission trucks, and above all battery electric trucks. Efforts to achieve this can build upon existing informational, administrative, and technical capacities, and leveraging the learnings from other regions that have successfully implemented similar standards. Fuel economy standards should also not be considered in isolation but will be most effective if they are part of a coherent and carefully crafted portfolio of policies.

India is world's fifth largest economy and third largest national emitter of greenhouse gases. In 2021, India amended its net zero target to achieve net zero GHG emissions by 2070 and has subsequently added an intermediary goal to reduce its emissions intensity from GDP by 45 percent by 2030, relative to the 2005 level. India's strategy focuses on long-term low carbon strategy of reducing emissions from seven major sectors, including transport[2] and power. In 2023, during India's G20 presidency, there was further emphasis on the need to reduce the country's emissions intensity and to triple renewable energy capacity to reach the net zero by 2070 goal.

1.1 Implementing fuel economy regulations can act as a catalyst to meet net zero by 2070 goals

The transport sector contributes approximately 14% of the country's national GHG emissions. Road transport is the dominant mode for both freight and passenger movement in India and is responsible for 92% of all transport-related energy demand and 94% of transport-related direct CO_2 emissions.

With demand for energy from the transport sector having tripled since 2000, road transport is the largest (44%) oil consuming sector and accounts for around 12% of the country's overall CO_2 emissions from fossil fuel. Within road transport sector, medium- and heavy-duty trucks (MHDTs) account for less than 3% of all vehicles registered, carry nearly 70% of the country's freight demand (around 1.5 trillion tonne-km

[2] Globally, decarbonizing the transport sector has emerged as a key agenda towards climate change mitigation actions, it is a significant contributor to CO_2 emissions. According to the IPCC Sixth Assessment report, direct emissions from operations of motorized vehicles account for 15% of global GHG emissions and 23% of global energy related CO_2 emissions. Transport sector emissions from the are also the fastest growing; with China and India recording 48% and 39% growth respectively.

[tkm], of 2.2. trillion tkm in total), and are responsible for 38% of fuel consumption and direct CO_2 emissions. Freight movement in India accounts for 14% of the nation's GDP, a share that is 4 to 6 percentage points higher than in most advanced economies.[3]

The freight transport sector is expected to continue to expand over the coming decades due to increasing demand for goods, driven by urbanization, population growth, the rise of e-commerce, and higher income levels. Freight demand is expected to triple from 2022 levels to 9.6 trillion by 2050 (Niti Aayog and RMI, 2022). NITI Aayog projects the of MHDT fleet to more than quadruple, from 4 million in 2022 to roughly 17 million trucks by 2050.

1.2 Fuel economy regulations can abate direct emission from vehicles

According to 2023 IEA estimates, strong fuel efficiency improvements and aggressive deployment of ZEV trucks could cut CO_2 emissions in 2050 by more than 100 Mt CO_2. The study takes note of the fact that fuel efficiency will be pivotal to reduce demand for diesel and related emissions. Nearly 70% of the emissions reductions are expected to come from direct electrification of the truck fleet, and fuel efficiency improvements would provide nearly 20% of the emissions savings.

Similarly, a 2023 assessment by the ICCT finds that the potential for cumulative well-to-wheel CO_2 emissions abatement in medium- and heavy-duty trucks to 2070 could range from around 9% to as high as 75%. The assessment splits the CO_2 emissions cuts coming from ICE truck improvements and those coming from electrification; similarly to the IEA assessment, it finds that 70%-84% of the long-term emissions emission reduction potential comes from BETs.

A crucial difference between the ICCT study and the current study is that our study seeks to isolate the impact of near-term fuel economy standards, while the ICCT study's scenarios assume that zero-emission truck sales requirements are implemented in the 2030s that drive increasing adoption of ZETs. While technology developments in the 2030s may make it politically, technically, and economic feasible to implement ZEV sales requirements for MHDTs, we do not aim model these potential developments but instead focus on the projected impacts through 2050 of a five-year limit value schedule (2028-2033) for fuel consumption standards.

Given these differences in scope and objectives, our study comes to similar conclusions to the IEA and ICCT studies, in terms of the potential for policy interventions to reduce fuel consumption and CO_2 emissions. Differences between our findings and those of recent ICCT (and IEA) studies are discussed in greater depth in the final section (Pathways for India) of this report.

[3] To improve the efficiency of its freight movements, India has launched PM – Gati Shakti national master plan for multimodal connectivity incorporating infrastructure projects of various ministries for providing integrated and seamless connectivity over different transport modes for movement of goods and services.

1.3 Updated Fuel Economy Standards can reduce oil and oil product import dependence

Medium and heavy-duty trucks in India consume about 40% of the total fuel consumed by the road sector. In its BAU ('Stated Policies') scenario, the IEA projects fuel consumption by MDTs to nearly double by 2050 from the 2025 level, to about 70 Mtoe. Under current policies, the ICCT projects fuel consumption by MHDTs to reach about 60 Mtoe by 2030 and about 125 Mtoe by 2050 from about 45 Mtoe in 2022.

The 'no-policy' scenario in the present study projects similar increases in diesel demand to the ICCT baseline, with fuel consumption by MHDTs rising to 63 Mtoe in 2030 and to 117 Mtoe in 2050. Increases in oil demand can be substantially mitigated by fuel consumption standards, with 2050 consumption projected to reach only 70 Mtoe under 'baseline' fuel consumption standards, and to be limited to 39 Mtoe under 'ambitious' fuel consumption standards, an increase of 60% and a decrease of 11%, respectively, from 2025 diesel consumption levels.

1.4 Updated FES can accelerate adoption of electric trucks and deliver economic opportunities, energy diversification, and air quality benefits

1.4.1 Accelerating electric truck market adoption

The market for battery-electric trucks (BETs) in India is at an early stage, with a few manufacturers having introduced to market at least 10 BET models thus far, all but two of which are in the N3 category, and with other manufacturers plan to introduce around 5 BET models in the coming few years. Currently upwards of 400 e-trucks are operating in closed-loop pilot operations.

Once a GHG / vehicle efficiency standard becomes sufficiently stringent, it can be particularly effective to support electric trucks, as electric trucks become the most cost-effective, and eventually the only technological viable, option for meeting the standard.[4]

GHG regulations for HDTs, and more generally supply-side regulations including fuel consumption/GHG standard and ZET sales requirements, provide three key advantages in promoting ZET adoption. First, they provide fair and equal treatment across all vehicle manufacturers, assuring all market players that the entire industry will need to meet the same regulatory requirements. Second, they increase ZET demand, while also driving down prices by harnessing market forces (e.g. through economies of scale and via competition). Finally, since the number of OEMs is general small (particularly in the MHDT segments), these regulations can be simpler to administer and enforce than incentive programs targeting consumers, such as purchase subsidies and tax credits.

[4] This is shown, for instance, in the analysis underlying the impact assessment of the EU's 2024 CO_2 emissions standards for HDVs, and separate in the impact assessment of the United States Phase 3 GHG standard. The impacts of both of these regulations, both in terms of accelerated ZEV adoption and on projected GHG / CO2 emission cuts, are outlined in chapters 2 and 3, respectively.

Stringent MDHT GHG emissions standards can significantly accelerate achieving first TCO parity, and eventual potential cost parity for ZEVs, as compared to internal combustion engine (ICE) vehicles. By promoting market adoption of ZEVs, and of electric trucks in particular, such standards can enable substantial, cost-effective reductions in life-cycle greenhouse gas (GHG) emissions, which ZEVs are particularly well suited to deliver.

1.4.2 Reducing fuel costs of road freight

GHG and fuel efficiency standards for trucks result in lower fuel costs, and ultimately in lower total cost of ownership and operations, as fuel and other savings exceed the costs associated with higher capital investments for vehicles and infrastructure development. Reduced energy costs are particularly pronounced for battery electric trucks (BETs), which range from around 55% to more than 70% as efficient as conventional ICE trucks, on a useful service metric (i.e. MJ/tonne-km), depending on the vehicle segment and duty-cycle.

Some share of the lower fuel expenditures for fleets are likely to be passed through, translating to lower prices on commodities and delivered goods. Even small cost reductions on a percentage basis can translate to savings on a macroeconomic level, as logistics costs are estimated at around 8%-9% of India's GDP. The degree of cost pass-through depends on the competitiveness of the road freight market and can range from around 30%-80%. The cost reductions as a share of the final good purchase price are generally higher for raw materials than for consumer goods, and while small in percentage terms, they can have a positive have a macroeconomic impact and translate to greater purchasing power for the consumer.

1.4.3 Opportunities for advanced efficiency technologies and electrification in truck manufacturing

The automobile sector contributes about 6% to India's GDP. India is the third-largest heavy-duty truck manufacturer globally with Indian OEMs including Tata Motors and Ashok Leyland being the major players in MHDTs. The shift to EVs presents an investment opportunity for existing and new manufacturers to expand automobile production in the country. The transition to EVs will not only reduce emissions but will create an economic impact by creating jobs, attracting investments and advancing technological innovations. Over the next decade, the sector is expected to generate approximately 5 million direct and indirect jobs, in areas like vehicle manufacturing, battery production, and charging infrastructure development.

This shift will drive significant value creation across the automotive sector, developing local supply chains, boosting domestic manufacturing, and enhancing energy security. Increased investment in R&D will accelerate technological advancements, positioning India as a solid player in the global EV market. A strong focus on localisation of battery and key components aim to reduce import dependence, strengthen domestic industries, and create a robust EV ecosystem. For example, schemes like the PLI ACC for Battery Storage require beneficiaries to achieve a 60% value addition within five years from the date of appointment, significantly cutting reliance on imports.

Moreover, the transition will unlock new business opportunities for startups and established players, fostering innovation across the automotive value chain. Between April 2000 and March 2022, the EV sector attracted equity inflows from Foreign Direct Investment (FDI) of USD 32.84 Billion. The growing demand for EVs will continue attracting both domestic and foreign investments, contributing to long term growth of the country.

1.4.4 Local air quality benefits of electric trucks

Nearly all of India's MHDVs are powered by diesel engines. An UNEP study suggests that MHDVs are significant contributors to vehicular air pollution, accounting for 40% of NOx, 60% of $PM_{2.5}$ and 20% of black carbon emissions from road vehicles. Niti Aayog's own estimates confirm these estimates; with MHDVs estimated to contribute 53% of India's total particulate matter (PM) emissions. Policy interventions could reduce these emissions considerably; effective implementation of India's scrappage policy (discussed in further detail below), and of Bharat Stage VI emission norms could reduce NOx emissions by 200 thousand tonnes (kt) NOx (a 17% reduction) and $PM_{2.5}$ emissions by 10 kt (11% reduction) annually in the near term. Longer term emissions reduction potential is even higher: by 2050, policies designed to cut trucks' emissions have been estimated by RMI to have the potential to cut $PM_{2.5}$ emissions by 15 million tonnes (Mt), and NOx emissions by 500 kt.

Longer term cuts in pollutant emissions are expected to come primarily from adoption of zero-emission MHDTs, powered by batteries or hydrogen fuel cells, which, as implied by their name, eliminate tailpipe air pollutant emissions. The cuts in pollutant emissions from vehicle tailpipes, which often occur in more densely populated areas and in greater proximity to people, generally far outweigh the potential for greater pollutant emissions needed to supply increased electricity demand from ZE MHDTs. Additional strategies to charge when electricity demand is low or when generation would otherwise be curtailed, as well as eventual opportunities to draw power from electric trucks back onto grids, can further mitigate these risks.

2. A supportive policy framework for electric trucks in India

In 2017, India notified fuel consumption standard for heavy-duty trucks, which was further amended in 2020 and 2022 (notably to include also medium-duty trucks (N2), and were notified in April 2022 (BEE, 2017; 2020; 2022). As of 2025, updates to the LDV FE norms are being evaluated for publishing, while updates to the fuel economy regulations for light-duty and heavy-duty commercial goods vehicles are yet to be formulated.

To update its fuel economy regulations, India can build upon learnings from economies where such standards are already in place, including the European Union (EU), the United States, Canada, Japan, and China. Additionally, India can tap into the knowledge and expertise of governmental, technical, intergovernmental, private, and academic institutions.

There is enough evidence globally on how fuel efficiency standards have promoted transitioning to cleaner transport, as well as evidence of benefits far exceeding costs by a multiple of 3-10, and by even more in the mid- to long-term (see, for instance, U.S. EPA, 2016; European Commission 2018; and ICCT, 2021). India has already dedicated significant resources to create the informational, technical, and legal framework necessary for developing working groups with pertinent stakeholders from both the private sector and government. This effort will need to culminate in the design, implementation, monitoring, and enforcement of standards. The final section of this report (Pathways for India) proposes a five-year schedule (2028-2033) and two options ("baseline" and "ambitious") for the stringency of standards across 14 MHDT segments, and uses projections of future market developments through 2050 and a stock-accounting model to estimate first-order benefits and costs of both stringency levels.

Fuel economy standards will provide the greatest benefits if they are part of a comprehensive policy portfolio that promotes fuel efficiency in road freight electrification. Such a portfolio could be built by doubling down on current policies and by prioritising among additional incentives and financing measures, as outlined below.

Some of the key ongoing initiatives and deliberations to promote electric vehicles and e-trucks includes the Niti Aayog led the Electric Freight Accelerator for Sustainable Transport (e-FAST) campaign to amplify the demand signal for ZET market, the National Highway for EVs initiative, the EV100+ campaign, the Global Drive to Zero campaign, the Laneshift program by Climate Pledge, and C40 Cities piloting ZETs for long-haul operations.

The Ministry of Heavy Industries (MHI) recently also introduced the PM E-DRIVE scheme as a demand incentive program for e-trucks**. The MHI had previously introduced** Production Linked Incentives (PLI) for auto and auto components (2023-2027), and for advanced chemistry cell (2025-2029), both of which were introduced to promote localisation of auto components and domestic battery and cell manufacturing. Budgetary outlay under these is USD 3.2 billion (INR 25,938 crores) and USD 2.26 billion (INR 18,100 crore) respectively.

The Ministry of Road Transport and Highways (MoRTH) introduced the Voluntary Vehicle Fleet Modernization Program (VVMP) in 2018. The VVMP provides incentives for voluntary scrappage of commercial vehicles beyond 15 years of age. The program was amended in 2021 to include mandatory fitness tests for old vehicles, tax incentives, and the establishment of Registered Vehicle Scrapping Facilities (RVSFs), as well as mandatory recycling of materials – all of which represent more readily enforceable measures to induce scrapping. Furthermore, in 2024, when the Ministry of Heavy industry announced PM e-drive scheme to promote the adoption of e-trucks, mandatory scrappage of old commercial vehicles was introduced as a qualifier to improve adoption of e-trucks.

Sub-national EV policies in 7 states (Assam, Uttar Pradesh, Madhya Pradesh, Maharashtra, Delhi, Odisha and Haryana) support fleet adoption targets to transition to zero-emission vehicles for either the government fleet, commercial cabs, or small last-mile delivery vehicles. The extension of such policies to cover truck fleets owned or operated by shippers, carriers, or third-party logistics companies could provide an important demand-side lever to accelerate electric truck adoption, especially if such policies were supported by financing and/or enshrined in binding legislation.

Over the last decade there has also been policies implemented at the central and national level that compliments the transition to Zero emission trucks. These include the Renewable Energy targets for 2030, Electric vehicles Mission 2030, The National Green Hydrogen Mission launched in 2022, upcoming BS VII standards.

2.1 Air pollution and emission reduction policies to fund state-level ZET adoption

While the national policies set ambition and direction, the state-level policies drive responsibility at the regional level. Globally, we have witnessed multiple countries scale their e-truck adoption through attractive incentive programs at the state level, largely motivated by improving ambient air pollution and reaching vehicle emission reduction targets.

