Transforming Trucking in India

Pathways to Zero-Emission Truck Deployment

NITI Aayog, RMI | September 2022

About Us

NITI Aayog

The National Institution for Transforming India (NITI Aayog) was formed via a resolution of the Union Cabinet on 1 January 2015. NITI Aayog is the premier policy 'Think Tank' of the Government of India, providing both directional and policy inputs. While designing strategic and long-term policies and programmes for the Government of India, NITI Aayog also provides relevant technical advice to the Centre and States. The Government of India, in keeping with its reform agenda, constituted NITI Aayog to replace the Planning Commission instituted in 1950. This was done in order to better serve the needs and aspirations of the people of India. An important evolutionary change from the past, NITI Aayog acts as the quintessential platform of the Government of India to bring States to act together in national interest, and thereby fosters Cooperative Federalism.

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RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing. RMI has been supporting India's mobility and energy transformation since 2016.

Authors and Acknowledgements

Authors

NITI Aayog

Sudhendu J. Sinha
Joseph Teja

RMI

Contacts

For more information, contact:

info@rmi.org

Acknowledgments

We would like to acknowledge Clay Stranger, Dave Mullaney, Samhita Shiledar, Marie McNamara, Pranav Lakhina, and Jake Straus of RMI, and Chetna Nagpal, and Isha Kulkarni of RMI India for their contribution to the development of this report

Suggested Citation

NITI Aayog, RMI, *Transforming Trucking In India: Pathways to Zero Emission Truck Deployment,* September 2022.

Available at NITI Aayog:

https://www.niti.gov.in/documents/reports/

Available at RMI:

https://rmi.org/insight/transforming-trucking-in-india/

Foreword

India is well-positioned to become a crucial player in the inevitable transition to zero-emission freight vehicles.

India is experiencing historical growth — urbanisation, population increase, the rise of e-commerce, and increasing income levels have heightened the demand for goods and services. The road freight sector is expected to grow fourfold by 2050 to meet this rising demand. By continuing to run on fossil fuel these burgeoning fleets will only further pollute air, exacerbate public health hazards, increase energy costs, and drive-up emissions at a time when many countries are working valiantly to bring them down. In India, for example, using conventional trucks to meet growing demand would require spending over US$1 trillion cumulatively on crude oil imports for diesel production by 2050.

ZETs are the clear-cut solution to all of these problems and more. By reducing both air pollution and costs while enhancing industrial competitiveness, ZET adoption can directly support the citizens and the Indian economy in addition to helping meet climate targets.

The Indian economy is poised to leapfrog diesel vehicles and scale ZET adoption. This will require synchronised effort amongst private and public actors to increase the manufacturing supply and deliver the needed charging infrastructure to support a robust ZET ecosystem. Policymakers can draw on previous national and state incentives that helped spur demand for passenger electric vehicle adoption. By coordinating similar efforts, they can help industry players transfer risk, reduce costs, and seed the nascent ZET market — ultimately harmonising ZET demand and supply to drive market scale.

We hope that this report will act as a foundation and prompt collaboration to make a ZET future a near-term reality in India. By pioneering early ZET adoption, ecosystem actors can unlock substantial economic, energy security, and emissions benefits for India, and together claim our position as a global leader in this urgent shift.

Mr. Clay Stranger,
Managing Director of RMI

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Executive Summary

India's trucking market is expected to grow over 4x by 2050 — fueling the nation's economy and transportation emissions

India is the world's sixth-largest economy, with a GDP close to US$3 trillion and growing.[1] The freight transportation sector is growing rapidly to ensure more goods and products reach a rising number of end consumers. Currently, India transports ~4.6 billion tonnes of freight annually, generating transport demand of 2.2 trillion tonne-kilometres (tonne-km) at the cost of ₹9.5 lakh crore.[2] Demand for goods is rising with urbanisation, population increase, the rise of e-commerce, and rising income levels. As this demand continues to grow, associated road freight movement is expected to increase to 9.6 trillion tonne-km by 2050.

Road transport (i.e., trucks) carries the bulk of India's goods, 70% of today's domestic freight demand. Heavy- and medium-duty trucks (HDTs and MDTs, respectively) are responsible for most of that road transportation. And as road freight travel continues to grow, the number of trucks is expected to more than quadruple, from 4 million in 2022 to roughly 17 million trucks by 2050 (see Exhibit 2, page 16).

In light of these market trends, zero-emissions trucks (ZETs) — including battery electric trucks (BETs) and fuel cell electric trucks (FCETs) — offer a compelling alternative to the diesel trucks that dominate India's road freight today. ZETs do not have tailpipe emissions and have lower operating costs, presenting an opportunity for India to showcase how the adoption of ZETs is economically efficient and better for air quality, public health, and environment.

India's opportunity to become global manufacturing hub for ZETs

Realising the economic and environmental benefits of ZETs, many countries are transitioning away from diesel trucks. The European Union has committed to electrifying freight vehicles, setting an objective to have 80,000 ZETs on the road by 2030; the United Kingdom has announced a pledge that all HDTs will be ZETs by 2040.[3] California adopted the Advanced Clean Trucks regulation requiring manufacturers to sell an increasing percentage of ZETs and the first global agreement on ZETs formed at COP26.[4] Increasingly, international platforms like the Zero Emission Vehicles Transition Council are creating global discourse on the ZET opportunity.

Scaling ZET adoption can enable India to differentiate itself in the global export market. As supply chains continue to become increasingly global, the most substantial growth in freight and trucking demand will be from emerging markets like India. India has the opportunity to exhibit global leadership by scaling ZET adoption. The growth of India's ZET market will require coordinated private and public actions to increase the manufacturing supply of ZETs and deploy the supporting charging infrastructure. Ambitious policies are required to drive growth, seed the market, and accelerate ZET supply and demand.

Key findings: ZETs can produce economic, energy security, and emissions benefits for India

In this report, we analysed India's potential for ZETs in four common scenarios for MDTs and HDTs in road freight trucking:

1. MDT operating short intrastate
2. MDT for regional haul
3. HDT for regional haul
4. HDT for long haul

This report takes a conservative approach to assessing capital and operating costs of ZETs based on the technology available today and with scaled vehicle manufacturing and charging infrastructure utilisation. In a mature production scenario, our analysis found meaningful economic, public health, industrial competitiveness, and emissions-saving opportunities for India. Highlights include:

1. **ZETs can lead to sustained logistics cost savings.** Transportation costs are a major driver (62%) of overall logistics costs in India, accounting for 14% of India's GDP.[5] Since diesel fuel costs account for the overwhelming majority of transportation costs, ZET adoption can dramatically lower associated fuel costs by up to 46% over the vehicle's lifetime, with broad implications for the Indian economy.

2. **A robust domestic ZET market can transform India into a global green hub for battery manufacturing.** ZETs would be a significant source of demand for domestically produced batteries (up to 4,000 gigawatt-hours [GWh] cumulative through 2050), supporting and underpinning the National Energy Storage Mission and providing the impetus for the nation to become a low-cost and low-carbon manufacturing hub.

3. **If produced at scale, the total cost of ownership (TCO) for ZETs in MDT segment can be less than diesel trucks, and TCO parity can be reached in the HDT segment by 2027.** Currently, ZETs have a higher upfront cost compared to diesel trucks, but ZETs also have significantly lower per-kilometre operating costs.

4. **With supportive polices ZETs can achieve an 85% sales penetration by 2050.** With cost competitiveness, and technology maturity, nearly 9 in 10 trucks sold in 2050 can be ZETs.

5. **ZETs can help shift India off oil import dependency, supporting the vision of a self-reliant India.** Today, road freight accounts for more than 25% of oil import expenditures—and is expected to grow over 4x by 2050. ZET adoption can eliminate a cumulative total of 838 billion litres of diesel consumption by 2050, which would reduce oil expenditures by ₹116 lakh crore through 2050.

6. **Widespread ZET adoption could reduce cumulative trucking particular matter (PM) and nitrous oxide (NOx) pollution ~40% by 2050, substantially improving air quality in India.** Today, trucks represent just 3% of the total vehicle fleet (including both passenger and freight) yet are responsible for 53% of PM emissions.[6] A purposeful transition to ZETs can lead to considerable improvements in air quality and benefit citizens' public health.

7. **Widespread ZET adoption could reduce annual trucking carbon emissions 46% by 2050, lowering the nation's greenhouse gas (GHG) emissions.** The trucking sector is responsible for one-third of transport-related CO_2 emissions in India. A determined transition to ZETs can lead to 2.8–3.8 gigatonnes of cumulative CO_2 savings through 2050, which is equal to or greater than India's entire economy-wide annual GHG emissions today.

8. **The early state of the overall ZET market in India requires a coordinated ecosystem approach spanning the public and private sectors.** Such an approach can help overcome challenges such as the upfront capital needed to make the ZET transition through a combination of finance, technology, infrastructure, and policy strategies.

Strategies and solutions for scaling India's ZET market

India can seize the far-reaching benefits of a ZET future through a blend of strategies and solutions, including:

POLICY

- **Demand-side policies to increase consumer demand,** such as purchase subsidies, feebates, interest subvention, scrappage incentives, zero-emissions zones, and fleet purchase requirements.
- **Supply-side policies to encourage traditional OEMs to innovate and start-ups to enter ZET manufacturing,** such as original equipment manufacture (OEM) ZET credit schemes, ZET production targets, air quality regulations, and fuel efficiency standards that promote ZETs and improve air quality.

TECHNOLOGY & MANUFACTURING

- **Improve battery chemistry, energy density, and fuel cell efficiency** to increase the range and improve the payload capacity of ZETs.
- **Foster a domestic manufacturing strategy** to help build a robust supply chain of wide varieties of ZETs, in turn helping fulfil India's long-term trucking demands.

CHARGING

- **Provide a mix of charging strategies and types,** with a focus on depot charging and en-route fast charging, which together can provide charging coverage for both short- and long-range freight trucking needs.
- **Leverage policy intervention to reduce charging costs,** including upfront subsidies, electricity tariffs that remove demand charges and/or implement EV-friendly rate structures, and concessional land for building out ZET charging infrastructure.
- **Strategically build adequate power infrastructure** to meet the electricity needs of a growing ZET market, including load assessments, dedicated funding for infrastructure buildout, demand-side management, investment in energy storage, and smart charging capabilities.
- **Streamline the infrastructure installation process to minimise the permitting and interconnection processing times;** also streamline the land procurement process for charging infrastructure development to minimise charging deployment soft costs.