In the United States, 29 states, including California, have funded ZET adoption through national and state-level schemes, voucher incentives, and grants. Federal funds that had state-level provisions include the Diesel Emissions Reduction Act (DERA) fund, the National Highway Traffic Safety Administration's Congestion Mitigation and Air Quality (CMAQ) fund, and the Volkswagen Settlement Fund (VW Settlement). In addition, multiple states had their own funding sources. Examples include: California's General Fund (GF), Air Quality Improvement Program (AQIP), Air Pollution Control Fund (APCF), Congestion Mitigation and Air Quality (CMAQ) Improvement Program, and Greenhouse Gas Reduction Fund (GGRF); the Regional Greenhouse Gas Initiative (RGGI) fund in New Jersey and Massachusetts; Chicago's Voucher incentive program; and New York's Truck voucher incentive program (U.S. DOE AFDC, 2025; CALSTART, 2024).

As of 2024, the EU probably has one of the most stringent pollution regulations to drive the adoption of e-trucks. In addition to fuel economy norms, the commission has applied a "polluters pay" principle to freight movement on trans-European transport (TEN-T) network roads by adopting a directive that offers up to 75% toll discounts to zero-emission MHDVs, among other ZE vehicles, starting in 2024 (EC, 2022).

In terms of key takeaways, each country has focused on its strengths and tailored its strategies according to its commitments and needs. In the US, policies emphasize a mix of federal and state-level incentives, which help lower upfront costs of zero-emission trucks (ZETs) through subsidies, tax credits, and operational incentives such as reduced tolls. Europe's strategies centre around strict emissions regulations, fines for non-compliance, long-term carbon reduction targets, and extensive investment in public charging infrastructure, especially along major freight corridors, which could guide Telangana in building a supportive charging network. Meanwhile, China's approach focuses heavily on supporting domestic ZET manufacturers; supporting battery-swapping in closed-loop operations for ports, steel, and mining industries; and implementing large-scale rollouts within designated clean zones and urban centres.

2.2 Fuel economy standards will be most effective in accelerating battery electric truck adoption if they are conceived as part of a comprehensive policy portfolio

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 owner-operators)[5] 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. Multiple policy options exist:

- **Demand-side policies such as clean fleet mandates:** Such policies complement fuel economy standards, requiring minimum BET adoption rates, and thereby accelerating electrification/ZEV adoption for large fleet owners by requiring early transition for fleets belonging to large logistic companies. Such policies make BETs 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 to BETs, 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. Due to low asset ownership, uncertainty of usage and informal economy operations, small fleet operators have low credit ratings and are unable to secure loans from commercial banks in India. Financing of entities including small fleet operators with low credit ratings is generally provided by Non-Banking Finance Companies (NBFCs), which are lending entities in India that charge higher interest rates than commercial banks.
- **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).

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[5] As in many other countries, India's road freight market is highly fragmented with about 70% of the market run by small fleet operators that own fewer than six trucks. Only about 7% of the market is run by fleet operators who own more than 20 trucks. Additionally, about 60% of the fleet is utilized based on demand with no fixed contracts.

Efforts to accelerate BET adoption must be complemented by policies that **accelerate the deployment of high-power charging infrastructure** needed by BETs. As in the case of vehicles, specific policy tools to address equity-related challenges. Priority actions include:

- **Integrating projections of MHDV charging needs in grid planning**: These should 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),
- **Investing in grids**, including use of public funds to support and/or finance grid investments,
- **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. Global best practices to date include regulations requiring minimum infrastructure roll-out like the European Union's Alternative Fuel Infrastructure Regulation. A regulatory approach can be complemented by parallel adoption of policies mobilizing public funding to stimulate deployment.
- **Setting 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.

Finally, India should continue to advance in its formulation of 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, including securing access to low-emission technologies at lower cost, managing risks of de-industrialization and overdependency, and seizing opportunities for a more diversified and equitable global development of EV value chains. This is relevant for the job creation, economic/industrial development, social stability, as well as from the security standpoint (especially for dual-use technologies).

3. Global Experience and Impact of supply side regulations

3.1 Projected impacts of the US and EU standards

3.1.1 US Phase 3 Standards

According to the EPA, the Phase 3 GHG standards are estimated to reduce cumulative tailpipe GHG emissions by 2.3 billion tonnes CO_2e, offset by an increase of 0.4 billion tonnes CO_2e in upstream electricity emissions, resulting in a net GHG emission reduction of 1.9 billion tonnes CO_2e over 2027-2055. The standards are projected to yield USD 13 billion in annualized net benefits through 2055, including USD 3.5 billion in operational savings, USD 450 million in energy security benefits, USD 10 billion in annualized climate benefits and up to USD 300 million in annualized benefits from reduced emissions of fine particulate matter ($PM_{2.5}$).

Operators of heavy-duty vehicles are expected to realise annualized savings of USD 3.5 billion, compared to annualized costs of about USD 1.1 billion. After factoring vehicle purchase tax credits provided under the Inflation Reduction Act, a typical buyer of new clean technology heavy-duty vehicles will recoup any additional capital expenses (e.g. higher purchase and infrastructure) through lower operational and fuel costs within 2-5 years.

To determine the stringency of the Phase 3 standards, the EPA estimated ZEV truck adoption rates across six heavy-duty truck categories using two newly updated models: the Heavy-Duty Technology Resource Case Scenario (HD TRUCS) Tool and the National Renewable Energy Laboratory's TEMPO model. EPA used the HD TRUCS tool to estimate technology feasibility and calculate payback schedule in MYs 2027, 2030, and 2032 of various powertrain technologies, including ZEVs, across 100 vehicle types. These payback figures were used to forecast adoption rates using the TEMPO model, according to a payback schedule.

The EPA capped ZEV market penetration in new truck sales at 20% in 2027 and 70% in 2032, noting that uncapped modelling earlier led to very rapid ZEV adoption. As a result, lighter HDV segments with shorter, closed-loop duty cycles and shorter payback periods, are expected to transition to ZEVs faster than heavy-duty regional and long-haul vehicle segments. There is a strong correlation between the projected ZEV adoption rate and the percentage reduction in CO_2 emissions within and across segments.

By MY 2032, projected ZEV penetration under the Phase 3 standards is estimated to range from 25% (for Long-Haul Sleeper Cab Tractors) to 60% (for Light Heavy-Duty Vocational vehicles), as shown in Figure 1.

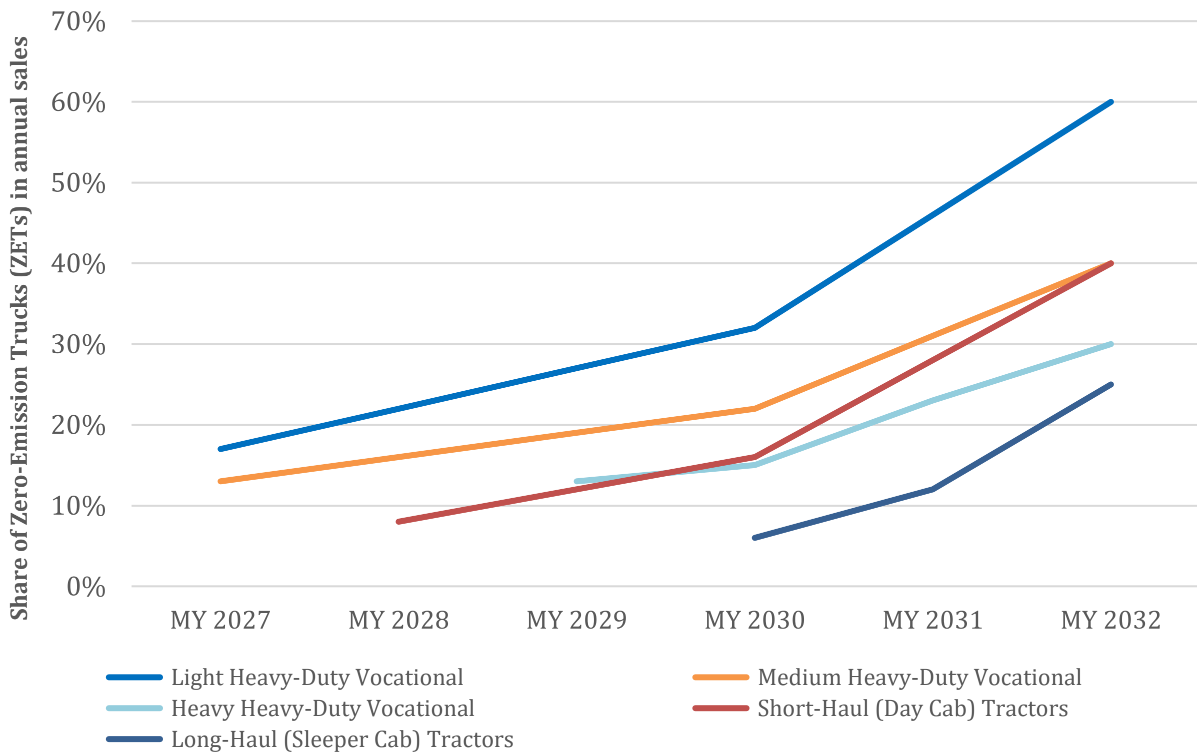

Figure 1: Projected Mix of ZEVs for U.S. Phase 3 GHG Standard Compliance

However, since the regulations allow fleet averaging, banking, and trading, as well as generating multiplier credits for advanced technology and ZEVs, and based on the actual evolution of technology costs and market strategies of MHDV manufacturers, the actual powertrain and technology shares that manufacturers adopt to comply with the standards may lead to upward or downward deviations with these projections. For example, the EPA developed an alternative compliance pathway for the Long-Haul Sleeper Cab Tractor category, wherein manufacturers could comply with 5% natural gas, 10% hybrid electric, and 17% hydrogen ICE vehicles.

3.1.2 EU CO_2 Standards (2024; second-round updated)

The European Union's Impact Assessment supporting Regulation (EU) 2024/1610 shows that baseline energy demand is projected to increase to an extent until 2030 and then gradually decline over the next 20 years. During the same period, CO_2 emission is expected to decrease by only 14% by 2030 and 70% by 2050, falling short of the reduction target needed to achieve to meet REPowerEU scenario goals of ending the EU's dependence on Russian fossil fuels to address the climate crisis (Figure 2).

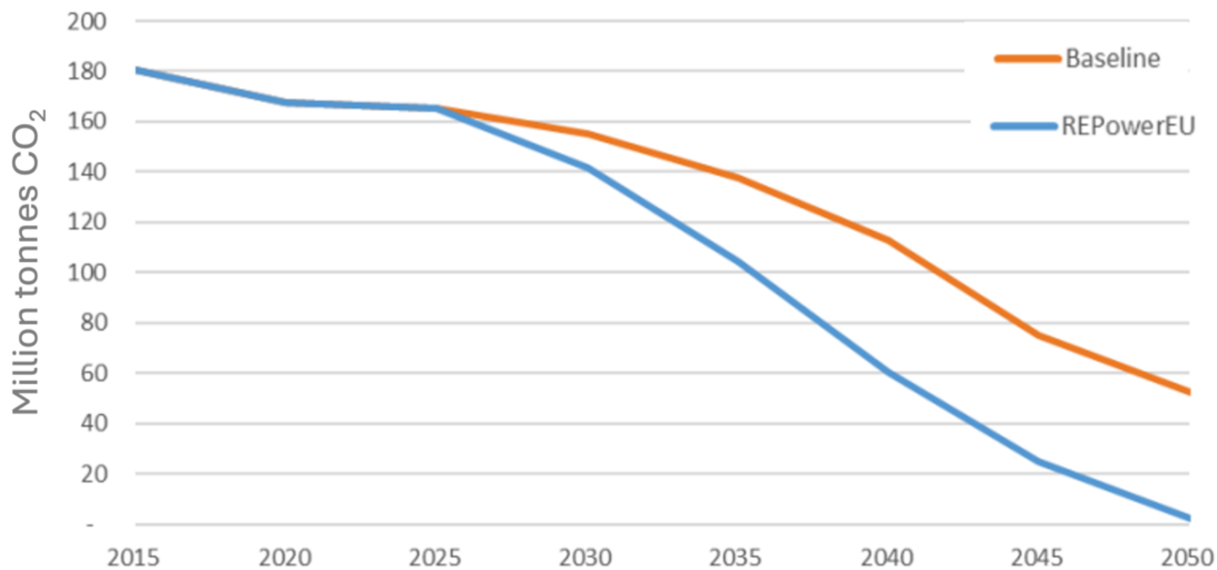

Figure 2: Heavy-duty vehicle tailpipe CO_2 emissions, in the Baseline and REPower EU scenario

Source: European Commission, 2023

The baseline scenario also projects limited ZEV deployment. ZEV shares under the Regulation (EU) 2024/1610) are projected to increase from 34% in 2030 to 57% in 2040 in the REPowerEU scenario, compared to just 12% and 31% in the baseline scenario, respectively

The impact assessment also evaluated benefits of fuel savings, operational savings and monetized environmental externalities. These benefits were estimated to be twice as high as the costs associated with higher capital investments in vehicles, infrastructure development, and battery and fuel cell replacements. Policy frameworks with broader scope including trailers, truck and bus groups were found to be more effective, with a higher benefit to cost ratio, broader scope allows reaching the same level of overall ambition with lower costs.

Policy action paired with more stringent emission reductions was also deemed to be more effective to support EU Member States under the Effort Sharing Regulation (ESR), which covers all sectors not falling within the scope of the EU Emission Trading Scheme (ETS) – before its extension to transport and buildings via the ETS2). Policy action was also more effective for the achievement of the 2050 climate neutrality requirement, in line with the 2021 EU Climate Law, which created a mandate and a legal basis for more ambitious legislation to support the EU's climate targets.

3.2 Policy continuity for incremental and long-term impact

Policy continuity is important to yield long term impact of transition. Both the US Phase 3 GHG standard and the EU's CO_2 emissions standards for HDVs build upon the earlier regulations and extend the coverage, in terms of vehicle categories and/or technologies, and increase the stringency from previous phases.

The U.S. Environmental Protection Agency (EPA) adopted in 2024 its Phase 3 greenhouse gas standards for HDVs, covering model years (MY) 2027 to 2032. These new standards extend beyond the Phase 2 standards (which run from 2021-2026), and increase the stringency of GHG emissions limits, building upon the earlier Phase 1 (adopted in 2011, effective from MY 2014) and Phase 2 (adopted in 2016, effective from MY 2021) GHG regulations for HDVs.

The EU CO_2 Regulation (EU) 2024/1610 notified in 2024 strengthens the CO_2 emission reduction requirements for new heavy-duty vehicles already established in Regulation (EU) 2019/1242 for 2030, extends coverage of HDV categories from around 65% to around 92% of the market, and introduces new requirements for 2035 and 2040.

India has a precedent of transitioning to new standards that leapfrog stages implemented by the EU (e.g. from Bharat IV to Bharat VI). It has the opportunity to build upon the fuel consumption standard for medium and heavy-duty vehicles notified in 2018, and to design a much more stringent trajectory.

3.3 Distinct reduction thresholds across all vehicle categories to account for variability in efficiency technology costs and their relative fuel/energy consumption reduction potential

The potential to reduce fuel/energy consumption, as well as the technological, economic, and operational viability of battery electric vehicles, varies widely across MHDT segments. Based on these factors, the US phase III regulation classifies the heavy-duty vehicles in 33 distinct categories, and the EU classifies into 10 VECTO groups, and then over 100 VECTO sub-groups, based on differences in operations (duty cycles).

Stringency determinations should be based on technology assessments that reflect the efficiency potential and costs of adopting more efficient technology. Establishing standards that are coherent across segments is needed to avoid leading to structural changes in the market, or compliance mechanisms that don't translate to actual efficiency improvements. These considerations are important, but lack of data availability and uncertainties in estimates of the marginal costs of efficiency improvements should not impede policy makers from establishing standards that reflect their analysis. Monitoring the impacts of standards on vehicle efficiency, costs, and market structure can enable refinements in subsequent updates to the regulation.