FINANCING & BUSINESS MODELS

- **Central and state governments can mitigate risks of investing in ZET production and expand access for ZET purchase** via strategies such as public-backed loans, demand aggregation, and interest subvention schemes and risk-sharing mechanisms.
- **OEMs and fleet operators can update their business models to lower the cost of owning ZETs and ultimately help nudge sector-wide adoption** via strategies such as lease purchasing, battery leasing or financing, as-a-service business models, performance guarantees, and more-robust and/or extended warranties.
- **Lenders and other financial institutions can work to structure more-favorable financing for ZET loans** through tailored loan products, better-informed depreciation criteria, and alternative credit evaluations.

Exhibit ES1: Pathways to ZET adoption in India

Pathways to ZET adoption in India

Policy

- Introduce demand-side policies to increase consumer demand.
- Craft supply-side policies to encourage traditional OEMs to innovate and start-ups to enter ZET manufacturing.

Financing & Business Models

- Central and state governments can mitigate risks of investing in ZET production and expand access for ZET purchase.
- OEMs and fleet operators can update their business models to lower the cost of owning ZETs and ultimately help nudge sector-wide adoption.
- Lenders and other financial institutions can work to structure more favorable financing for ZET loans.

Charging

- Provide a mix of charging strategies and types.
- Leverage policy intervention to reduce charging costs.
- Strategically build adequate power infrastructure.
- Streamline the infrastructure installation process to minimise processing times.

Technology & Manufacturing

- Improve battery chemistry, energy density, and fuel cell efficiency.
- Enhance performance characteristics such as payload capacity.
- Foster a domestic manufacturing strategy.

ZET corridors can be a catalyst that aligns ecosystem solutions

Currently, 50% of India's vehicle freight traffic travels along seven major corridors, connecting the country's cities and ports. The concentration of road freight travel and economic activity along these corridors presents an opportunity to strategically invest in charging infrastructure development to scale ZET adoption. Enabling ZETs on high-use routes can build market momentum and empower invaluable testing and refining of best-in-class solutions.

Effective multistakeholder collaboration is the key to accelerated ZET deployment

India is in a prime position to stand as a global leader in the transition to zero-emissions trucking. In order to realise the significant long-term economic and environmental benefits of ZETs, however, government, technology, industry, and finance leaders must align decisively to develop and enact near-term, precise market and policy intervention.

Introduction

ZETs are becoming a global phenomenon

Corporate social responsibility, consumer awareness, and global commitments to reduce carbon emissions have driven the transport sector to become increasingly conscious of the embodied carbon content of goods. Large fast-moving consumer goods and e-commerce providers have driven electric MDT and HDT fleet adoption, as they are gradually being driven by corporate social responsibility commitments to adopt ZET fleets. In conjunction, major OEMs are announcing lofty electrification targets and are scaling their manufacturing of ZETs to meet rising demand. Scania, Volvo, Daimler, BYD, Chanje, and several other major OEMs have launched MDT and HDT ZETs that can meet a range of duty cycles and operational needs.[7] These firms recognise the long-term opportunity and inevitable global market shift to net-zero. Firms are also increasingly forming joint ventures to raise capital for charging infrastructure to meet the growing charging demand of ZETs.[8] Volvo, Daimler, and Traton are investing 500 million euros to build out a high-power electric tuck network in Europe.[9]

Countries and states worldwide are setting zero-emissions freight targets, and there are now multilateral actions aimed at accelerating the manufacturing of ZETs. Global platforms like Zero Emission Vehicle Transition Council (ZEVTC) have provided an invaluable platform for knowledge sharing and collective action.[10] Additionally, countries are increasingly forming partnerships to develop joint pathways to reduce vehicle emissions, particularly for scaling electric HDTs. As part of the Drive to Zero Campaign, several European countries as well as Canada and Australia signed a memorandum of understanding to foster leadership and international coordination to accelerate ZET adoption.[11]

As the countries look to make progress on their nationally determined contributions (NDCs) and reduce emissions, there is a growing need to address road transport emissions particularly from the trucking sector. The global economy is rapidly evolving; costs are no longer the sole decision-making factor for the private sector, and policymakers are more acutely aware of the environmental and social implications of economic activities. Thus, these actors are more aggressively exploring opportunities to spur ZET development to remain competitive in global supply chains. Over time ZETs are rapidly becoming more economically efficient, and the adoption of ZETs represents a tremendous opportunity to improve air quality and reduce carbon emissions.

India has an opportunity to capitalise on the nascent ZET market. ZETs represent a cleaner and cost-effective solution to freight transport and India can be a key player in the global transition to zero-emissions freight vehicles. The Indian economy is well-positioned to leapfrog diesel vehicles and scale ZET adoption. India can exhibit global leadership by scaling ZET use and garnering a larger market share in the global transport economy. Domestic policies that spur ZET supply and demand will be critical for catalysing the domestic ZET market and catapulting India as a global leader in clean freight transportation.

India's trucking market is expected to grow 4x by 2050 — fueling the nation's economy and transportation emissions

India boasts the world's sixth-largest economy, with a GDP close to US$3 trillion.[12] The pressure is on the freight transportation sector to ensure more goods and products reach a rising number of end consumers, with expedience, economy, and environmental priorities all front and center.

Currently, India transports around 4.6 billion tonnes of freight annually at the cost of ₹9.5 lakh crore.[13] Demand for goods is rising with urbanisation, population increase, the rise of e-commerce, and rising income levels. As this demand continues to grow, associated road freight movement is expected to increase to 9.6 trillion tonne-kilometres (tonne-km) by 2050.

Road transport (i.e., trucks) carries the bulk of India's goods, meeting 70% of today's domestic freight demand and carrying nearly 2.2 trillion tonne-km of freight today (see Exhibit 1). Heavy- and medium-duty trucks (HDTs and MDTs, respectively) are responsible for most of the road transportation, accounting for 76% and 21% of the road freight demand.

By 2050, HDTs' demand share of road freight travel is expected to increase to 83%, carrying nearly 8.4 trillion tonne-km of long-haul freight. MDTs will continue to play an important role in short intrastate movement and regional movement, accounting for 1.2 trillion tonne-km by 2050. As road freight travel continues to grow, the number of trucks plying on Indian roads and highways is expected to more than quadruple, from 4 million in 2022 to roughly 17 million trucks by 2050.

Exhibit 1: Modal split for freight movement in India in 2022 (% of tonne-km)

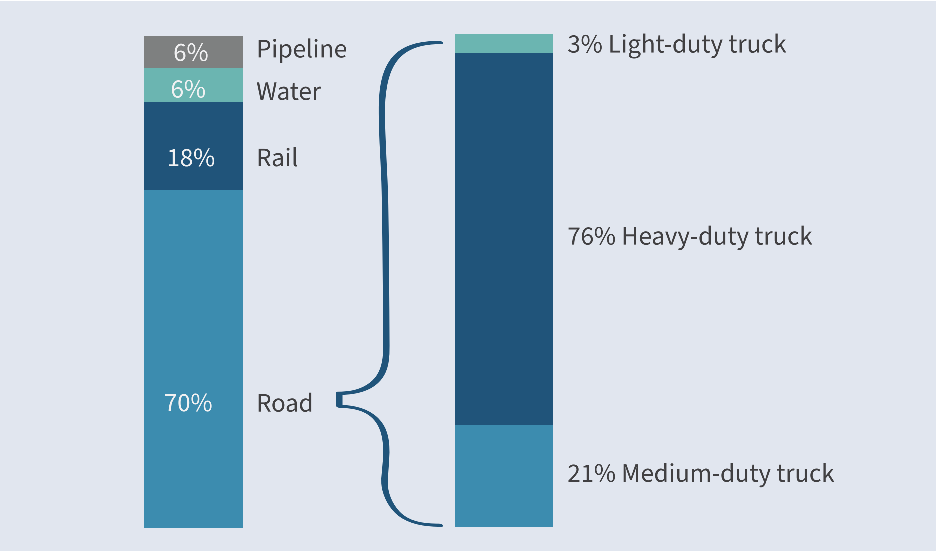
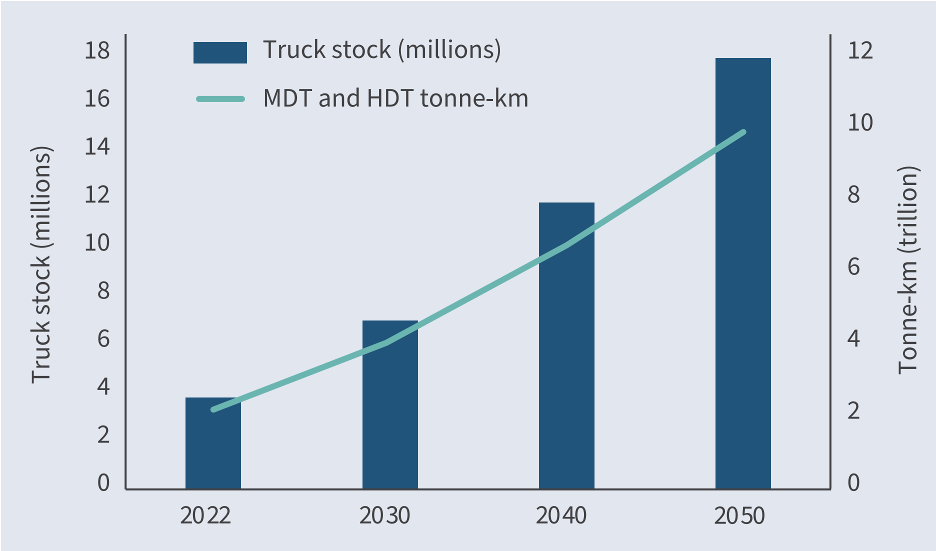