Moreover, it is not necessary to set standards for all vehicle categories, but instead more valuable to focus regulatory analysis and design (including stringency determination, flexibilities, etc.) on the segments that account for the highest shares of fuel consumption and/or sales shares. Leveraging continued development on the VECTO tool, the EU has successfully expanded the coverage of its standards from around 65% of the market in the CO_2 standards notified in 2019, to 92% in the standards notified in 2024.

Table 1: Comparison of the U.S. Phase 3 standard and the EU CO_2 standard for HDVs

Key Elements	US Phase 3 GHG emission standards	EU CO_2 standard for HDVs
Implementation period	Phase 3 covers MY 2027 to MY 2032. These new standards and more stringent GHG emissions limits and build upon the earlier Phase 1 (adopted in 2011, effective from MY 2014) and Phase 2 (adopted in 2016, effective from MY 2021) GHG regulations for HDVs.	Calendar years 2025, 2030, 2035, 2040 (depending on vehicle categories). For HDVs, the updated EU regulations for 2035 and 2040 are more stringent and

		extend beyond the 2019 regulations for 2030.
Regulation	The Phase 3 GHG emission standards for 2032 requires reductions ranging from 5% to 60% more stringent than the MY 2026 levels, depending on vehicle category. All phase 1, 2 and 3 GHG standards set separate GHG and CO_2 emission limits for different categories of heavy-duty engines and for vehicle segments	Differs by vehicle sub-category with requirements tightening every five years. For HDVs as a whole, the updated standards require 90% CO_2/tkm reduction by 2040, with intermediate cuts of 65% in 2035, 45% in 2030[6] and 15% in 2025.
Tool	The United States' simulation tool GEM is used to test and certify vehicle-level CO_2 emissions and fuel consumption.	The EU's simulation tool VECTO is used to test and certify CO_2 emissions and fuel consumption.
Regulated entities	Regulations apply to vehicles and engines separately and hence both vehicle manufactures, and engine manufacturers are required to report	Vehicle manufacturers
Regulated vehicle categories	28 distinct sub-categories (34 in Canada), defined as: - Class 7 & 8 (10 sub-categories with varying weight class, height and cab design) - Class 2b-3 Vocational vehicles, - Class 4-8 buses and trucks (15 sub-categories varying w.r.t usage, engine type, and weight category)	Heavy-duty vehicles are divided into multiple VECTO groups, and then into sub-groups based on vehicle operations (duty cycles). The 2024 standards expand scope of vehicle sub-categories from only trucks in 2019 to buses, trucks, and trailers (all M2, N2, and N3 vehicles, plus trailers) in 2024.
Projected ZEV adoption	Based on increased adoption of ZEVs beyond the MY 2027 Phase 2 baseline, no improvements in ICE technology were assumed; Phase 2 MY 2027 standards strengthened for vocational vehicles to reflect ZEV adoption. Projected adoption by 2032 of 25%-60%.	Projected ZEV shares under the 2024 Regulation, as reflected in the REPowerEU scenario, range from 34% to 57% between 2030 and 2040.

[6] Up from 30% mandated in Regulation 2019/1242, only applicable to rigid lorries and tractors with more than 16 t of permissible maximum laden mass.

3.4 Introduction of credit mechanisms to incentivise zero- and low-emission vehicle technologies

Both US and EU have introduced flexibility mechanisms like credits to promote market adoption of zero- and low-emission vehicle technologies. Credits incentivise cleaner technologies and accrual of credits by early movers can be traded to other manufacturers or used later to offset against the deficit accrued against other vehicles.

To incentivize early compliance and adoption of EV and other advanced vehicle technologies, the U.S. Phase 3 standards enable vehicle manufacturers to generate advanced technology multiplier credits through MY 2027 for plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs). The credit multipliers are set at 3.5 for PHEVs, 4.5 for BEVs, and 5.5 for FCEVs. Credits can be banked and traded against deficits only up to a period of five years. Similar to credits, manufacturers can also earn deficits when they breach the Co2 targets.

However, it is important to note that super credits or credit multipliers should be applied under strict conditions, to prevent dilution of the effective stringency of the GHG targets. Higher multipliers can reduce the actual number of ZEVs that need to be produced to meet compliance targets and also reduce actual CO_2/GHG emissions reductions. To address this, the EPA's Phase 3 limits the use of credits multipliers to model years 2027-2029, with a complete phase out by MY 2030. During MYs 2027–2029, manufacturers are required to exhaust base credits (i.e., credits earned without the use of multipliers) before applying any multiplier credits. The intention is to ensure continuity in manufacturers' commitments to increasing sales of ZEVs year over year. Strict rules also apply to the order in which credits are applied.[7]

Similar to the U.S., the initial 2019 EU HDV CO2 standards both define and determine credits for zero- and low-emission vehicles (ZLEVs). ZLEVs are defined as those that emit less than half of the average of their vehicle (VECTO) sub-group. Regulated entities are allow to double-count the CO_2 emission savings of ZLEVs (in g CO_2/tkm), up to 2025, effectively applying a credit multiplier of up to 2 for ZLEVs) Contributions toward CO_2 targets from zero-emission vehicle sales beyond the categories of vehicles that are directly regulated (e.g. lorries with less than 16 t of maximum permissible maximum laden mass) were also enabled under the EU's initial (2019) HDV CO2 standards. The CO_2 emission savings (in g CO_2/tkm) that ZLEV could generate were capped at 3%, remaining open (up to 1.5%) to contributions from zero-emission heavy duty vehicles beyond those directly regulated. The 2019 standards also set a 2% minimum benchmark of ZLEV sales for the period 2025-2030 under which the super-credit would not apply.

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[7] The Phase 3 program requires manufacturers to prioritize the use of credits to address any credit shortfalls in the averaging set in the following order: 1) base credits banked or traded within the same averaging set; 2) base credits earned in the same model year from other averaging sets; 3) base credits banked or traded in other averaging sets; 4) multiplier credits within the same averaging set for the same model year; 5) multiplier credits banked or traded with the same averaging set; 6) multiplier credits in the same year from other averaging sets; and 7) multiplier credits banked or traded in other averaging sets.

In the 2024 updated CO_2 standards, limit values on specific energy intensity for ZLEVs were redefined to allow mono-fuel and dual-fuel hydrogen combustion engines to qualify as zero-emission heavy-duty vehicles. Trailers equipped with a device that actively supports their propulsion without an internal combustion engine or with an internal combustion engine and that emit less than 1 g CO_2/kWh also qualify as ZEVs, including for ZEV trading, even if trailers cannot report their emissions as 0 g CO_2/tkm.

3.5 Strict penalties act as a deterrent to allow manufacturers to continue producing vehicles that will earn deficits instead of credits

The USEPA requires manufacturers to comply to the regulations and takes a multi-pronged approach to monitor compliance by the manufacturers, failing which, the manufacturer may be liable to pay penalty as prescribed under the Clean Air Act civil penalties (fines) and/or injunctive relief (remediation) up to $45,268 per noncompliant vehicle or engine. Similarly, the EU commission can fine manufacturers on per vehicle penalty of €4,250 for each gCO_2/t-km of excess emissions from 2025 onward. It has also increased penalty of €6,800 per gCO2/t-km from 2030 onwards was dropped in the amended regulation.

Similarly, the European Union applies a single non-compliance penalty of 4250 EUR/g CO_2/tkm. This marks a revision of the Regulation (EU) 2019/1242, which defined different penalties before and after 2030, setting them at 4250 EUR/g CO_2/tkm for years before 2030, and 6800 EUR/g CO_2/tkm beyond 2030. More broadly, 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 CO_2/tkm target (Mulholland, 2024).

Table 2: Comparison of credit accrual and compliance mechanism of the U.S. Phase 3 standard and the EU CO_2 standard for HDVs

Key Elements	US Phase 3 GHG emission standards	EU CO_2 standard for HDVs
Credit multipliers for advanced technologies	Credits through MY 2027-32 for PHEVs (3.5), BEVs (4.5), and FCEVs (5.5) Accrual of multiplier credits ends after MY 2027; use restricted to MY 2027-2029, and then phased out in MY 2030	ZLEVs (defined as having specific emissions in g CO_2/tkm or pkm at half of their sub-group average, or lower) are awarded credit multipliers ranging from 1 (for 50% reduction), to 2 (for ZEVs), with a linear scale for credits in between.
Credit averaging	Allows transitional flexibility to use credits across averaging sets for MY 2027-32, and phased out thereafter.	Averaging is based on the sub-group specific mileage and payload factors, meaning that vehicles that provide greater useful service (e.g. long-haul trucks) have far higher weighting factors than vehicles with lower payload and mileage.
Credit banking and deficits	Credits may be carried over for 5 years; deficits must be balanced within 3 years	Manufacturers can bank credits; Credits or debts may not be carried over for 5 years.

Credit trading	Manufacturers may purchase credits from other manufacturers	The 2024 standards update allows for trading of emissions under certain conditions (e.g. a 5% cap on trading of ZLEV credits).
Reporting and data transparency	Manufacturers submit annual reports through EPA's Engines and Vehicles Compliance and Certification Information System (EV-CIS). Summaries of overall market compliance are reported by the EPA.	Manufacturers report CO_2 emissions and fuel consumption data for each new HDV sold to EU Commission and the EEA, which then makes publicly available detailed testing and certification results as per VECTO modelling.
Compliance process	Pre-production certification requires manufacturers to submit applications to the EPA with emissions and fuel economy data before a vehicle or engine can be sold. These reports are routinely reviewed. EPA also conducts conformity of production testing and enforcement audits	Manufacturers must report CO_2 emissions and fuel consumption data, as determined by VECTO, for each new HDV sold in the EU. The EU conducts audits to verify reported data. Regulations establish the procedure for type approval and market surveillance of HDVs, trailers, and components, including for Euro 7 pollutant emission tests and limits and battery durability requirements.
Penalties for non-compliance	Clean Air Act civil penalties (fines) and/or injunctive relief (remediation); EPA can fine up to $45,268 per noncompliant vehicle or engine.	EU commission can fine manufacturers on per vehicle penalty of €4,250 for each gCO2/t-km of excess emissions from 2025 onward. An increased penalty of €6,800 per gCO2/t-km from 2030 onwards was dropped in the amended regulation.

4. Pathways for India

Fuel economy and CO_2 emission standards are typically designed primarily as technology neutral standards that mandate minimum performance thresholds for market eligibility (e.g. maximum specific fuel consumption or tailpipe CO_2 emissions in per vehicle- or tonne-kilometre). However, credits for zero-emission powertrains, which allow manufacturers to apply multipliers for each ZET manufactured or sold, are a common design feature built into standards to incentivize the initial adoption of ZETs. Such credits present risks, including potentially reducing the stringency of standards, if the volume of credits is too high, and of limiting incentives for ZET adoption if the credit multiplier is insufficient.[8]

Considering these risks, we advise to not adopt credit multipliers higher than 5, and, considering the prospects for battery electric trucks across many segments to achieve parity with conventional ICE trucks within the 2030s, to rapidly ramp down and phase out multipliers by the final year of the standard (i.e. in the early 2030s). Further description of the credit system proposed is provided in the section "Development of Baseline and Ambitious fuel consumption standards" below.

4.1 Benchmarking a stock-accounting model of India's N2 and N3 trucks

Like global markets, medium and heavy-duty commercial goods vehicles in India can be grouped into gross vehicle weight (GVW) of (3.5T to 12T) and (12T to 55T) referred to as N2 and N3 category respectively as prescribed under the MV Act, Ministry of Road Transport and Highways (MoRTH). These can be further classified further on the basis of granular GVW compositions, axle configuration and mileage. For the study we have considered 14 MHDV sub-classes.

Historical sales data for the primary categories, N2 (medium duty) and N3 (heavy-duty), were sourced from the Vahan dashboard (Vahan, n.d.), provided by MoRTH, spanning the financial years 2002 to 2025 (Figure 3). We subdivided the N2 and N3 categories further based on GVW using data from the Society of Indian Automobile Manufacturers (SIAM) database (SIAM, 2025). For N3 trucks, adjustments were made to address discrepancies between the SIAM and MoRTH classifications that align with MoRTH classification.

[8] A more economically efficient and effective alternative is to develop separate regulatory instruments. In addition to the fuel economy / CO_2 emissions standards under consideration by the MEMR, a ZET sales requirement could serve as a complementary or parallel regulatory approach. This measure would mandate that OEMs gradually increase the share of ZETs produced and sold over time. This approach is likely to offer a pathway that can be developed more quickly and with less administrative burden.

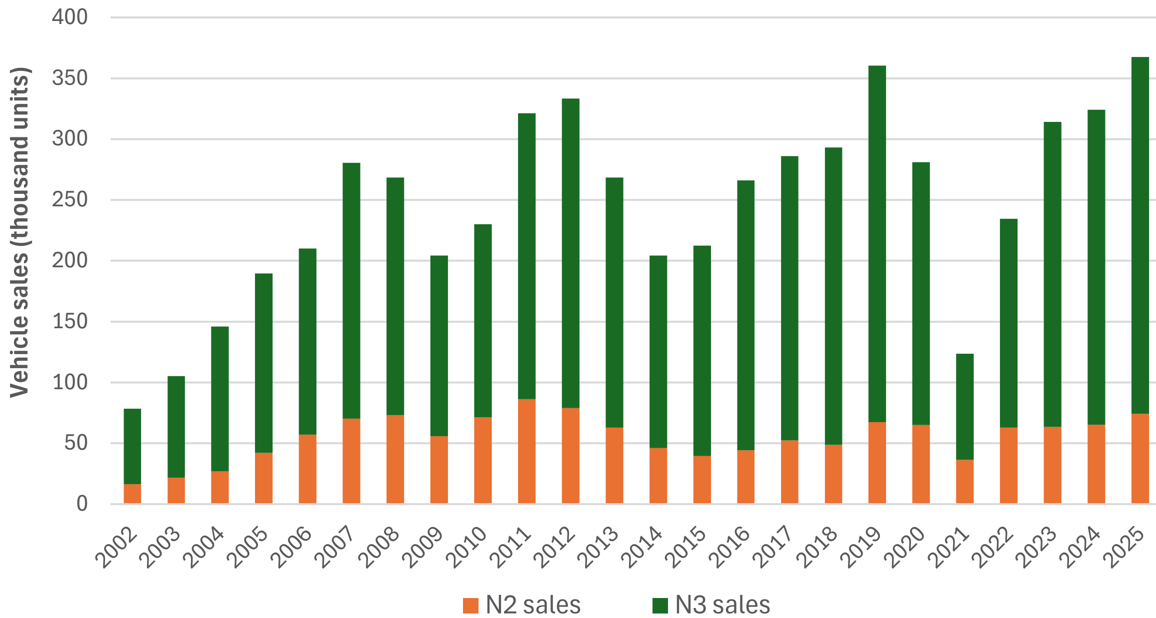


Figure 3: Annual MHDV sales in India (FY 2002–FY 2025)

Baseline assumptions for fuel consumption were draw upon ICCT simulation modelling of the best-selling models in each of 5 vehicle segments (ICCT,2023), for the remaining nine segments, we referred to various commercial sites and literature (Shakti, 2014) and applied general approximations. We adopted a Weibull probability distribution model to develop age-based survival curves to estimate vehicle scrappage, with parameters taken from an extensive study on on-road vehicle operations from 1993 to 2018 (Guttikunda, 2024). This enabled an estimate of the on-road stock from 2010 to present (Figure 4 and Figure 5).