Exhibit 2: Growth of India's truck stock and road freight market through 2050



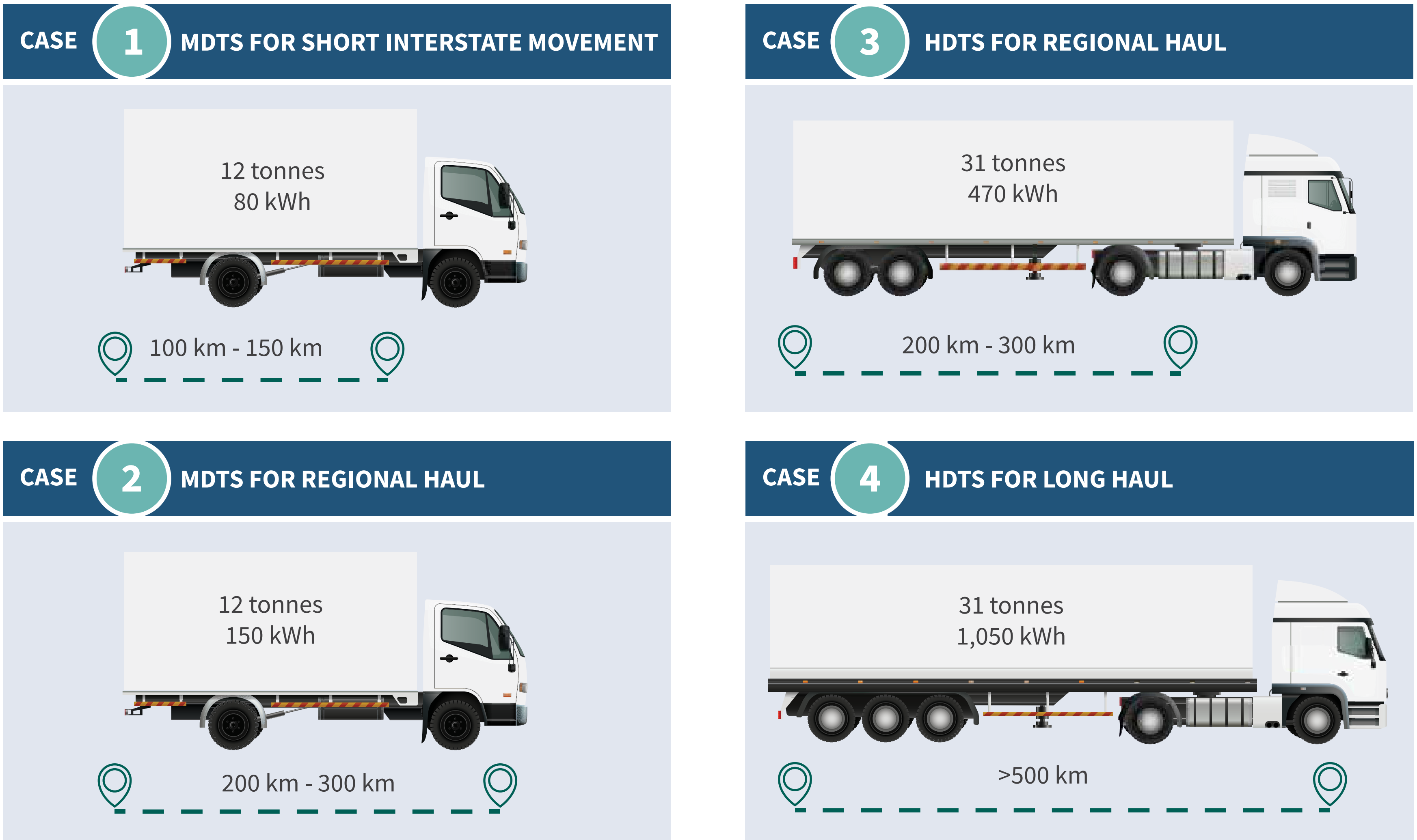
The growth of freight demand and the growing trucking sector is an integral part the Indian economy and transport system. However, existing diesel trucks disproportionately contribute to ambient air pollution. Given the expected market growth, it will be critical to ensure that new trucks contribute to a cleaner and more sustainable transport system. Zero-emissions trucks (ZETs) — including battery electric trucks (BETs) and fuel cell electric trucks (FCETs) — offer a compelling alternative to the diesel trucks as they produce zero tailpipe emissions and offer an opportunity for sustained fuel cost savings:, and ZETs can effectively replace existing diesel trucks. Exhibit 3 offers a comparison between ZETs and diesel vehicles, outlining how ZETs can meet India's trucking needs effectively.

Exhibit 3: ZET technologies vs. diesel trucks[14]

	DIESEL TRUCK	BATTERY ELECTRIC TRUCK	FUEL CELL ELECTRIC TRUCK
Fuel	Diesel	Electricity	Green Hydrogen
Advantages	• Conventional technology • Faster refueling (vs. BETs) • Readily available models to fit all use cases	• No tailpipe emissions • Lower CO_2 emissions (which go even lower as India's power grid shifts to renewable energy) • Up to 82% "tank-to-wheel" powertrain efficiency • Lowest operating costs • Pleasant driving experience	• No tailpipe emissions • Lower CO_2 emissions (if powered by green hydrogen vs. conventional sources of hydrogen) • Up to 45% "tank-to-wheel" powertrain efficiency • Faster refueling • Equivalent payloads to diesel trucks
Challenges/ Drawbacks	• Highly inefficient • High operating costs, especially for fuel • Huge environmental impact in terms of air pollution and carbon emissions • Up to 18% "tank-to-wheel" powertrain efficiency	• Limited range due to battery capacity • Bigger batteries in heavier trucks could lead to a weight penalty that reduces payload capacity • Longer charging times of 1–8 hours required for charging	• Nascent technology • High cost of producing hydrogen leading to higher TCO • Not environmentally friendly if hydrogen is produced from natural gas or coal

To assess the economic feasibility of ZETs, we analysed four common use cases for MDTs and HDTs used for road freight trucking: 1) MDT operating short intrastate, 2) MDT for regional haul, 3) HDT for regional haul, and 4) HDT for long haul (see Exhibit 4).

Exhibit 4: Four scenarios for MDTs and HDTs in India's road freight sector



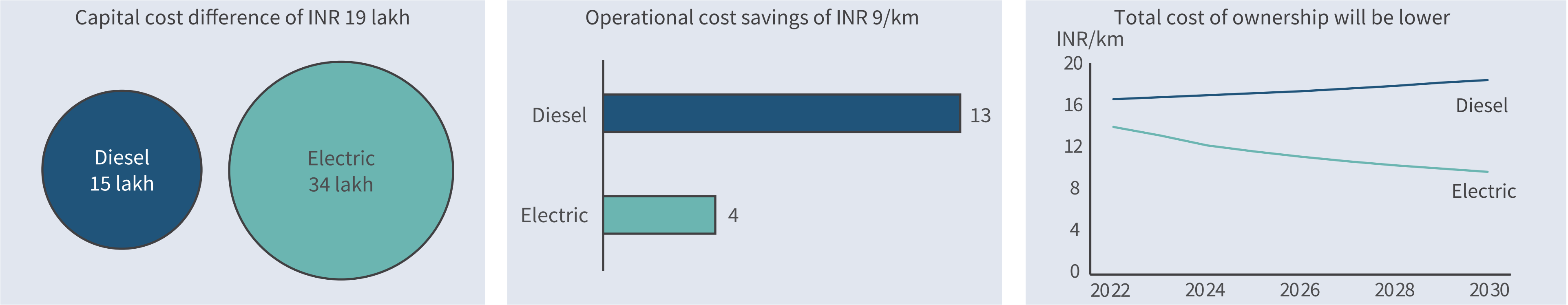
Economic Analysis

Understanding ZETs' cost-competitiveness in relation to diesel trucks will be crucial to achieving a sustainable future for goods transport in India. To assess the economic feasibility of transitioning to ZETs, we conducted a robust market assessment to derive the capital costs and vehicle operating costs of ZETs and diesel vehicles in a mature production scenario, i.e. with a dedicated production facility that will lead to reasonable scale and a competitive market price. Due to the lack of ZETs in the Indian market, we performed a bottom-up analysis which included calculating the costs of ZETs as if they were produced at scale in the market today. To estimate the costs of ZETs, the battery size required to meet different use cases was derived based on prescribed travel distances and payload capacities. Vehicle CAPEX was calculated by adding the cost of batteries, electric motors, power electronics, thermal management, and chassis. Based on conservative cost analysis, the exhibits below outline the capital and operational costs based on existing technologies. These inputs were then used to estimate and compare the TCO of ZETs and diesel trucks. The findings below depict the total operating costs of BETs and diesel trucks in a mature market. The cost figures represent the costs of ZET technology today with scaled vehicle production and charging infrastructure utilisation. These figures capture the economic opportunity of ZETs; the subsequent solution section addresses how private and public actions to harmonise ZET supply and demand can enable the market to reach economies of scale efficiently.

1 Electric MDTs for short intrastate movement — Delivering operational savings of nearly ₹55 lakh for fleet operators over the vehicle's lifetime, with a payback period of just 5.2 years

For a 12-tonne electric MDT with an 80 kilowatt-hour (kWh) battery, the capital cost is ~2.3 times that of the diesel counterpart. This battery capacity is sufficient to travel from Mumbai to Pune, for example, or to serve similar use cases for distances in the range of 100–150 km. Due to the low cost of electricity compared to diesel and lower maintenance costs, the operational cost savings to operate electric MDTs on a per-km basis is as much as ~₹9/km, resulting in cumulative savings of over ₹55 lakh over the vehicle's lifetime. This translates to a payback period of just 5.2 years (i.e., in just over five years, a truck operator will be able to offset the capital cost differential of the electric and diesel truck). On a TCO basis, an electric truck for this use case is ~16% cheaper than its diesel counterpart when manufacturing capabilities are mature, and the TCO becomes even more economically beneficial in years to come (Exhibit 5). Overall, the adoption of electric MDTs for regional haul is the low-hanging fruit that can spearhead the ZET transition in India.

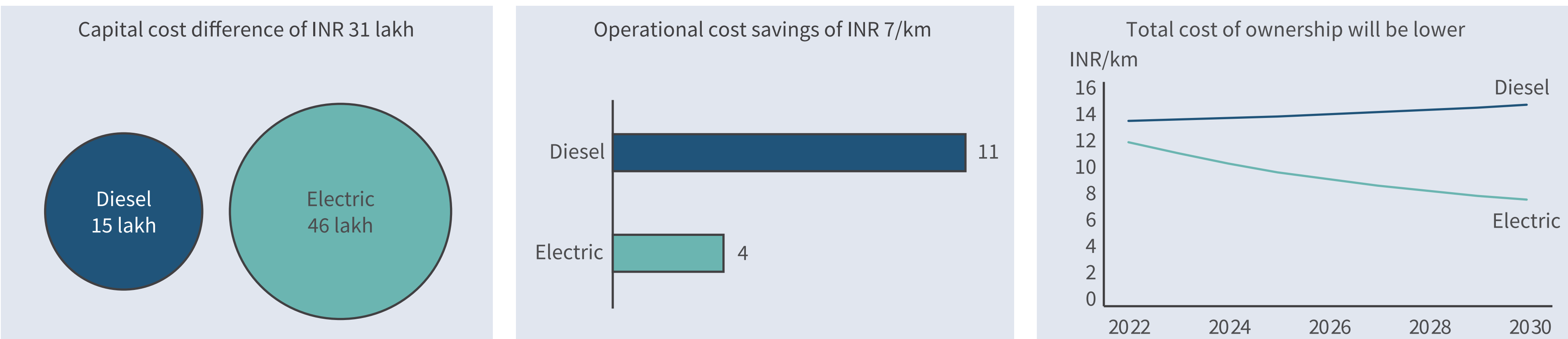
Exhibit 5: Capital, operational, and total ownership cost of MDTs for short interstate movement (Mumbai to Pune) in a mature production scenario



2 Electric MDTs for regional haul — Yielding operational savings of over ₹74 lakh over the vehicle's lifetime, with a payback period of 6.4 years

To buy an MDT of the same 12-tonne capacity but with a larger battery size of 150 kWh, the capital cost requirement is 31.3 lakh more than the diesel truck. However, despite larger battery capacity, the operational cost savings from running an even longer distance of 200–300 km (e.g., between Delhi and Jaipur) is ₹7/km. Consequently, the electric MDT fleet operator can save more than one crore over the vehicle's lifetime. These operational savings can offset the capital cost differential of an electric MDT in ~6.4 years. Considering massive operational per-km savings, the TCO of electric MDTs is already ~12% lower than its diesel equivalent. The economic competitiveness will further improve in years to come as ZET technology improves (see Exhibit 6).

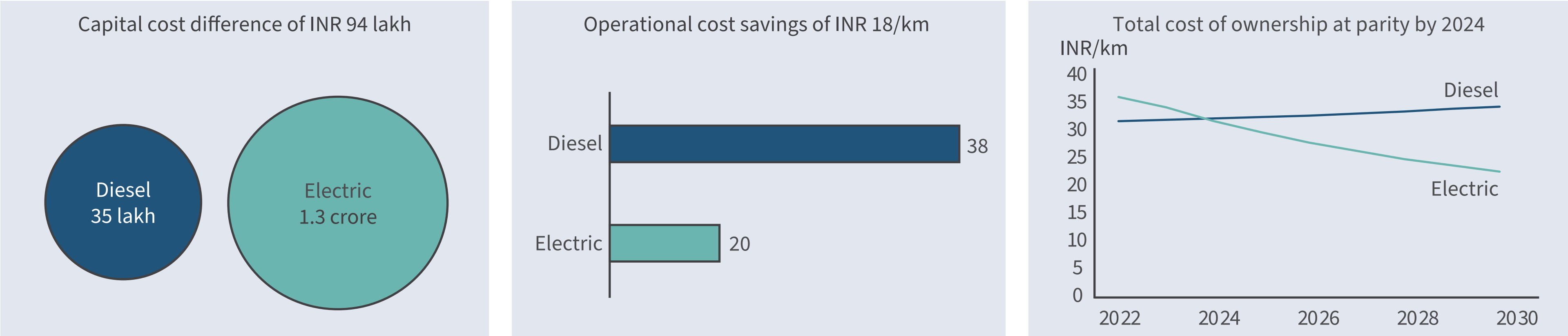
Exhibit 6: Capital, operational, and total ownership cost of MDT for regional haul from Delhi to Jaipur in a mature production scenario



3 Electric HDTs for regional haul — Generating operational savings of over ₹1.3 crore over the vehicle's lifetime, with a payback period of 10.7 years

A 31-tonne electric HDT with a larger battery of 470 kWh costs 3.7 times the cost of its diesel counterpart. Operational cost savings are expected to be ₹18/km (see Exhibit 7), making it far more affordable to operate than a conventional diesel truck. Though there is a high capital cost difference, the operational saving are significant and by 2024 electric HDTs will be at parity with their diesel counterparts. Moreover, due to high operational savings of 1.3 crore over the vehicle's lifetime, a fleet operator will be able to pay back the differential upfront capital of 95 lakhs in 10.7 years.

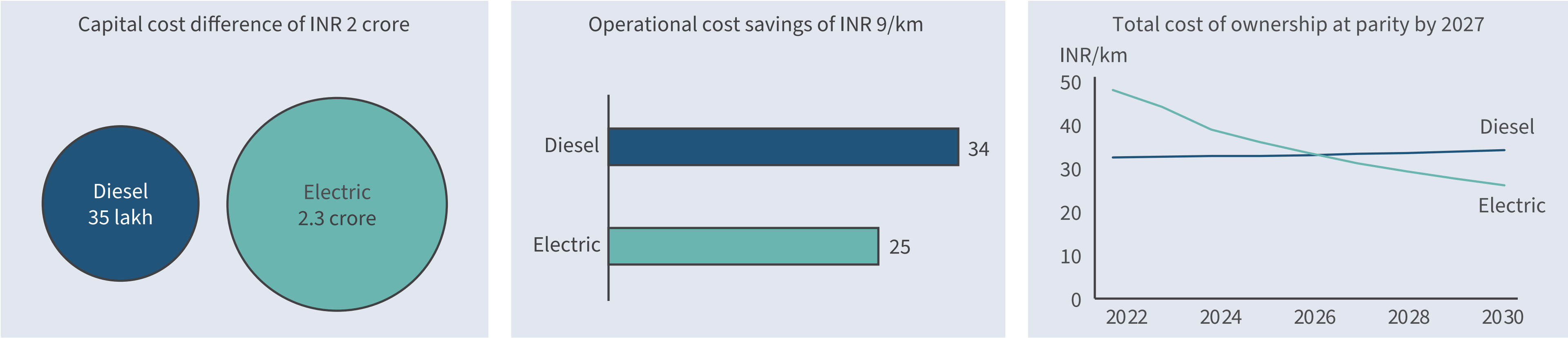
Exhibit 7: Capital, operational, and total ownership cost of a HDT for regional haul from Delhi to Jaipur in a mature production scenario



4 Electric HDTs for long haul — Leading to operational savings of nearly ₹1.1 crore over the vehicle's lifetime, with a payback period of 18.3 years

The upfront capital cost of a 31-tonne electric HDT with 1,050 kWh battery is 6.6 times more than the diesel HDT.[i] While the cost of operating a diesel HDT from Delhi to Mumbai is ₹34/km, it is only ₹25/km for an electric HDT. Considering operating savings of ₹9/km, the fleet operator can save over ₹1.1 crore over the vehicle's lifetime. Though electric HDT accrues significant operational cost savings, its TCO is 1.5 times higher than its diesel counterpart today. However, with the development of the ZET market, the electric HDT could reach TCO parity with diesel HDT in 2027 (see Exhibit 8).

Exhibit 8: Capital, operational, and total ownership cost of a HDT travelling for long haul from Delhi to Mumbai in a mature production scenario



[i] A 1,050 kWh battery pack is not currently deployed in vehicles. However, each of the four use cases assumes that a vehicle can meet the duty cycle requirements of the given trucking application with a single charge. Thus, a 1,050kWh battery was required to meet the duty cycle requirements of the long-haul trucking application assessed, and the associated costs of this size battery and truck were derived to accurately compare diesel truck and ZET operations for long-haul trucking.

TCO parity is not the sole condition that freight operators will consider when assessing the type of ZET vehicle to adopt, particularly for long-haul trucking applications. A vehicles' ability to meet operational requirements will also be critical when operators consider ZET adoption. For long-haul applications where it takes several days to reach the trucks' ending destinations, FCET trucks may be the preferred technology pathway. These trucks would require fewer stops along routes and can be re-fueled quickly—within minutes compared to the long charge time required to charge a greater than 31-tonne truck via a 500 kW charger. Additionally, FCETs have a lower gross vehicle weight given their smaller batteries, and this feature may enable FCETs to better match the payload capacity of diesel equivalents.

Fulfilling the duty cycle requirements of long-haul trucking applications with BETs poses challenges. In today's global market, trucks do not have battery packs that meet the trucking demands of long-haul duty cycle in a single charge. Additionally, a high-powered charger is required to time-effectively charge a vehicle, leading to substantial infrastructure and refueling costs for BET operators. Battery degradation is also a concern, especially when the required battery pack is greater than 500 kWh. Given the operating constraints of BETs in long-haul trucking applications, FCETs may emerge as the preferred truck type when operators need to travel prolonged distances with minimal downtime.

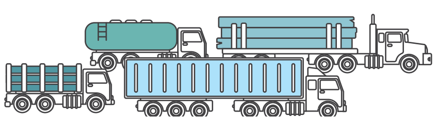
ZETs can reduce both air pollution and costs while enhancing industrial competitiveness, benefiting the citizens and the India economy.