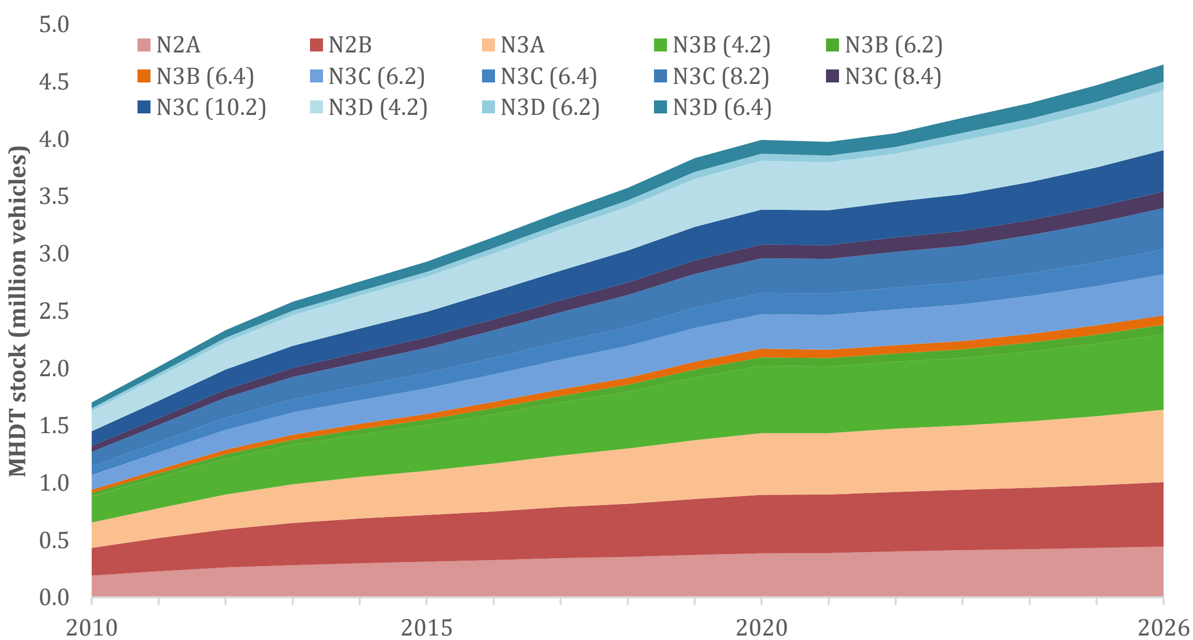


Figure 4: Evolution of the MHDV stock in India across sub-segments of N2 and N3 classes, 2010-2026

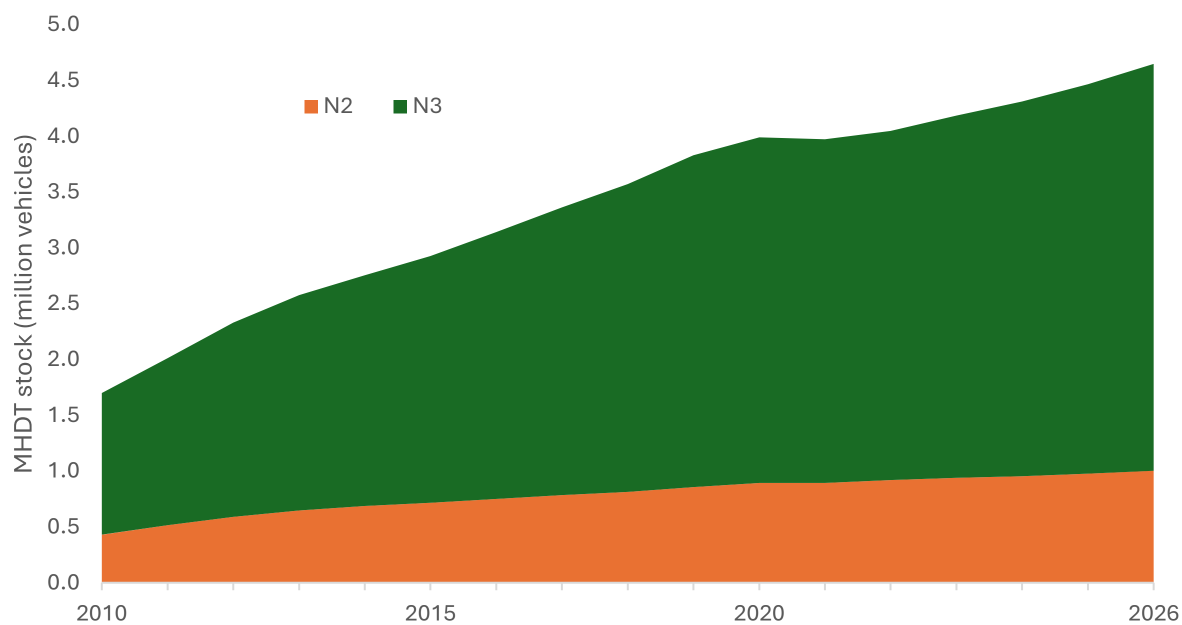


Figure 5: Evolution of the MHDV stock in India for N2 and N3 classes, 2010-2026

Vehicle mileage, including initial mileage and annual decay, was modelled using an exponential decay function from LBNL (LBNL, 2021). Initial (first year) mileage for various segments was estimated based on daily driving distance from 100-350 km per day (depending on segment). For vehicles sold between FY2016 and FY2025, we assume that vehicles operate 240 days a year. For vehicles sold before 2015, a lower initial mileage estimate was used, based on insights from relevant literature (Mukherjee and Rao, 2015; MoRTH, n.d.).

These inputs were used to develop a stock-accounting model for each vehicle segment. Annual fuel consumption for each of the 14 vehicle segments was calculated by integrating data on yearly stock (based on the survival function), estimated mileage (based on the mileage decay function), and baseline fuel consumption, thereby producing fleet-wide annual estimates of fuel use.

India publishes national statistics for annual diesel consumption (PPAC, 2025). The end-use share of diesel was reported to be 28.25% for trucks including heavy and light commercial vehicles in 2013 (Nielsen, 2013). The share of diesel consumption by trucks almost doubled to 55.4% by 2021 (CRISIL, 2021). The fleet-wide annual estimates of fuel use for 14 vehicle segments were calibrated with the reported diesel consumption share by trucks. N2 and N3's consumption share is estimated to be 7% and 93% for 2024 based on vehicle stock, mileage and fuel consumption. The national estimates for 2014-2018 were derived by linear interpolation.

On comparing both the estimates, the reported diesel consumption is on an average 16% higher than the fleet-wide consumption estimates for the last five years (2020-2024), as shown in the left-hand side of Figure 6. The higher reported consumption could be attributed to LCVs which have been not considered in this analysis. We matched projected sales growth to official tonne-kilometres projections from Niti Aayog (2022), as shown in Figure 6 and Figure 7.

Sales shares were assumed to remain constant based on the average sales shares for each of the 14 segments, over the past 13 or 5 years, for N2 and N3 trucks, respectively, as shown in Table 3.

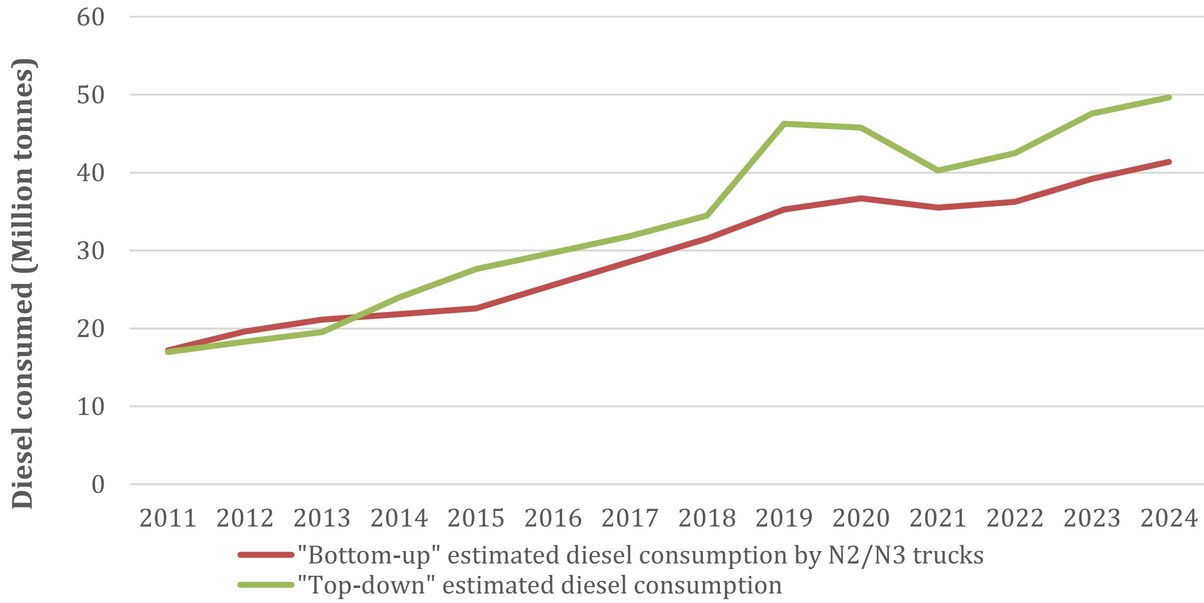


Figure 6: Calibration: diesel consumed by N2/N3 trucks, 2011-2024

Note: "Top-down" estimates are based on total domestic diesel consumption and sectoral shares thereof, as reported by the Petroleum Planning and Analysis Cell of the Ministry of Petroleum & Natural Gas (PPAC, 2013; 2021). Estimates for trucks include LCVs (< 3.5 tonnes GVW), which are not considered in this analysis, as they are in the light-duty segment and hence are not covered by MHDT fuel consumption standards. Top-down estimates for 2014-2018 are linearly interpolated.

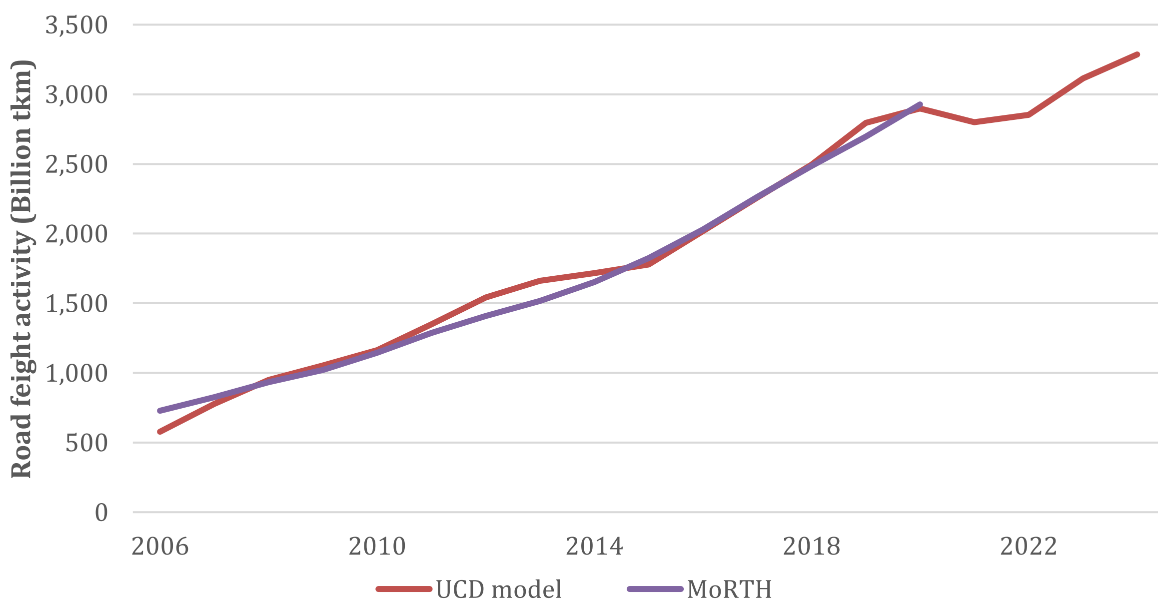


Figure 7: Calibration: tonne-kilometres by N2/N3 trucks, 2006-2022

Table 3: Medium- and heavy-duty truck segments, estimated baseline fuel consumption, and average market share over 2011-23 within the N2 and N3 categories

Vehicle category	GVW	Axle config.	Top-selling model in recent years	Fuel consumption [FC] (l/100 km)	FC source	Sales share	FC share (2024)	Initial mileage (km/yr)
N2A	>3.5 - <7.5	4x2	Tata 712	14.0	Shakti, 2014	19%	2%	24,000
N2B	7.5 - <12	4x2	Tata 1212	16.7	ICCT, 2023	24%	5%	52,000
N3A	12 - <16.2	4x2	Ashok Leyland 1615	18	ICCT, 2023	10%	9%	72,000
N3B	16.2 - <25	4x2		18	–	10%	9%	72,000
		6x2		26	–	1%	1%	72,000
		6x4		27.9	Shakti, 2014	1%	2%	72,000
N3C	25 - <49	6x2	Tata 2818	34.9	ICCT, 2023	6%	11%	84,000
		6x4	Tata Signa 2823	34.9	Truck Junction	3%	7%	84,000
		8×2	Tata Signa 3525	30	Tucks Dekho	6%	11%	84,000
		8×4	Tata Prima 3530.K	36	Truck Junction	2%	5%	84,000
		10×2	Ashok Leyland 4220- 5.7TD HM 10x2	36	ICCT, 2023	6%	11%	84,000
N3D	31 - 55	4x2		40	–	8%	18%	84,000
		6x2		45	–	1%	3%	84,000
		6x4	Ashok Leyland 5525	53.8	ICCT, 2023	2%	7%	84,000

As shown in Figure 6, the estimated diesel consumed by N2/N3 trucks is broadly in line with reported official estimates. The gap between the 'bottom-up" estimates derived by the process outlined above and the "top-down" official estimates increasing from around 7% in 2014 to 22% in 2019 and then stabilizing at around 10%-15% from 2020 onwards. The remaining gap is likely attributable, at least in part, to the fact that the official estimates include diesel consumed by N1 trucks (< 3.5 tonnes GVW), which are not considered here.

5. Development of Baseline and Ambitious fuel consumption standards

The study considered two scenarios of fuel consumption standards to estimate the potential costs and benefits of standards differing in their level of stringency and the speed of adoption.

Both modelled fuel consumption emissions standards scenarios (baseline and ambitious), take effect in calendar year 2028, and require linear improvements in fuel efficiency for each of the 14 modelled segments through calendar year 2033.

For both the fuel consumption standards scenarios summarised below, we considered a credit mechanism based on previous research by the UC Davis India ZEV Research Centre focusing on a sales credit mechanism for trucks. As long as a credit system is conceived with a clear phase-out schedule, incorporating it into fuel economy standards can help to accelerate market adoption of battery electric trucks, while reducing the fiscal burden on governments as compared with subsidy or incentives schemes. The proposed credit scheme, shown in Table 4, is inspired by the weight-based multipliers and credit trading mechanism among segments in California's Advanced Clean Trucks (ACT) rule.

Table 4: Proposed credit scheme for battery electric trucks in the Indian fuel economy standards

Description	GVW range (tonnes)	Annual credit multiplier					
		2028	2029	2030	2031	2032	2033
N1	GVW < 3.5	2	1.5	1	1	1	1
N2A	3.5 ≤ 7.5	3.5	3	2.5	2	1.5	1
N2B	7.5 ≤ 12	3.5	3	2.5	2	1.5	1
N3 2 axle rigid	12 ≤ 16.2	4	3.5	3	2.5	2	1
N3 Multi axle rigid	16.2 ≤ 25	5	4	3.5	3	2	1
N3 Multi axle rigid and Tractor trailer	GVW > 25	5	4	3.5	3	2	1

The proposed credit system would allow credit trading among manufacturers, and across all segments based on the multipliers shown in the 'weight credit' column. We propose to apply similar restrictions on credit trading in the N3 segment to the ACT: i.e. credits generated in the N2 and N1 segments would be tradable only across these two segments, and not eligible for use in the N3 segment. Banking of credits could be allowed over a set number of years, and potential subject to an 'interest rate', as has been done in the United Kingdom's ZEV sales mandate.

Since the proposed credit scheme, in contrast to the ACT, would not be a ZEV sales requirement, we propose to phase out credit multipliers over the period of the regulation from 2028-2033. Projections of battery electric truck adoption incorporate the expected impact of both the baseline and adopted standards consider this proposed credit mechanism.