Exhibit 9: The impact of each ZET on the road

Vehicle	Oil expenditure reductions (lakh INR)	CO_2 savings (tonnes)	PM savings (kg)	NOx savings (kg)
Case 1	0.9	57	5	184
Case 2	1.5	99	8	319
Case 3	3.7	102	16	375
Case 4	5.5	152	23	559

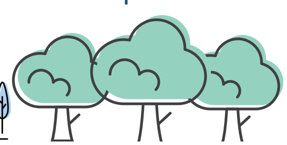
CUMULATIVE IMPACT BY 2050

9.6 million ZETs on the ground



2.8 gigatonnes of CO_2 emissions reductions

Equivalent to 46 billion trees planted



750 thousand tonnes of PM emissions reductions

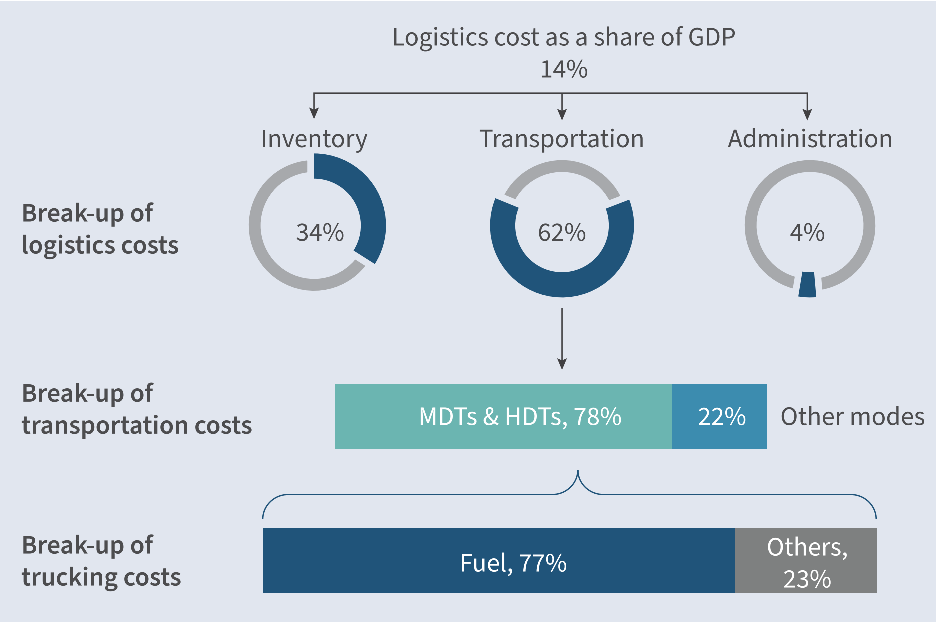
24.5 million tonnes of NOx emissions reductions

Key Findings

1 ZETs can lead to sustained logistics cost savings.

The cost of logistics as a share of GDP is roughly 14% in India, which is comparatively higher than peer nations where this metric is in the range of 8%–11%. Transportation costs are a major driver (62%) of overall logistics costs and fuel costs account for the overwhelming majority of these transportation costs (see Exhibit 10).[15] ZET adoption can lower associated fuel costs by 46% over the vehicle's lifetime, leading to a 17% savings in logistics costs. Logistic cost reductions by reduction of transportation costs have the potential to directly reduce the cost of end goods and commodities, creating lasting benefits for consumers.

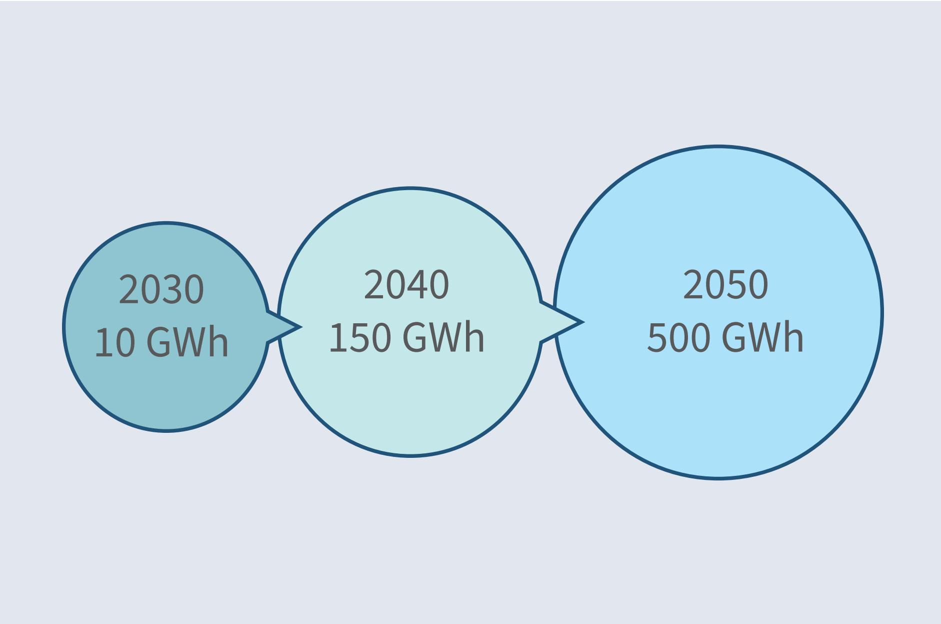
Exhibit 10: Fuel costs as a major driver of transportation and logistics share of GDP



2 A robust domestic ZET market can transform India into a global green hub for battery manufacturing.

ZETs would be a significant source of demand for domestically produced batteries, supporting and underpinning the National Energy Storage Mission and the Production Linked Incentive Scheme for Advanced Chemistry Cell Batteries. By 2050, up to 4,000 GWh of cumulative battery demand could be created by ZETs alone (see Exhibit 11), creating substantial demand for India to become a low-cost and low-carbon manufacturing hub.

Exhibit 11: Annual Domestic battery demand in a high ZET adoption scenario



3 Estimated total cost of ownership for MDTs under a mature production scenario will be cheaper than diesel; parity could be reached for HDTs by 2027.

Currently, ZETs have a higher upfront cost than diesel trucks and are not widely manufactured or available in India. The cost difference can be around 2x for MDTs to ~6x for HDTs (Exhibit 12). HDTs in particular, have a higher upfront cost difference as longer distances and heavier loads require a much larger battery pack, and batteries count for ~40% to 70% of electric HDT purchasing price. By leveraging currently available technologies, however, ZETs could also have significantly lower per-kilometre operating costs. Under a mature production scenario, the resulting TCO for ZETs is 12% –16% cheaper than MDT diesel trucks, and for heavy-duty trucking applications, ZETs can feasibly reach TCO parity by 2027. This will result in payback periods of 5.2–6.4 years for MDTs and 10.7–18.3 years for HDTs, but these operational cost savings will remain out of reach without decisive market creation and policy action.

Exhibit 12: The upfront cost of ZETs vs. diesel across four use case scenarios

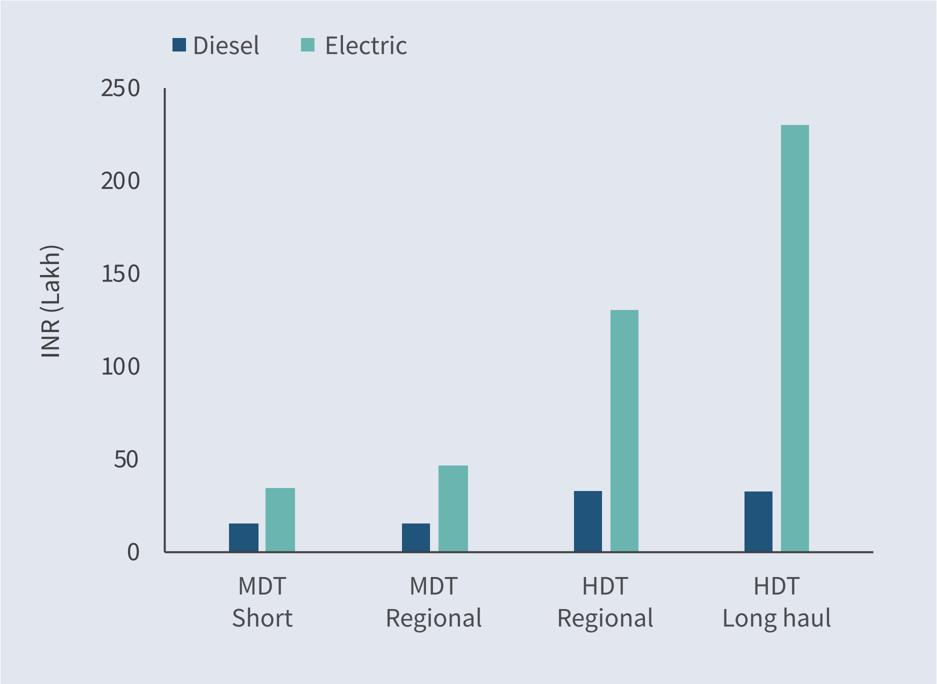


Exhibit 13: The vehicle operating cost of ZETs vs. diesel trucks across scenarios

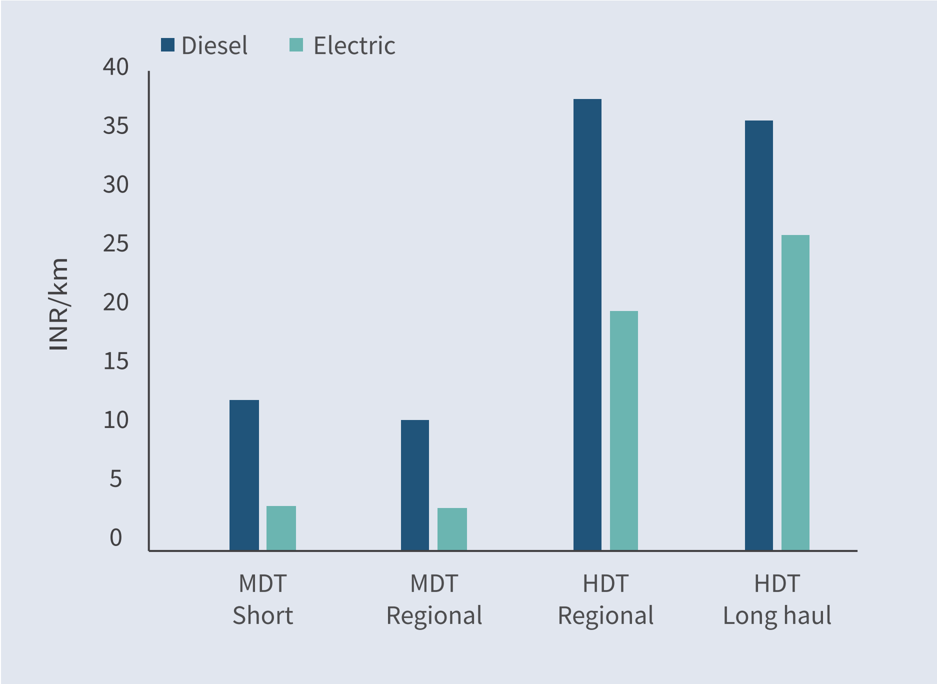


Exhibit 14: TCO of ZET vs. diesel for MDTs under a mature production scenario

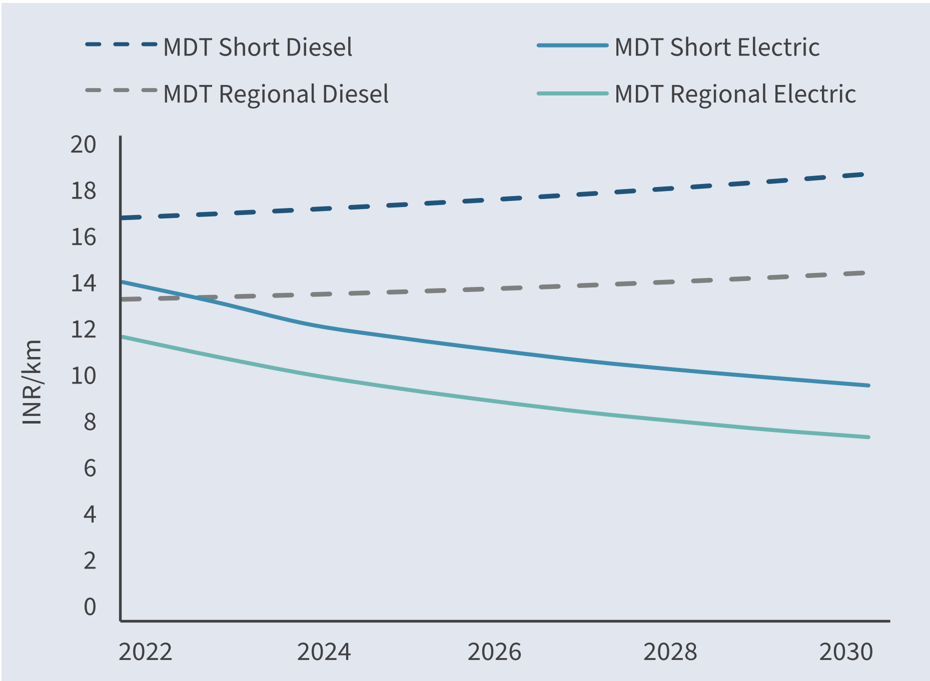
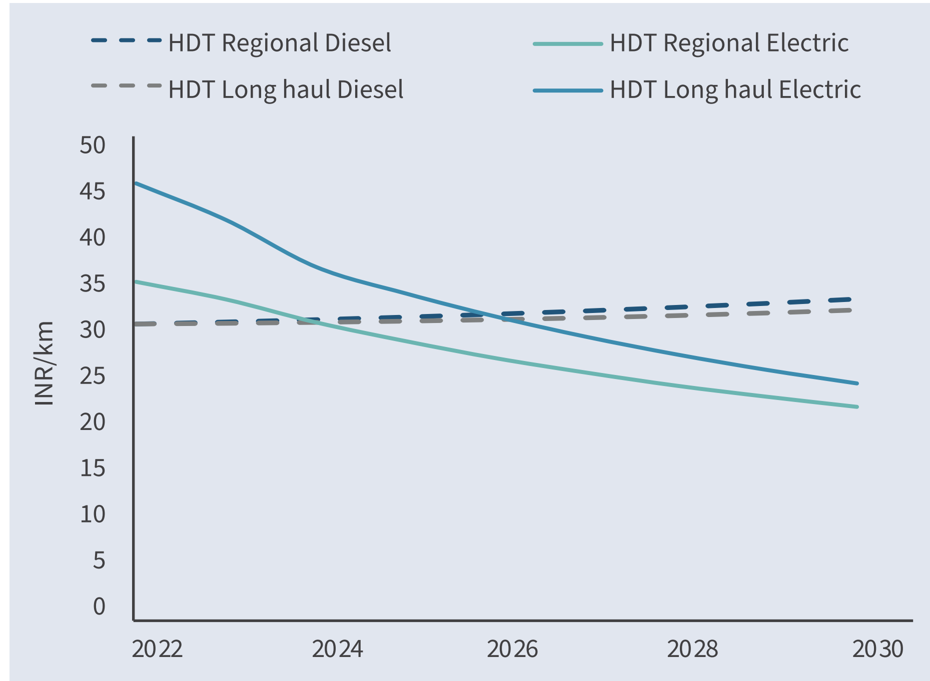


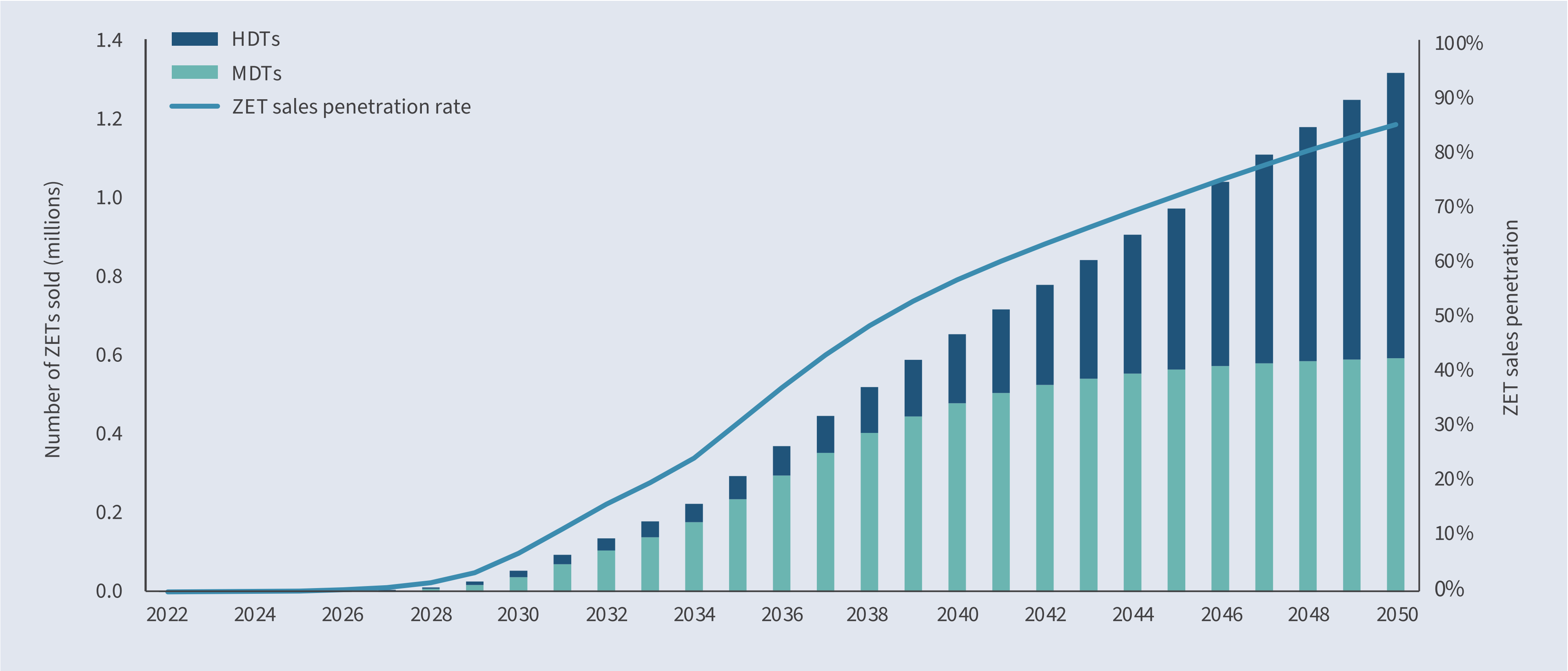
Exhibit 15: TCO of ZET vs. diesel for HDTs under a mature production scenario



4 With supportive policies ZETs can achieve an 85% sales penetration

Based on global market momentum seen already, the existence of supportive polices, and an experienced private sector to drive ZET cost competitiveness in India, the majority of trucks sold in 2050 — nearly 9 in 10 trucks — can feasibly be ZETs. Achieving a 100% sales penetration level for MDTs and a 75% sales penetration rate for HDTs by 2050 would lead to an 85% overall sales penetration level for trucks. This level of sales penetration would help transform the trucking sector and by 2050, 57% of truck stock would be ZETs.

Exhibit 16: Projected number of ZETs in India



5 ZETs can help shift India off oil import dependency, supporting the vision of an *Aatmanirbhar Bharat.*

Today, road freight accounts for more than 25% of annual oil import expenditures and is expected to grow over 4x by 2050 (see Exhibit 17). ZET adoption in any time frame leads to sustained fuel savings and a significant reduction in oil imports, but a more intentional and rapid transition can boost savings and strengthen India's energy security. ZET adoption can reduce oil spend by 838 billion litres of diesel cumulatively by 2050. This will result in ₹116 lakh crore of reduced oil expenditures by 2050 (see Exhibit 18).

Exhibit 17: Crude oil import expenditures for diesel production under business as usual