5.1 Standard stringency determination

The stringency of the ***baseline fuel consumption standards***, in terms of the reduction in specific fuel consumption (in litres/km) by vehicle segment, is based on technology package 3 of the ICCT assessment of the technology potential and costs of fuel efficiency technologies in India's MHDT segments (ICCT, 2023). All the efficiency technologies incorporated into this package are commercially available on global MHDT markets. In this technology package, fuel consumption reductions, expressed in litres/100 km, range from 15% to 36% across the five truck segments modelled, and payback periods range from around 2.5 to 7 years. For the remaining nine truck segments, stringency is estimated based on the relative stringency of India's notified fuel economy norms for heavy-duty vehicles, as notified in 2017, amended in 2020 and 2022, and implemented in April 2022 (BEE, 2017; 2020; 2022). The resulting stringency ranges from an improvement of only 15% in the cases of the N3C - 8x2 and the N3D - 4x2 segments, up to 36% in the case of the N2B - 6x2 and 6x4 segments (Figure 8 and Figure 9).

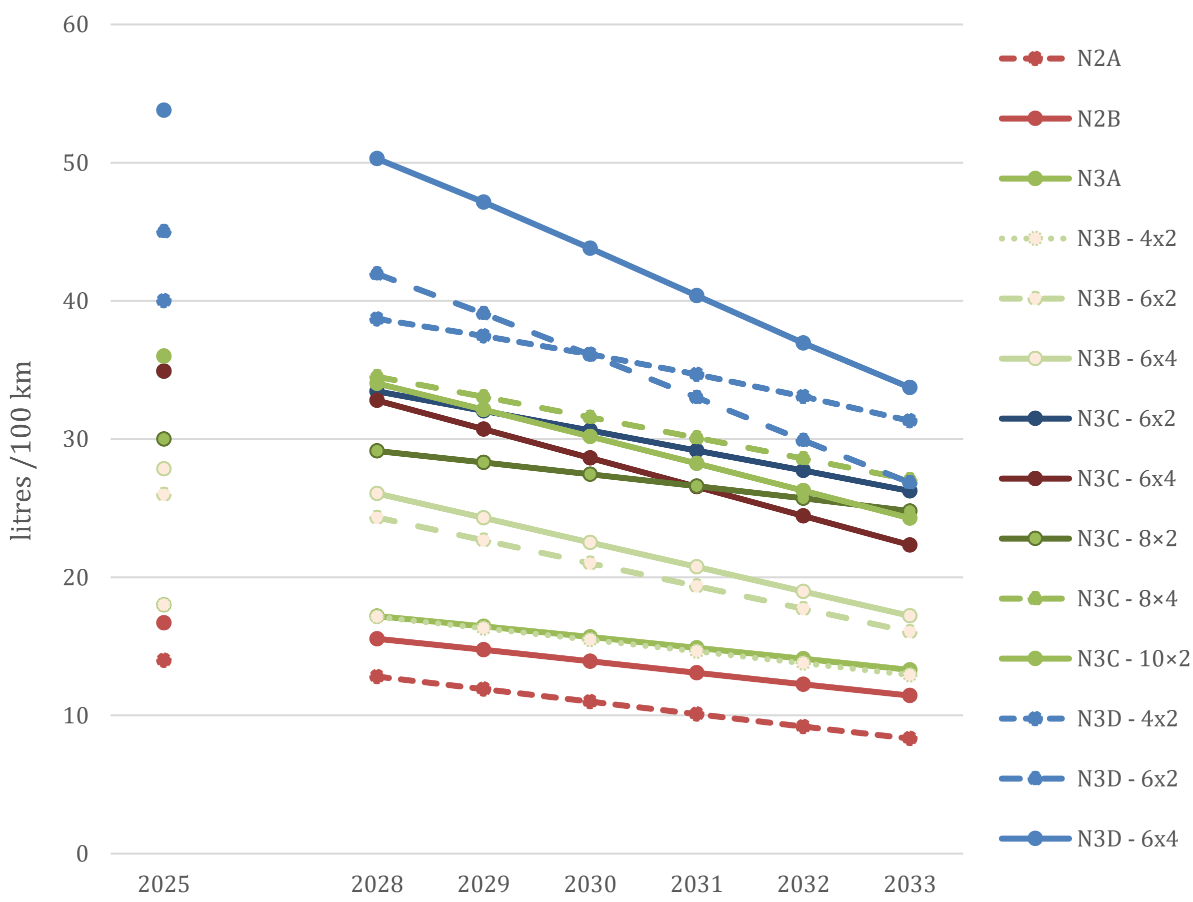


Figure 8. Baseline fuel consumption standards for MHDTs in litres/100 km

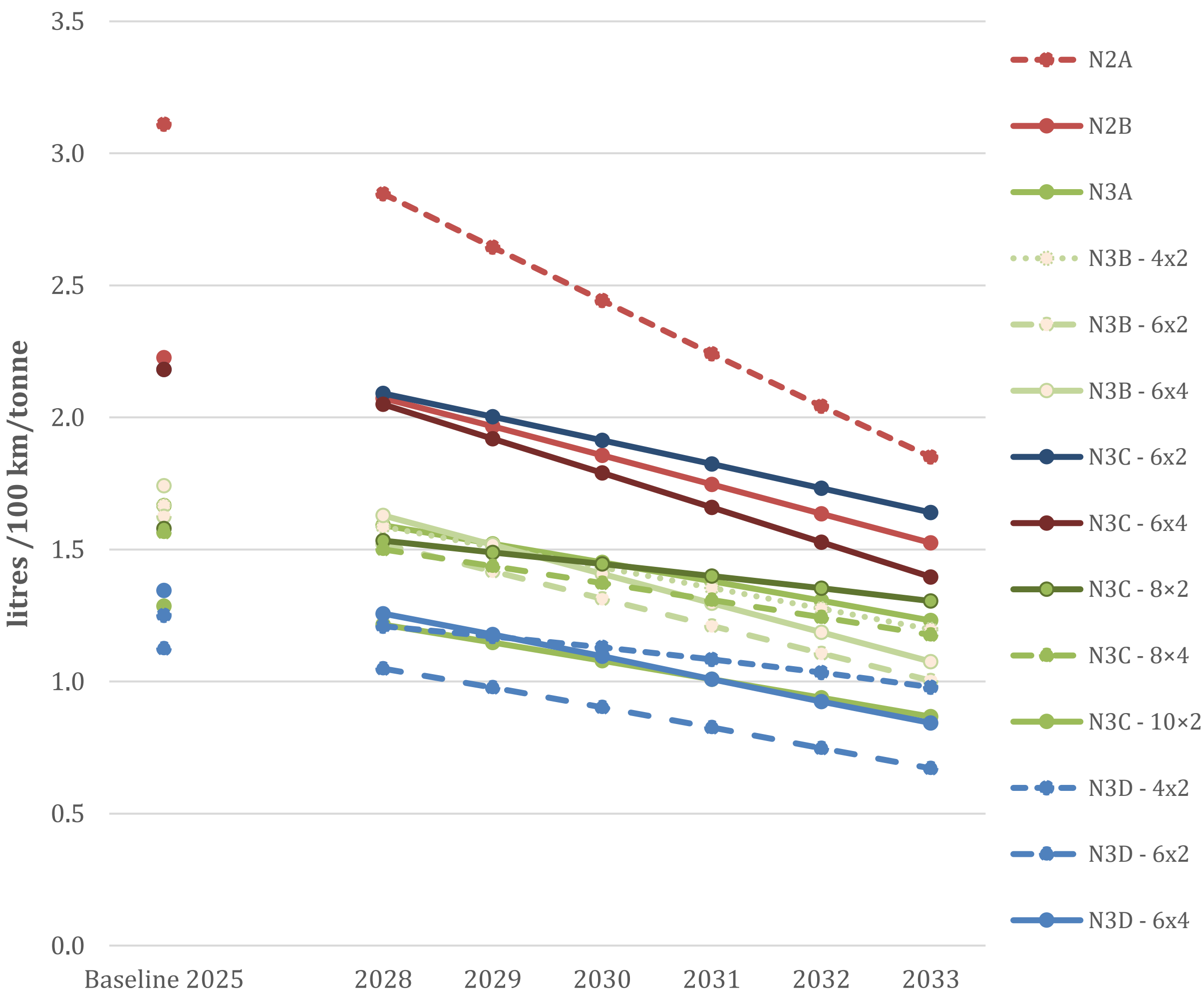


Figure 9. Baseline fuel consumption standards for MHDTs in litres/100 km/tonne (right)

Notes: Segments are defined by their initial N2/N3 segments (based on gross vehicle weight [GVW] bins of 3.5-12 tonnes for N2, and > 12 tonnes for N3), and then by the axle configuration. Benchmark fuel consumption is based on estimates of real-world fuel consumption at representative payloads, based on fuel consumption as estimated by ICCT (2023), and, for the remaining nine segments, based on various commercial sites and literature (Shakti, 2014) and applied general approximations.

The stringency of the ***ambitious fuel consumption standards*** is based on technology package 5 of the ICCT technology potential and cost assessment (ICCT, 2023). Technologies in this package are not currently commercialized but could be deployed. In this case, fuel consumption reductions, expressed in litres/100 km, range from 27% to 52% across the five truck segments modelled, and payback periods range from around 5 to 15 years. As in the baseline case, the stringency of standards for the remaining nine truck segments is scaled based on the relative stringency of India's current fuel economy norms for heavy-duty vehicles (BEE, 2017; 2020; 2022). The resulting stringency ranges from an improvement of only 27% in the N3C - 8x2 segment, up to 52% in the case of the N3D - 6x2 segment (Figure 10 and Figure 11).

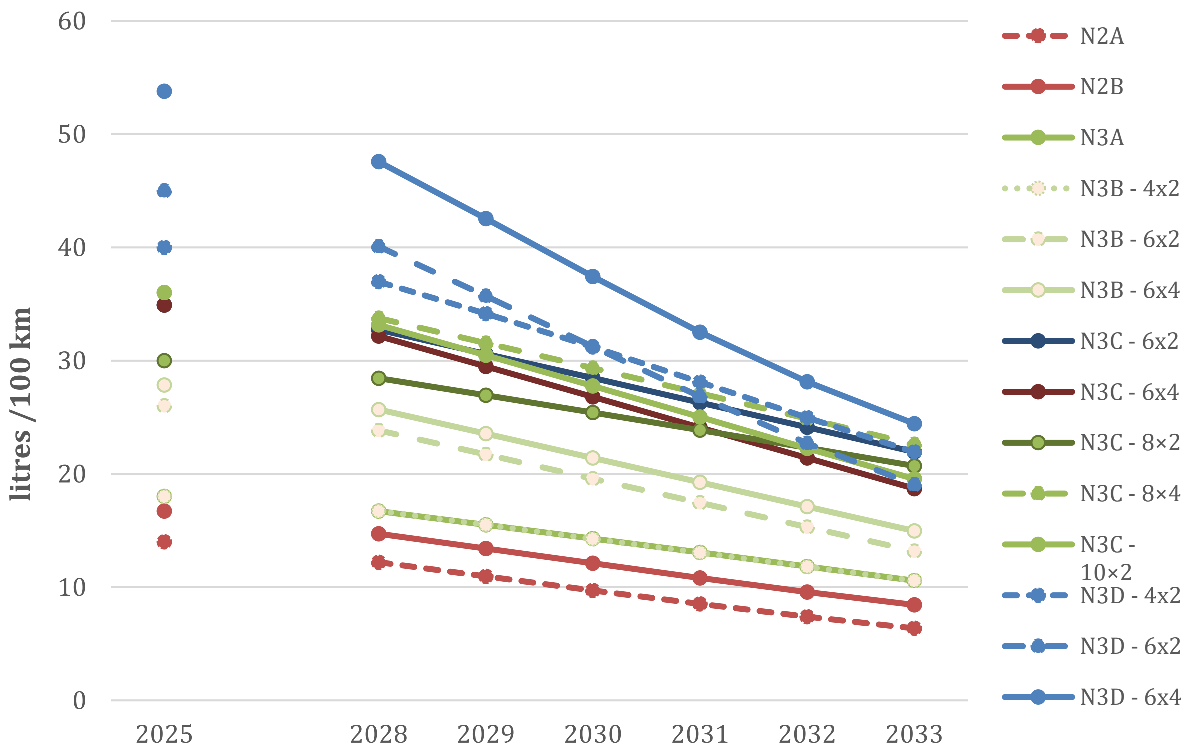


Figure 10: Ambitious fuel consumption standards for MHDTs in litres/100 km

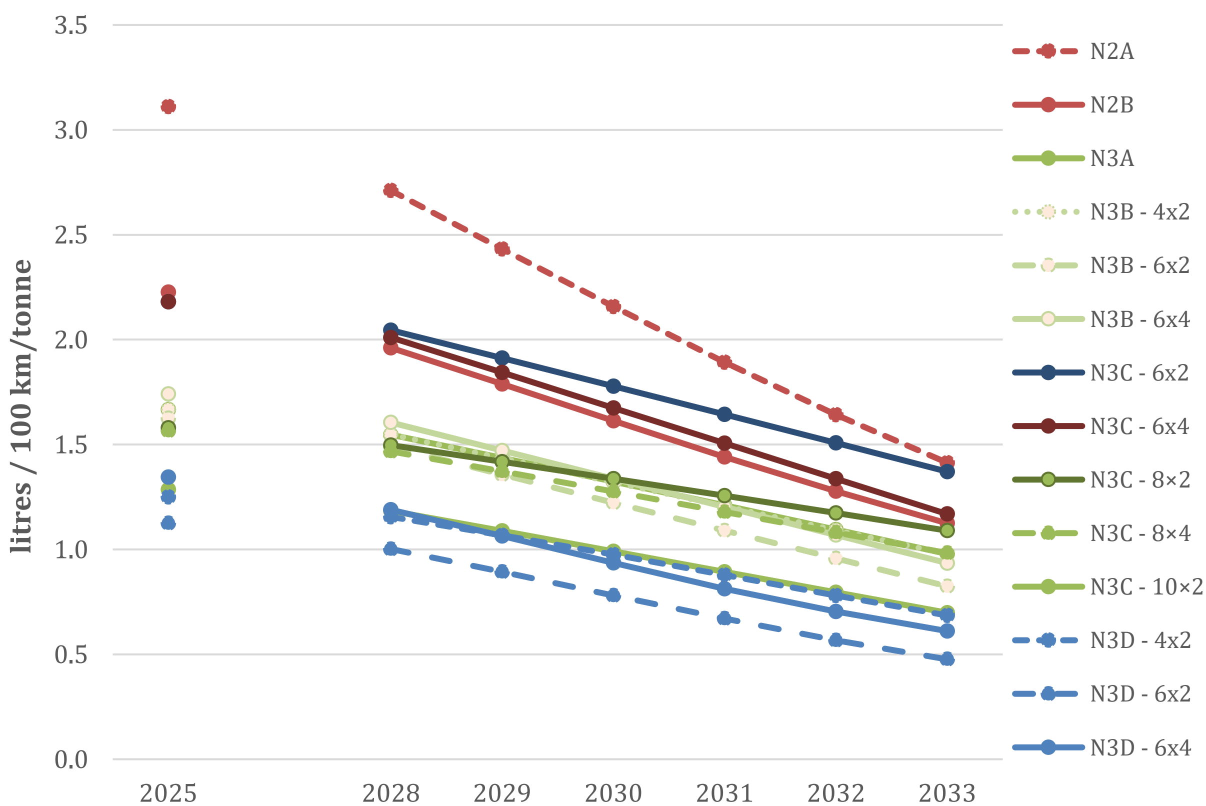


Figure 11: Ambitious fuel consumption standards for MHDTs in litres/100 km/tonne

In the absence of detailed modelling of the ownership structure, capital availability and implicit discount rates, and most common operations and duty-cycles of truck segments, there is a high degree of uncertainty in project electric truck adoption rates.[9] Figure 12 shows the vehicle category-wise fuel consumption reduction for the baseline and ambitious FC standards by 2033, reducing by 29% and 44%, respectively, from the 2025 baseline (without standards).

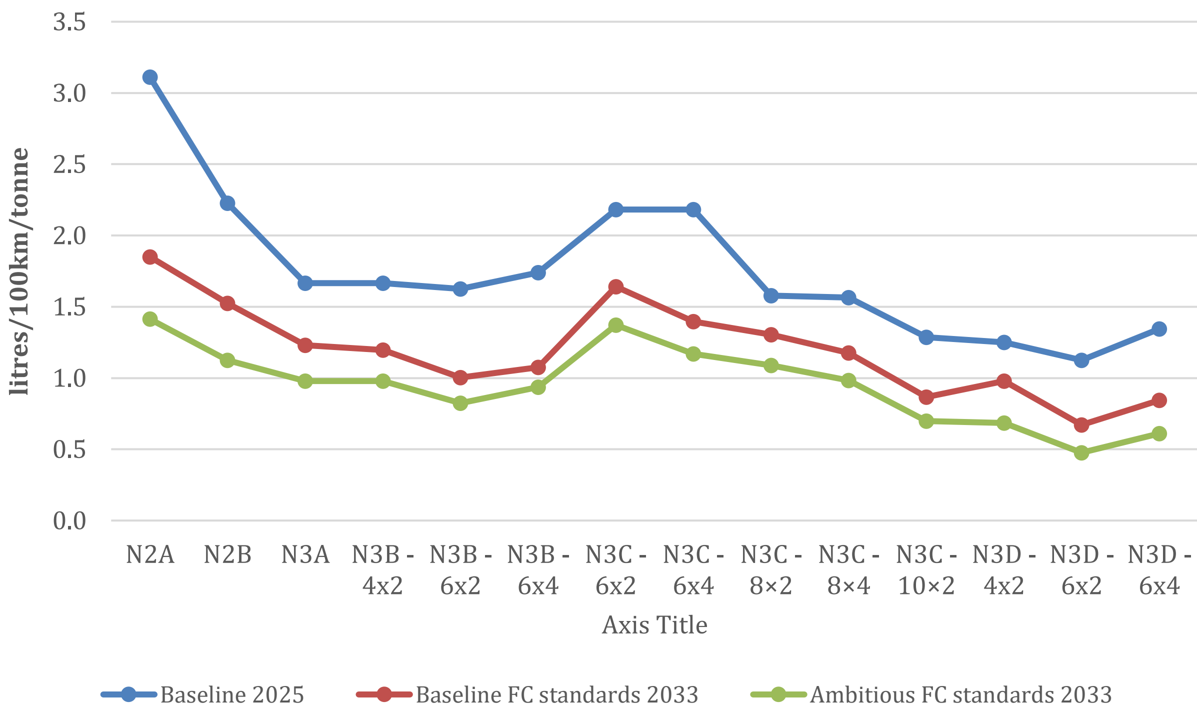


Figure 12: Comparison of 2025 baseline (no standards) and 2033 targets for fuel consumption under baseline and ambitious scenarios

To project BET adoption in each scenario, we use a total cost of ownership (TCO) calculation tool to determine the TCO parity year at which the TCO of BETs trucks breaks even with ICE trucks. These estimates are then used to inform the projected technology transition using s-curves to develop ZET sales projection for India. The TCO calculation is done for five ICE MHDT models, representing each vehicle category except N2A (see Table 5 and Table 6) along with an equivalent BET model in each vehicle category currently available in the Indian market. Table 5 lists the representative ICE and BET models of each vehicle category covered along with the annual mileage considered for the TCO analysis.

[9] Many of these considerations are incorporated into tools that support impact assessments of fuel consumption standards in the United States and the European Union. Examples include the EPA's HD TRUCS tool and NREL's TEMPO model, in the U.S.

Table 5: Representative ICE and BET models used in TCO analysis

Vehicle category	Representative model GVW (tonnes)	Reference ICE model	Reference BET model	Annual mileage (km/yr)
N2B	7.5	Eicher Pro 2059XP	Tata Ultra T.7	60,000
N3A	14	Ashok Leyland Ecomet Star 1415	Ashok Leyland Boss 14T EV	75,600
N3B	19	Eicher Pro 6019	Ashok Leyland Boss 19T EV	75,600
N3C	28	Ashok Leyland 2825 tipper	Olectra Meghaetron Electric tipper	88,200
N3D	55	Tata Prima 5530.S	Montra Electric Rhino 5538EV	88,200

Table 6 lists the technical specifications of the BETs considered for the analysis including battery capacity, range, and fuel economy with payload. Certified ranges are lower than for vehicles of similar GVW and duty cycles in the U.S. / European context, given the high price sensitivity in India, and the lower speeds and shorter daily mileages. The fuel economy (kWh/km) with payload is calculated by applying a factor of 0.9 to the certified vehicle range to adjust for real-world range.

Table 6: Technical specifications of BETs considered for TCO analysis

BET model	Battery capacity (kWh)	Certified Range (km)	Source for battery capacity and range	Fuel economy with payload (kWh/km)
Tata Ultra T.7	65	110	Truck Junction, 2022	0.63
Ashok Leyland Boss 14T EV	202	230	Ashok Leyland, 2024	0.88
Ashok Leyland Boss 19T EV	201	195	Ashok Leyland, 2024	1.15
Olectra Meghaetron Electric tipper	200	150	Olectra, 2023	1.48
IPLT Rhino 5536e	282	185	Montra Electric, 2025	1.55

The TCO tool used for the techno-economic feasibility analysis of ZETs considers over 40 input parameters including vehicle specifications, operational characteristics, vehicle cost, and financing and operational characteristics. The key assumptions and inputs considered for the analysis are described below:

a. Currently, the ex-showroom cost of BETs is about 2-3 times that of an equivalent ICE truck, with a higher multiplier for segments with higher GVW. The ex-showroom price of ICE trucks is taken as an average from truck aggregator websites in India. The cost of ICE trucks is assumed to be constant from MY 2025 to MY 2027, increase from MY 2028 to MY 2033 on account of implementing the baseline fuel consumption standards (see figure 6) and again constant from MY 2033 onwards. The cost increases by 4-11% for MY 2028 and 28-80% for MY 2033 relative to MY 2025. The incremental costs of all the models is based on technology package 3 of the ICCT technology potential and cost assessment (ICCT, 2023).

b. The battery cost is considered as INR 15,120/kWh ($180/kWh) for MY 2025, INR 9,240/kWh ($110/kWh) for MY 2030, and INR 7,560/kWh ($90/kWh) for MY 2035 for BETs. The powertrain costs (including motor, power electronics and battery management system) are considered to decrease by 11%, 16% and 19% in MY 2030, 2035 and 2040 relative to 2025 on account of increased local production and scaling up of the market (ICCT, 2024). The energy intensity of BETs is assumed to be constant for all MYs for the purpose of TCO calculation. Currently, the battery cost constitutes 30-40% of the total ex-showroom price of BETs depending on the GVW category.

c. The fuel economy of ICE trucks is taken from truck aggregator websites. We consider a 30% reduction in fuel economy with full payload relative to no payload driving conditions (DfT, 2007). The energy intensity of BETs is derived as described above (see Table 9).

d. The maintenance cost of an ICE truck is considered 5% of the purchase price (ITF, 2024). As per current market conditions and subsequent consultations, the maintenance cost for BETs is considered 20% higher than ICE trucks for MY 2025. For MY 2030, the maintenance cost of BETs is considered to be the same as ICE trucks. For MY 2035, it is considered 20% lower than ICE trucks as the market is expected to achieve economies of scale.

e. The proportion of debt and equity for purchase of BETs and ICE is considered as 80:20 as per India's market conditions. The interest rate for debt financing is considered as 15% for both ICE trucks and BETs based on stakeholder consultations. A discount rate of 6% is used to calculate the net present value of TCO for each MY.

f. The insurance premium of BETs is assumed 25% higher for BETs than ICE trucks for MYs 2025 and 2030 due to the technological risks built into the premium. However, with expected BET market scale and technological maturity, the insurance premium is considered to reduce linearly, reaching the same as ICE trucks by MY 2035 and remaining the same till MY 2040.

g. The electricity tariff and diesel fuel cost are taken as INR 8/kWh and INR 95/litre for all the MYs due to uncertainty involved in their future projections. The analysis also includes the cost of installation of charging infrastructure at trip origin, varying from INR 1,25,000 – 14,50,000 depending on the battery capacity and fleet size, is included (C40 Cities Finance Facility, 2020). Since, about 80% of India's fleet operators own less than six trucks, a similar fleet size of trucks is considered for estimating charging infrastructure costs (pManifold, 2021).

h. We consider a first vehicle ownership period of 7 years for both types of trucks for each MY. The battery replacement occurs in the 7^{th} year, and an annualised cost is included in capex component of TCO calculation. The annual mileage of trucks is taken as constant over their first operating life.

i. The analysis considers a vehicle residual value of 33% for both BETs and ICE trucks. The battery's residual value is taken as 50% after an operating life of 7 years (ICCT, 2024).

Based on the inputs and assumptions described above, the 7.5T BET model achieves TCO parity in MY 2034 (Figure 13). The BET becomes 4% cheaper to own and operate by 2040 relative to an ICE equivalent model.

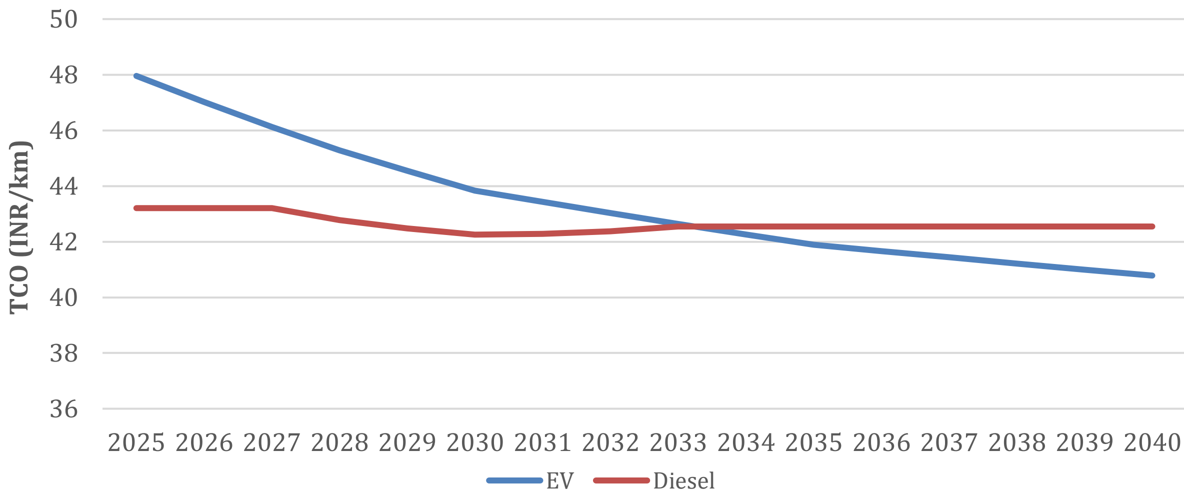
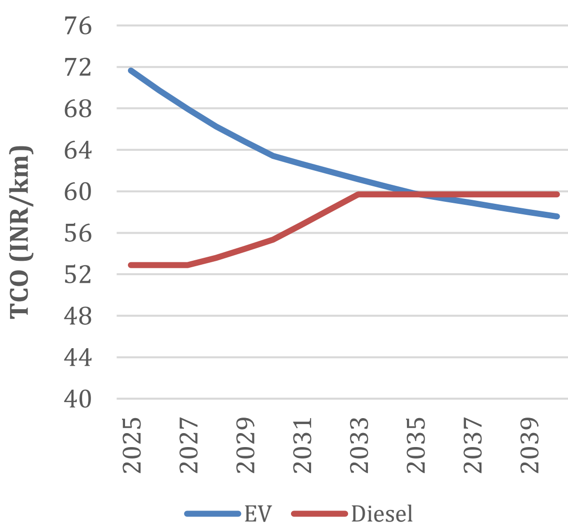


Figure 13: TCO (INR/km) of 7.5T (N2) BET and ICE model

The 14T BET model achieves TCO parity in MY 2036 on account of decreasing BET purchase costs and increasing ICE purchase costs due to improvement in fuel efficiency technologies. It also becomes 4% cheaper to operate by 2040 relative to an ICE model. However, the 19T BET does not achieve TCO parity through year 2040 and remains 14% more expensive than the ICE equivalent (Figure 14 and Figure 15).



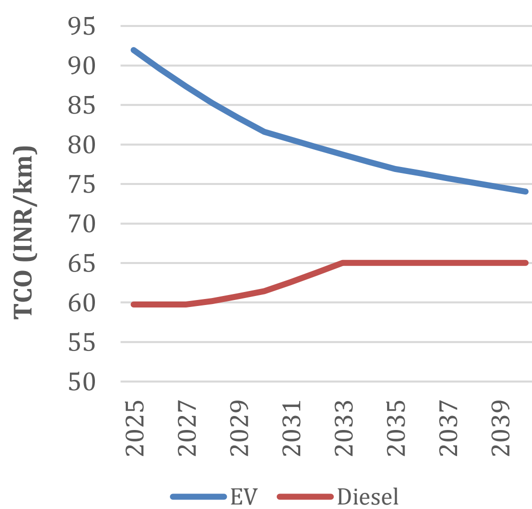
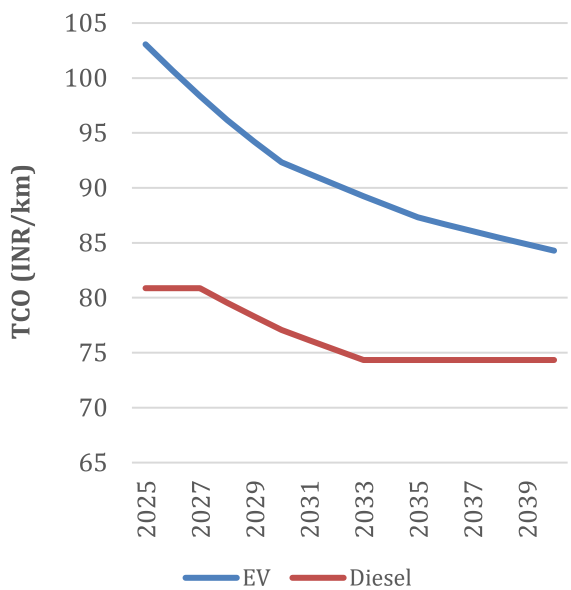


Figure 14: (Left) TCO (INR/km) of 14T (N3A) BET and ICE models

Figure 15: (Right) TCO (INR/km) of 19T (N3B) BET and ICE models

The 28T BET model does not achieve TCO parity with ICE by 2040 and remains 13% more expensive than the comparable ICE truck. However, the 55T tractor trailer BET achieves TCO parity in MY 2036 even with declining TCO of ICE trucks on account of lower operating costs due to improved fuel efficiency (Figure 16 and Figure 17).