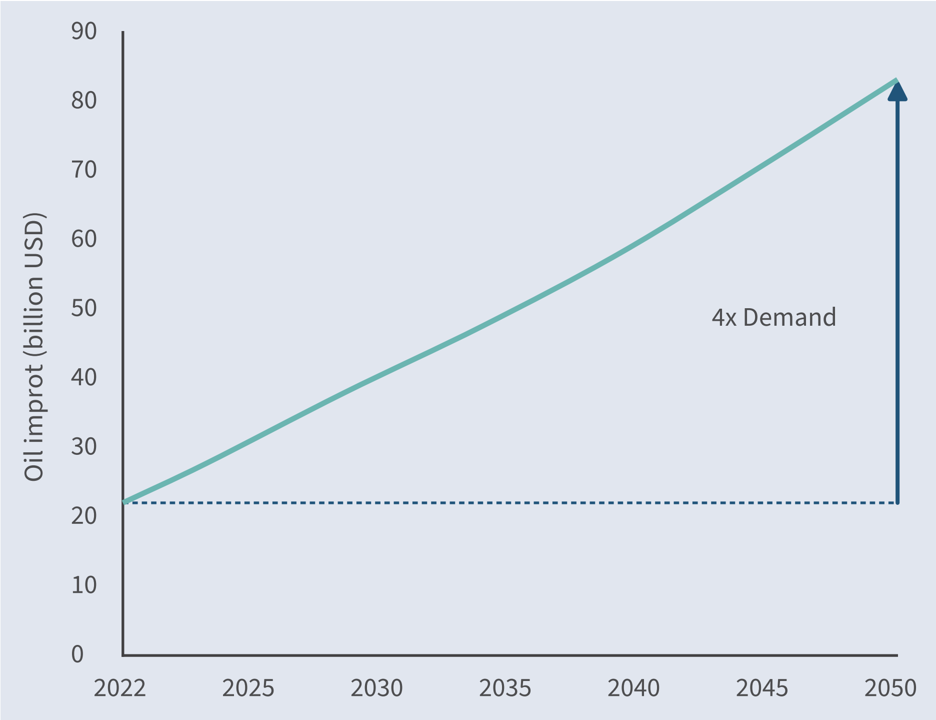
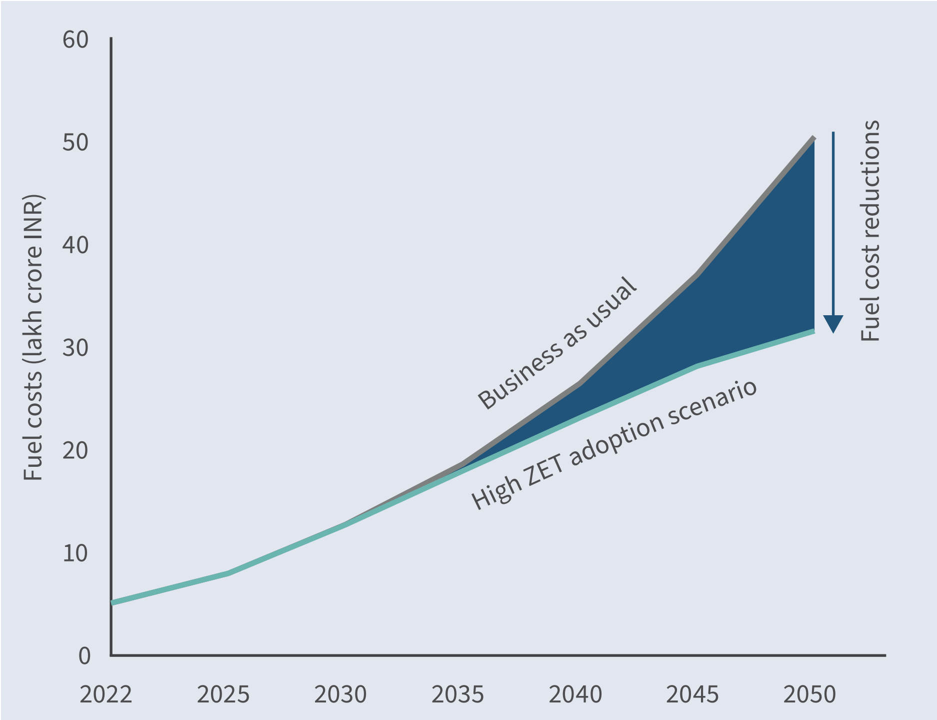


Exhibit 18: Diesel fuel costs in a business-as-usual vs. high ZET adoption scenario

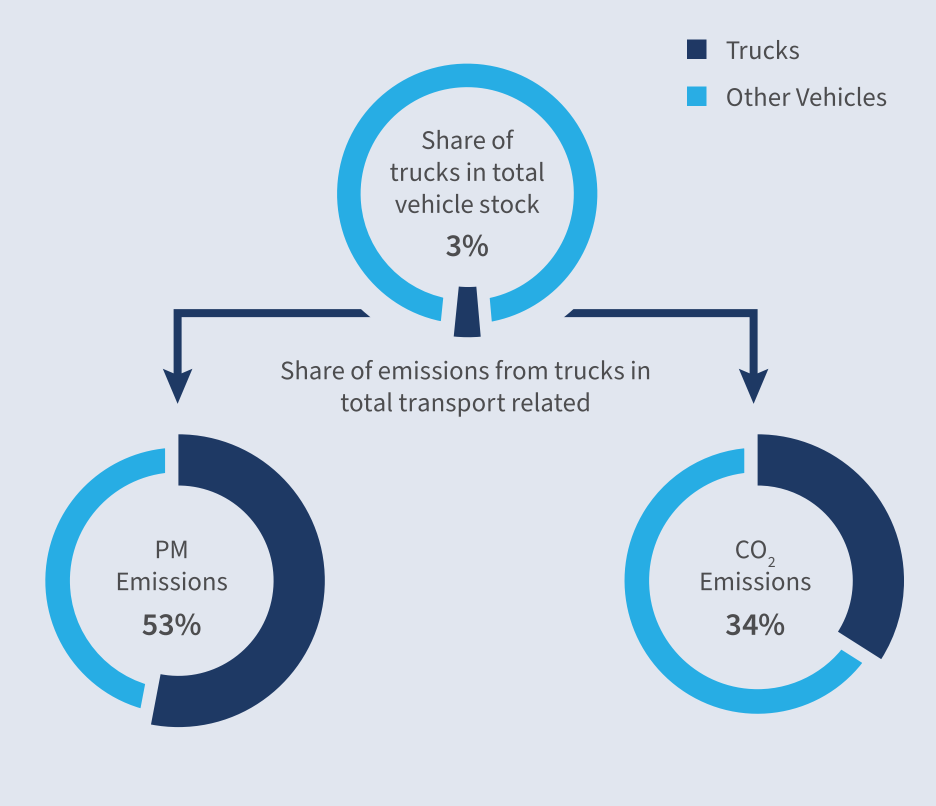


6 Widespread ZET adoption could reduce cumulative trucking particulate matter (PM) and nitrous oxide (NOx) pollution ~40% by 2050, substantially improving air quality.

The trucking sector currently contributes to a disproportionate number of transport-related criteria emissions. Today, trucks represent just 3% of the total vehicle fleet (including both passenger and freight) yet are responsible for a staggering 53% of PM emissions (see Exhibit 19).[16] In 2021 alone, MDTs and HDTs were responsible for emitting around 1.6 million tonnes of NOx and 53,000 tonnes of PM emissions.

Despite the Government of India's push towards reducing criteria pollutants through the implementation of stricter emission standards, such as Bharat Stage VI, NOx and PM emissions through 2050 are expected to increase under a business-as-usual scenario. While the PM and NOx emissions factors of individual trucks will decline with the implementation of the stricter standards, the growth in trucking demand will supersede this decline. The adoption of ZETs is the best long-term solution to reduce air pollution from the trucking sector.

Exhibit 19: Trucking as a portion of vehicle stock vs. contributions to PM emissions and CO_2 emissions



A purposeful transition to ZETs can lead to considerable improvements in air quality and benefit public health, given that ZETs emit zero tailpipe emissions. Achieving an 85% ZET sales penetration by 2050 would lead to a reduction of 750 thousand tonnes of PM and 24.5 million tonnes of NOx emissions through 2050, reductions of roughly 40% (see Exhibit 20 and 21).

Exhibit 20: NOx emissions from diesel business-as-usual vs. high ZET adoption scenario

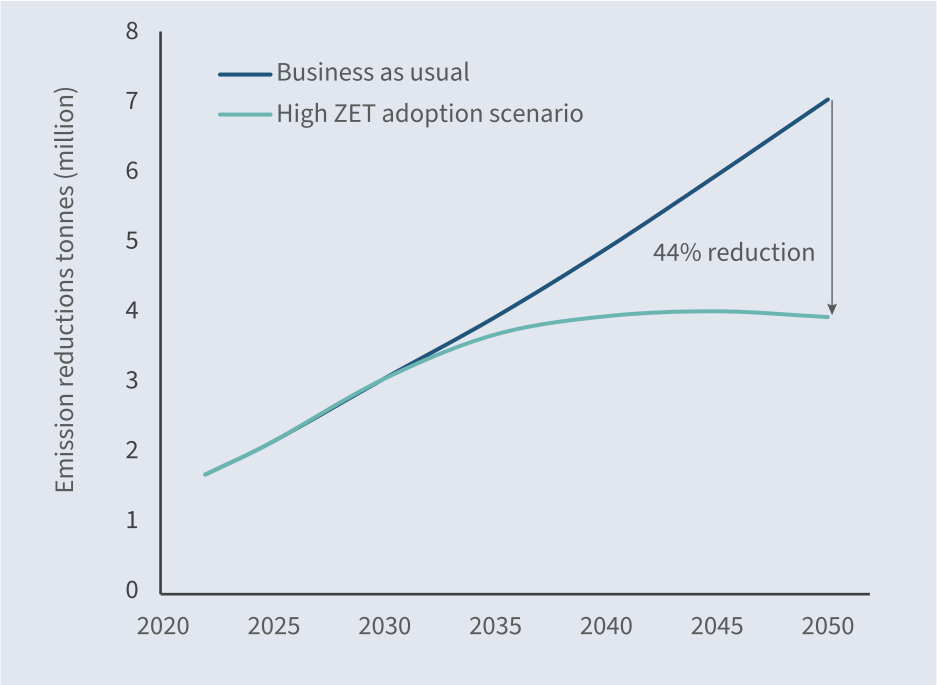
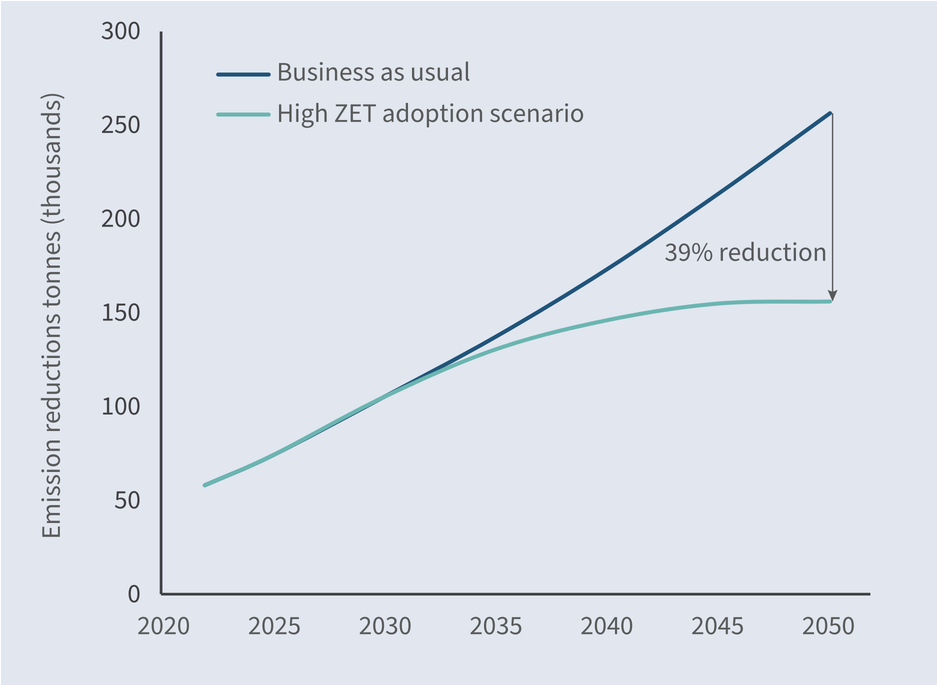