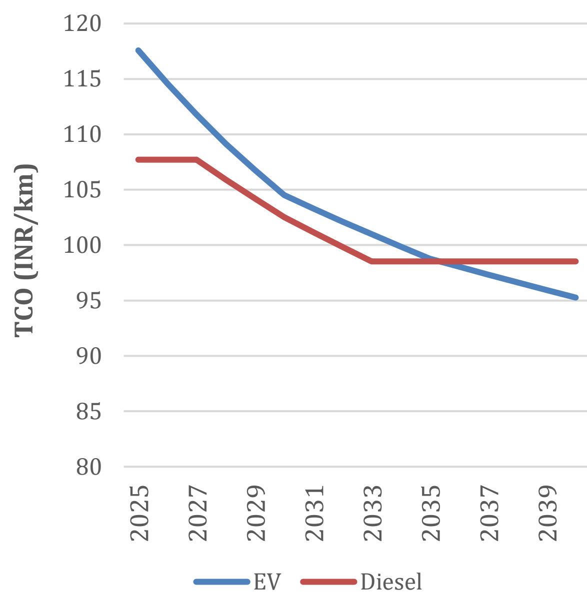


Figure 16: (Left) TCO (INR/km) of 28T (N3C) BET and ICE models

Figure 17: (Right) TCO (INR/km) of 55T (N3D) BET and ICE models

5.2 Comparing this UC Davis analysis with other recent modelling efforts

5.2.1 Historical benchmarking and modelling resolution

The historical benchmarks for MHDT fuel consumption are about 18% lower than those of the ICCT (as reported for a 2022 baseline) and about 25% higher than those estimated by the IEA. In recent years, they range between 15%-20% lower than the total diesel consumption by all trucks (i.e. including N1) as estimated from the Petroleum Planning and Analysis Cell of the Ministry of Petroleum & Natural Gas (PPAC, 2013; 2021). This, together with the bottom-up resolution of our analysis and the very close alignment with tonne-km estimated by MoRTH (MoRTH, 2020), makes us confident that the careful historical benchmarking provides a solid basis for modelling of costs and benefits of fuel consumption standards.

In our *Baseline scenario* reflecting current policies, independent of policy developments and based primarily on continuing reductions in battery costs and other performance improvements (e.g. energy density and calendar life and cycle durability).

Further differences between the results of this study and recent IEA (2023) and ICCT studies (ICCT 2023, 2024), come from the analytical focus of this report (to estimate the impacts of a near-term, ambitious but achievable fuel economy standard), and from our estimate of the potential for such a standard to accelerate and lead to higher BET adoption than the benchmark case.

5.2.2 Projections of battery electric truck market adoption

Figure 18 shows recent projections for zero-emission technology adoption (primarily BETs, with some assumed shares of FCETs) in India's N2 and N3 categories from the IEA (2024), and ICCT (2025). The **baseline / adopted policies** scenarios of both organisations reflect the fact that India's currently adopted HDV fuel economy norms are not sufficiently stringent to drive additional ZET adoption beyond the gradual rates of technology uptake that can be expected based on continuing reductions in battery costs and durability and performance improvements engendered by technology innovation. In the current policy context, therefore, sales shares for MHDTs are expected to remain below 10% through 2035 (interestingly, the ICCT sees potential for the sales share of N2 electric trucks to increase to 25% by 2050, based on technology development alone, while the IEA projects sales shares to remain below 10% through mid-century across both N2 and N3 categories). In the IEA's Announced Pledges Scenario (APS), which incorporates India's policy targets (including net-zero by 2070), ZEV sales shares of N2 trucks reach 35%, and of N3 trucks exceed 50%, by 2050.

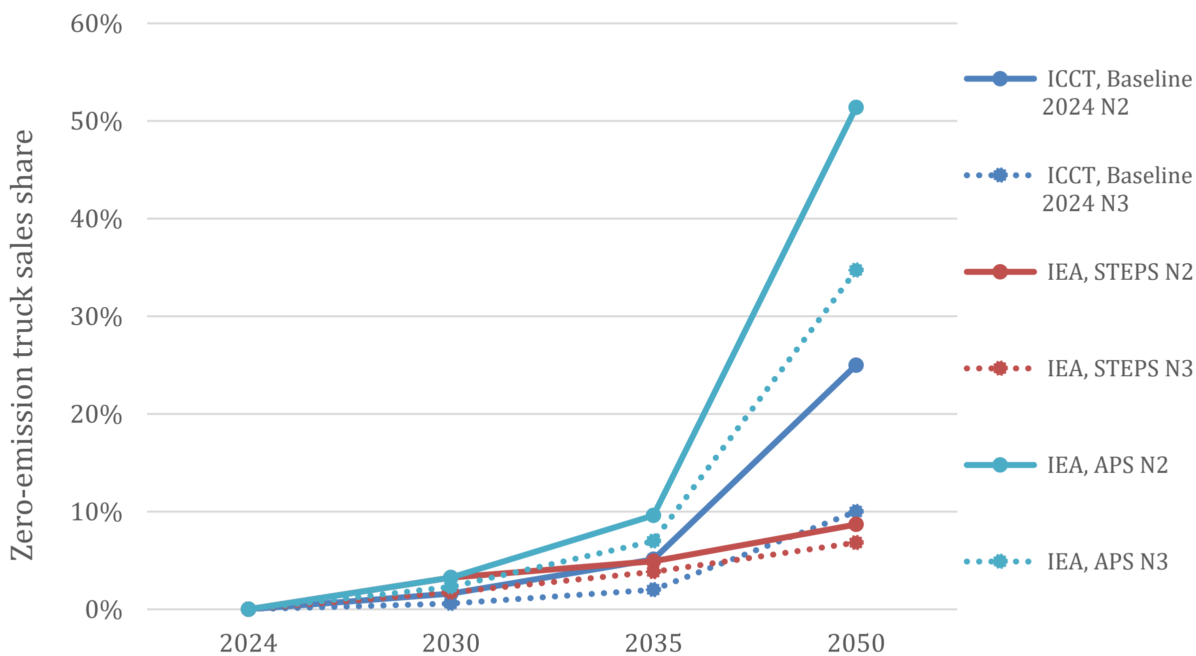


Figure 18: Zero-emission truck sales share projections by the ICCT and IEA

Both the IEA and ICCT expect electric truck adoption in the N2 segment to proceed at a pace that ranges from marginally (25%) to more than twice as fast as in the N3 category. This expectation is predicated on several factors, and reflects the prevailing wisdom encapsulated by the "beachhead strategy" theory of change first formulated by CALSTART (2022). The dynamics supporting this expectation include the fact that heavier trucks generally require greater battery capacity (and hence have a higher differential purchase price), the fact that they are less likely to be able to complete their daily operations by relying solely on depot charging and hence face greater cost and operational barriers around charging. In contrast, lighter-weight trucks performing urban and regional delivery and municipal operations cover high daily mileages (and hence can leverage energy price differentials to achieve faster payback of the purchase price differential of BETs), while, in many cases, having sufficient range to cover daily operations on overnight depot charging alone (potentially supplemented by charging at the site of delivery or during driver breaks).

There are, however, reasons to expect that adoption of electric trucks in the N3 category could outpace that of adoption in N2 trucks in the near-term in India. Electric truck adoption hinges on multiple factors, including:

a. **Lower road speeds and short distances mean that N3 trucks can make due with smaller batteries**, compared with their analogous trucks in the U.S, Europe, or even China. This translates to a lower purchase price premium of BETs in the N3 category, as well as to a higher share of energy provision that is possible through depot charging.

b. **TCO viability** – TCO analysis focusing on India-specific operations, fuel consumption, and costs suggests that certain N3 segments (namely, N3A and N3D) are likely to attain total cost of ownership parity as quickly as N2 due to higher annual mileages, relatively higher incremental cost of efficiency improvement in ICE trucks and smaller batteries (and resulting lower purchase price premium) enabled by lower daily mileages (as compared with other countries).

c. **MHDV ownership** – Ownership data suggests that while big fleet owner (major shipping and logistics companies) hold 20 trucks or more, owned fleet barely meet 15 % of their operations and these operators depend on small fleet operators for 85% of their business operations. As of 2025, E-commerce giants like Amazon, and shippers like Delhivery, Ekart in India are asset light and opt fleet leasing models with small fleet operators.

d. **Capital availability, financing** and **sophistication of logistics and vehicle operations** (including telematics) tend to be higher in large fleets directly owned by shippers (like Great Eastern, and Shipping Corporation of India), carriers (e.g. Transport Corporation of India, DHL, Transvolt), large scale companies such as steel and cement industries. These companies form the organized market for MHDVs with a fleet mix of larger share of N3 trucks above 12 tonnes. This indicates relatively higher availability of capital and higher chances of financing for N3 vehicles owned by them. Existing fleet financing by commercial banks and NBFCs and also benefits large fleet operators while small fleet operators face higher lending rate that hampers its operating costs making it expensive. However, despite owning some fleet, the organised market is dependent on small fleet owners or owner-operators, who contract their services. This dependence retains the challenges of small fleet operators in terms of capital, scale, tech upgradation and sophistication of operations and more.

e. ***Historical sales –*** Historical sales data over last 25 years suggests that for every 1 N2 sold, 4 N3 are sold in Indian market, similar to markets in the US, EU and China. However, unlike Indian market which witnessed EV adoption in the N3 category first, MHDV markets in the US and EU saw witnessed higher sales in the N1 category followed by N2 category. In the global market sales in N3 category is relatively recent, but in the last two years these markets have witnessed progressively higher growth rate in the N3 segment along with introduction of newer models.

f. ***Availability of new models*** - Current e-truck market dynamics suggests that 10 out of 14 models and variants in the e-truck market are N3 variants while only 4 are N2 models. Review with market leaders indicate newer variants under trial are mostly N3 models.

g. ***New market entrants*** – In addition to conventional OEMs, about 4 new OEMs namely IPL tech, Tresa motors, Olectra and Propel have entered the e-truck market in India, in comparison Daimler is the only new entrant in with the e-N2 category. The conventional N2 truck market is dominated by Tata, Ashok Leyland, Volvo Eicher, Mahindra, Force motos and Isuzu in this order and N3 market is dominated by Tata, Ashok Leyland, Volvo Eicher, Mahindra, and Daimler.

h. **E-fast** – In 2023, 15 companies came together to create demand signal for deploying 7,750 electric trucks in India by 2030. The demand signal targeted deploying 3385 N2 and 3450 N3 e-trucks respectively. While the demand signal for both N2 and N3 was equal, as of 2025 we have seen higher traction in the N3 segment with multiple pilots including EV corridor, closed loop operations in the steel and cement industry.

For these reasons, we project somewhat faster initial adoption of electric trucks in the N3 category in the coming few years in comparison to the adoption rates given in both the IEA and ICCT scenarios discussed above. However, changes in policy direction and stronger market signals could drive higher e-truck growth rate in the N2 category, potentially leading to higher e-truck sales than the N3 category.

Projected sales shares at the 14-segment level and condensed to N2/N3 shares are shown in Figure 19 and Figure 20, respectively. These are broadly more optimistic in the both the near-term (i.e. to 2030 and 2035), and in the long term (i.e. to 2050) than both the IEA and ICCT scenario results discussed above. They are, however, less optimistic than projections in the 2023 ICCT assessment, which are predicated on India adopting a ZEV sales requirement in the 2030s.

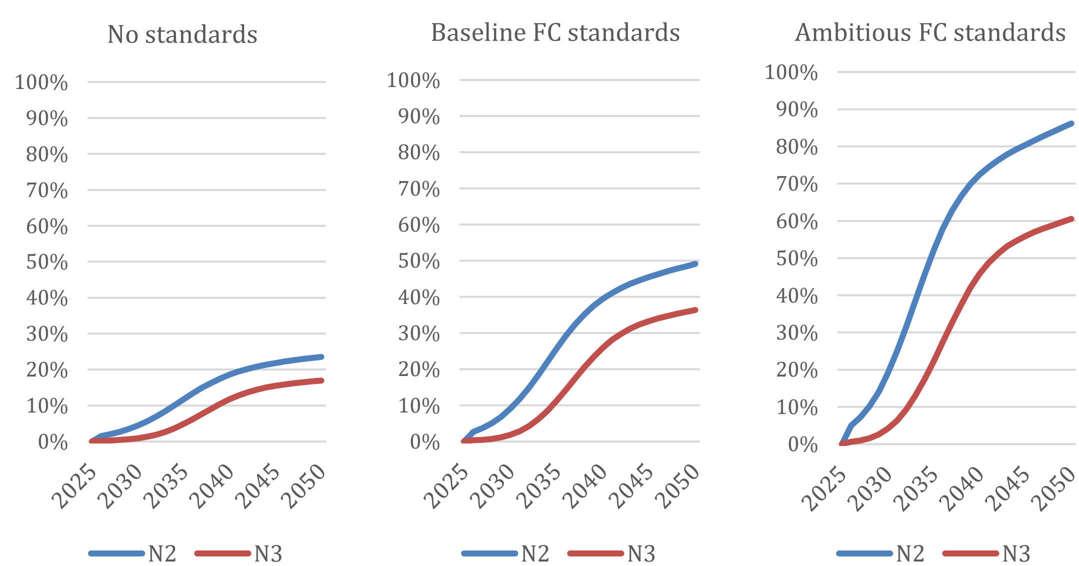


Figure 19: Electric truck adoption at the N2/N3 resolution in the three ITS Davis scenarios

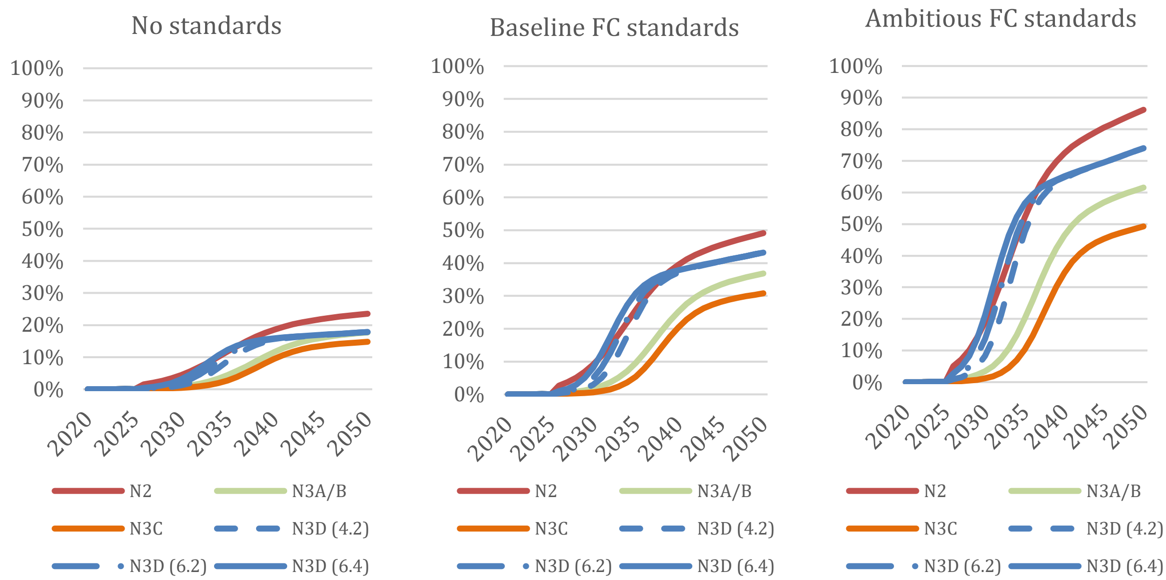


Figure 20: Electric truck adoption at the 14-segment resolution in the three ITS Davis scenarios

Battery electric truck sales shares for N2 and N3 trucks, and for all MHDTs overall, are shown in Table 7. Overall BET adoption in the baseline and ambitious fuel consumption (FC) scenarios can be usefully compared with official projections of zero-emission heavy-duty vehicle adoption projected under the U.S. Phase 3 GHG emissions standards and the EU's CO_2 emission standards for HDVs.

Table 7: Battery electric truck sales shares in the three ITS Davis scenarios

	No standards			Baseline FC scenarios			Ambitious FC scenarios		
	N2	N3	MHDTs	N2	N3	MHDTs	N2	N3	MHDTs
2030	4.5%	0.9%	1.6%	9.1%	1.8%	3.3%	19.0%	4.1%	7.1%
2032	7.0%	1.9%	2.9%	14.9%	4.2%	6.4%	31.6%	9.3%	13.8%
2033	8.5%	2.7%	3.8%	18.3%	6.1%	8.5%	38.4%	13.0%	18.1%
2035	11.8%	4.9%	6.3%	25.7%	11.2%	14.1%	52.1%	22.3%	28.3%
2040	18.6%	11.7%	13.1%	39.5%	26.0%	28.7%	72.4%	45.8%	51.1%

The U.S. EPA projected ZEV sales shares in 2032 to increase to 25% (for long-haul class 8 sleeper trucks) to 60% (for class 2b trucks, which are analogous to LCVs and hence have a lighter GVW than all truck classes considered here). Taking 25% as the lower threshold, and comparing 2032 projections for India, baseline fuel consumption standards are projected to lead to BET adoption in the heaviest segments considerably lower (4.2%), but ambitious standards could lead to N3 penetrations that begin to approach levels incentivized by the U.S. Phase 3 standards (9.3%).

The comparison with the EU projections shows the potential for India to catch-up, and in the 2040s, potentially even surpass battery electric sales shares promoted by world-leading standards. Based on the REPowerEU scenario, ZEV truck sales share rates are projected to increase to 34%-57% by 2040, based on the EU's most recent (2024) CO_2 emission standards for HDVs. These adoption rates are broadly in line with the overall MHDT BET sales shares projected in the baseline fuel consumption standards scenario (28.7%) and the ambitious standards scenario (51%), respectively.

6. Results

Benefits are estimated based on the projected reductions in fuel consumption and direct "tank-to-wheel" CO_2 emissions in the Baseline and Ambitious fuel consumption standard scenarios shown in Figure 21.

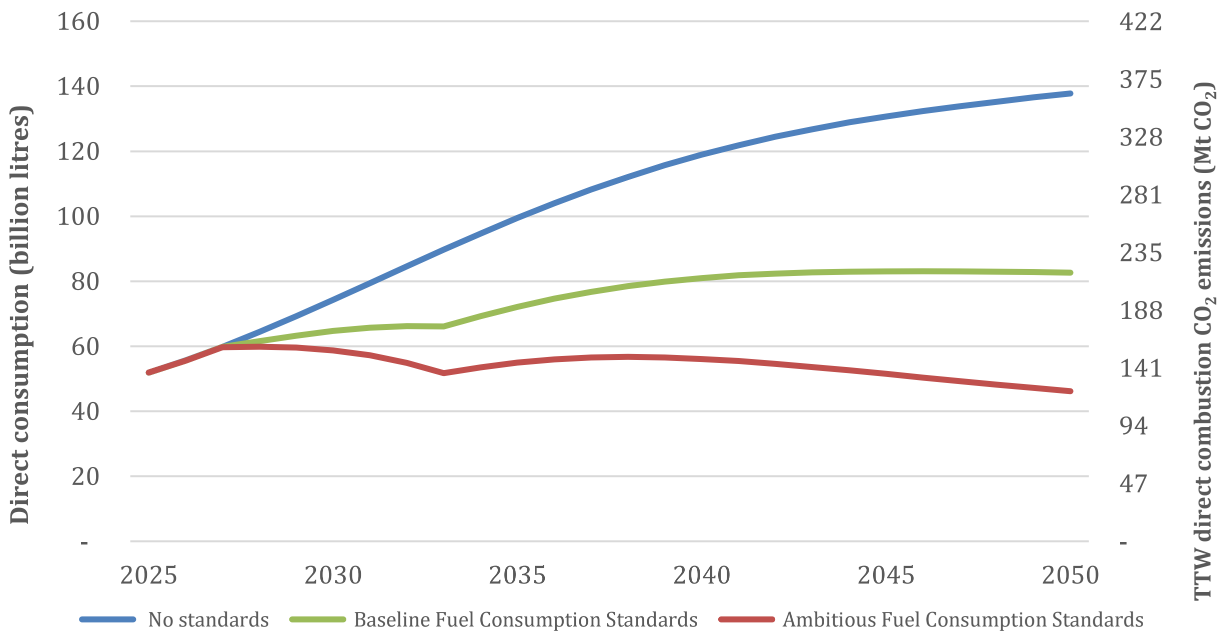


Figure 21: Projected fuel consumption (left axis) and direct tailpipe combustion CO_2 emissions (right axis) in the ITS Davis scenarios

The accelerated shift to BETs in both the *baseline* and *ambitious* fuel consumption (FC) standards scenarios leads to a shift of truck cargo hauled (in tonne-km [tkm]) from diesel ICE trucks to battery electric trucks. The share of tkm hauled by BETs in 2050 increases from 14% as projected in the no-policy case to 31% in the Baseline FC standards, and 53% in the Ambitious FC standards scenario (Figure 22).

Estimating CO_2 emissions on a well-to-wheels (WTW) basis enables an assessment of the CO_2 emissions attributable to electricity consumption by BETs and compares this on a methodologically comparable basis with emissions from diesel ICE trucks. The 'upstream' emissions associated with producing and refining oil to produce diesel (based on well-to-tank emission factors from Cai et al., 2022 and from GREET, 2024), are taken to be constant over time. In contrast, emissions associated with electricity generation are likely to decrease over time, meaning that as more BETs enter the fleet, their specific emissions (in gCO_2/MJ) are likely to decline. Business-as-usual projections carbon intensity of electricity generation under current policies (in the Constrained RE Scenario – or CRES) by TERI (2024) were used to project declines in generation emission intensity. Transmission and distribution losses in India were assumed to decline to shares in advanced economies by 2050, and losses associated with charging were assumed to be a constant 7.5%.

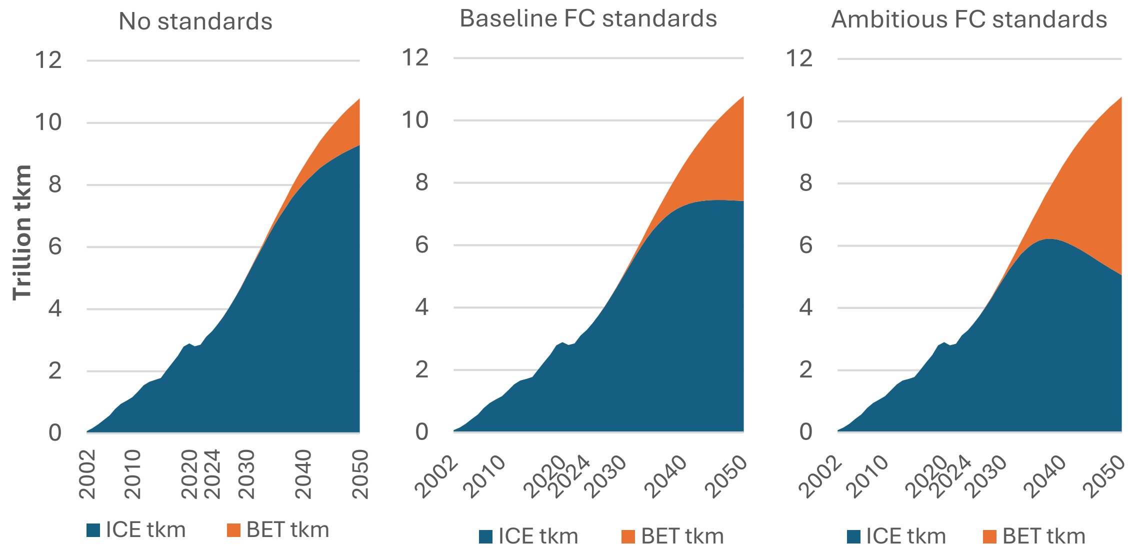


Figure 22: Tonne-kilometres hauled by ICE trucks and battery electric trucks in each scenario

This, plus the fact that some of the vehicle efficiency technologies are powertrain-agnostic (e.g. low rolling resistance tyres, drivetrain/transmission improvements, aerodynamics and light-weighting), means that BETs are set to become more energy efficient over time, albeit with less dynamic improvements than ICE trucks. We assume that 25% of the efficiency improvements spurred by fuel economy standards for trucks apply to BETs.

The resulting estimates of WTW CO_2 emissions are shown in Figure 23. Total WTW emissions in 2050 can be reduced by 33% and 53% respectively, in the baseline and ambitious FC standards scenarios, as compared with the no-policy scenario. The share of electricity emissions depends both on the penetration of BETs and their projected efficiency, as well as the pace of carbon-intensity reductions associated with electricity. BETs contribute only a very small share of total WTW emissions (from 6.8% of cumulative emissions in the baseline FC scenario to 14.1% of emissions in the ambitious FC scenario).

The benefits were monetized to enable a first-order cost benefit analysis. Benefits accruing to vehicle owners/operators, in terms of reduced fuel expenditures, were estimated based on the current diesel price (about 1.08 USD/litre). Benefits associated with CO_2 emission cuts were estimated based on a schedule of social cost of carbon (SCC) estimates that starts at 64 USD/tonne CO_2 in 2020, based on the global average estimate from OECD (2024), grows linearly to 115 USD/tonne CO_2 by 2035, and is assumed to continue to grow at the same linear rate thereafter through 2050.

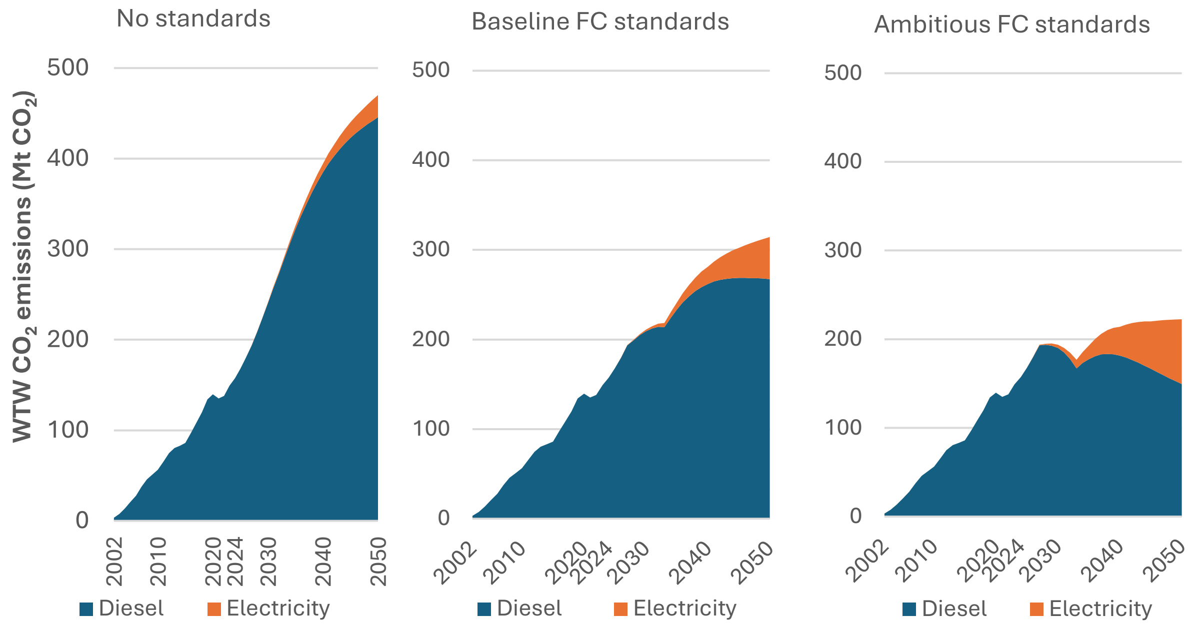


Figure 23: WTW CO_2 emissions by diesel ICE trucks and battery electric trucks in each scenario

Human health and other benefits of reduced tailpipe emissions of air pollutants, which would mainly derive from the adoption of electric trucks, are not estimated, given the complexities in modelling. Table 8 shows the cumulative monetized benefits and costs coming from reduced fuel expenditures and from CO_2 emission cuts through 2050. The projected benefit to cost ratio of the baseline FC standards for the period 2026-2050 is around 16:1, and is lower, but still with unambiguously higher benefits, at 10:1, in the ambitious FC standards.

Table 8: Estimated cumulative benefits and costs, from 2026 through 2050 (billion USD)

	Benefits		Costs	
Fuel consumption standard scenario	Fuel savings (billion USD)	WTW CO_2 cuts (billion USD)	Incremental purchase costs (ICE trucks)	Incremental purchase costs (BETs)
Baseline	838	316	39	34
Ambitious	1,385	502	112	75

Note: estimated benefits are from reduced fuel expenditures and CO_2 emission reductions, and costs estimates include incremental technology costs that are reflected in higher purchase prices of conventional ICE trucks, as well as the incremental costs of additional BETs promoted by the fuel economy standard.

Industrial policy has been at the centre of India's approach to vehicle electrification, especially post-pandemic, since the launch of the Production Linked Incentive schemes focused on shoring EV and cell manufacturing. A stringent fuel efficiency regulation for medium and heavy duty trucks, provides market certainty for the scaled deployment of zero emission trucks, and in turn, for domestic battery demand.

The fuel efficiency regulation alone can derisk and unlock private capital flows to India for indigenizing domestic lithium-ion cell production.

As in Figure 24, India's annual battery demand from zero emission trucks can reach 48 GWh by 2035 in the ambitious fuel efficiency standards scenario, double and five times that of the base case fuel efficiency standards and the no fuel efficiency standards scenarios, respectively.

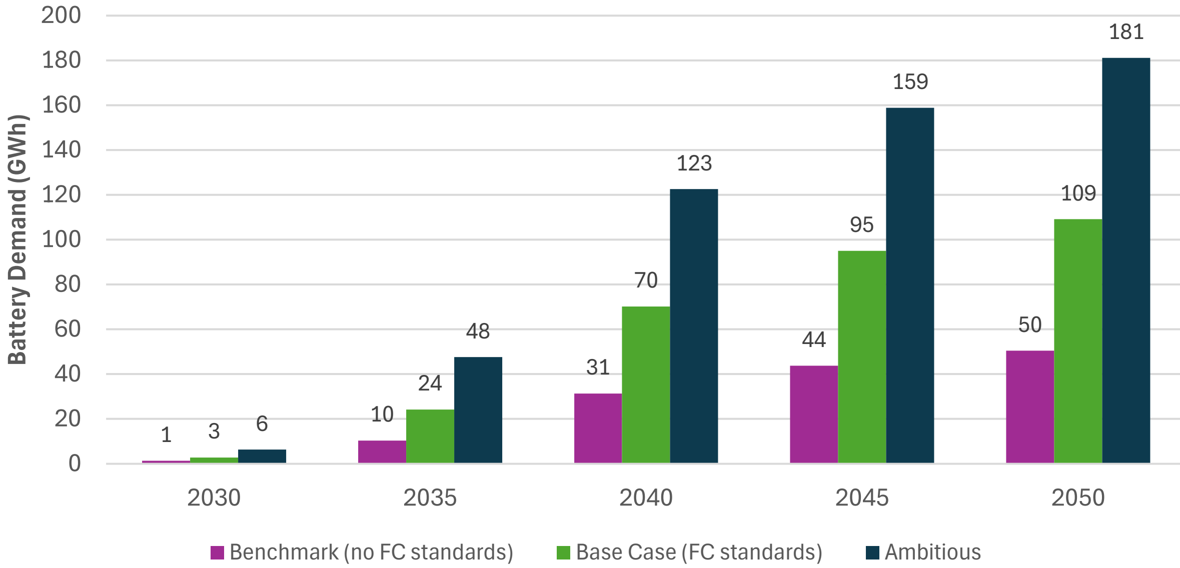


Figure 24: Battery demand (GWh) from zero emission trucks in each scenario

More importantly, as shown in Table 9, the cumulative battery demand by 2035 can reach 146 GWh in the ambitious fuel efficiency standards scenario, and 71 GWh in the base fuel efficiency standards scenario. It is important to note that the no standards scenario will present a risky demand outlook, as there will be no regulatory incentive for the market to transition to zero emission trucks and will leave India's industrial policy outcomes at risk.

Table 9: Estimated cumulative battery demand (GWh) from year of standards implementation

	2028 – 2030	2028 – 2035	2028 – 2040
Base FC Standards	5	71	327
Ambitious FC Standards	12	146	609