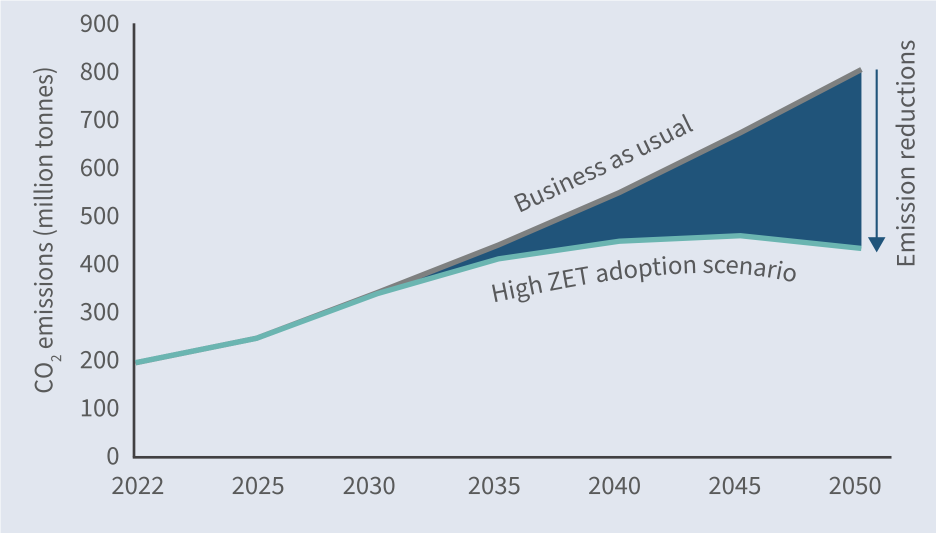
Exhibit 21: PM emissions from diesel business-as-usual vs. high ZET adoption scenario



7 Similarly, widespread ZET adoption could reduce associated trucking carbon emissions 46% annually by 2050, lowering the nation's greenhouse gas (GHG) emissions.

The trucking sector is responsible for one-third of transport-related CO_2 emissions in India. If India's trucking sector stays on its current trajectory, trucks will be responsible for annual CO_2 emissions of 800 million tonnes by 2050, with HDTs accounting for over 50% of the share. In India, widespread ZET adoption could reduce CO_2 emissions by 46% by 2050, totaling 2.8–3.8 gigatonnes of cumulative CO_2 savings today through 2050 (see Exhibit 22).

Exhibit 22: CO_2 emissions reductions in diesel business as usual vs. high ZET adoption scenario

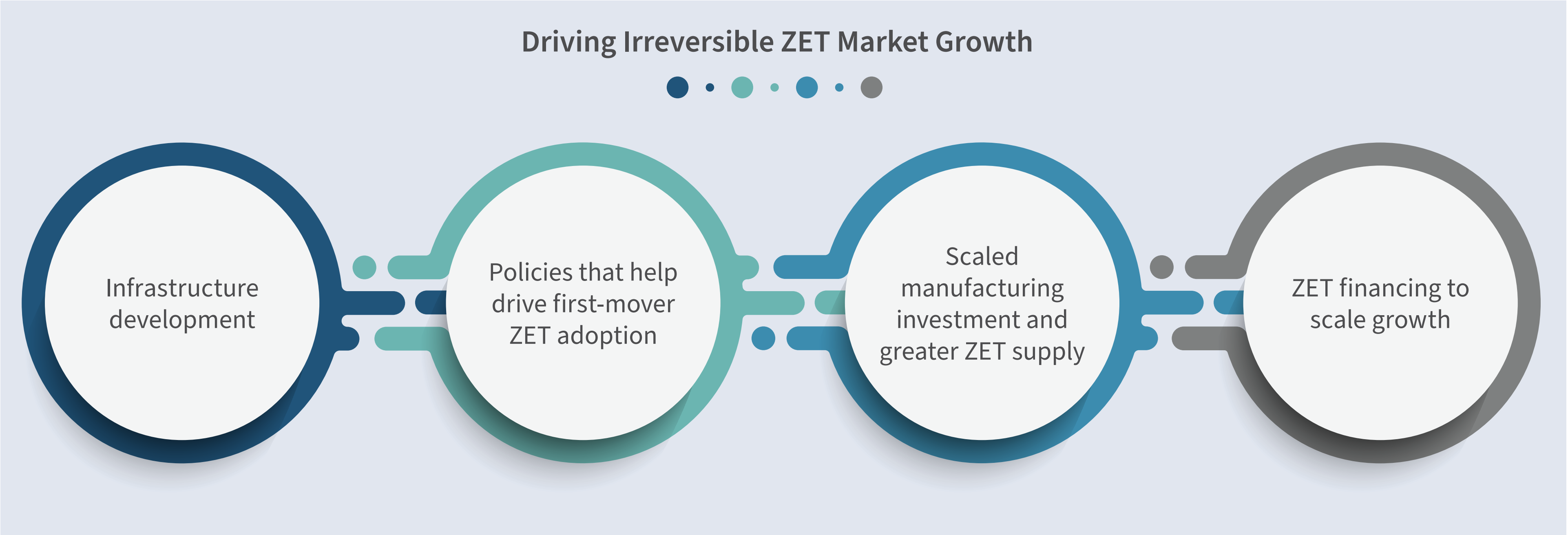


8 The early state of the overall ZET market in India requires a coordinated ecosystem approach spanning the public and private sectors.

The benefits of the ZET transition are clear and profound, yet they will not unfold naturally or without decisive intervention. To capture the benefits of ZETs, a concerted and coordinated effort across stakeholder groups is required to harmonise ZET demand and supply and to drive market scale. Left unchecked, a range of policy, infrastructure, and market barriers will prevent India from fulfilling the vast potential of trucking electrification. Without dedicated efforts, fleet operators cannot simply or efficiently convert their fleets into zero-emissions vehicles, which currently carry higher upfront capex costs compared with diesel trucks. Lack of charging infrastructure and unavailability of ZET models hinder high-speed adoption.

Yet with innovative policy, technology, infrastructure, and finance strategies, public-private partners can help India unlock opportunity and seize value in the transition, from connecting fleet operators and manufacturers with policy and finance solutions, to supporting critical emissions-reduction and energy security goals.

Exhibit 23: Interconnected actions to drive irreversible ZET market growth

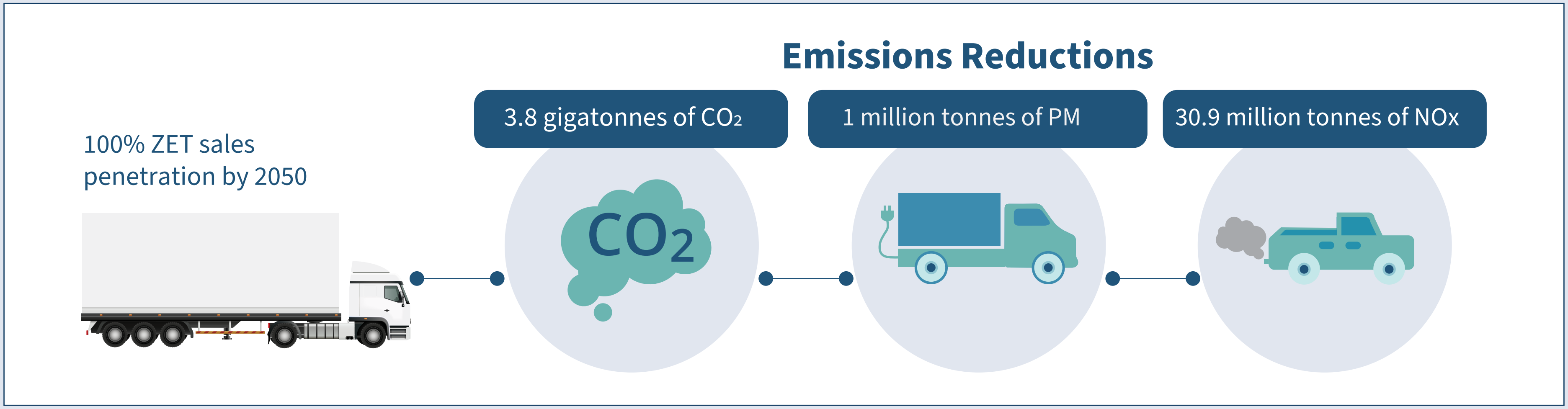


Box 1: Scaling ambition to reach net-zero 2070 targets in the trucking sector

Under a more ambitious scenario that aligns with India's net zero 2070 goal, the trucking sector will be on track to achieve a 100% ZET sale penetration by 2050. Achieving this target in the trucking sector is entirely possible. By leveraging policies, financing, and domestic R&D investments, India can become a zero-emissions trucking hub.

By achieving 100% ZET sales penetration, 3.8 gigatonnes of carbon emissions can be eliminated from the trucking sector — an additional gigatonne compared to the high ZET adoption scenario shown in exhibit 24. Reaching a 100% sales penetration level can also yield additional air quality improvements, lowering PM emissions by 57% (1 million tonnes) and NOx emissions by 59% (30.9 million tonnes).

Exhibit 24: Impact of 100% ZET sales penetration



Solutions

Overcome barriers to mass ZET adoption with policy, technology, charging, and financing pathways

ZET adoption presents significant economic, public health, industrial competitiveness, and emissions-saving opportunities for India. Yet, seizing those opportunities will require new solutions and coordination across the market ecosystem. The far-reaching benefits of a ZET future are within reach for India, with concerted, near-term market creation and policy action. From fostering supply and demand to investing in targeted charging infrastructure, India's leaders have an actionable toolset available now to help scale ZET adoption across the country.

The following section explores key questions that many public- and private-sector leaders may have about ZET solutions, including:

1. How can **policy interventions** support demand- and supply-side market dynamics to help industry players manage risk, reduce costs, and seed the nascent ZET market?
2. What role should R&D investment play in ensuring **technology and manufacturing** is equipped to support a ZET model with the right mix of duty cycles and trucking options?
3. What potential pathways exist for Indian leaders to ramp up **charging infrastructure**, from cost reduction and grid infrastructure development to reliable load management?
4. How can **financing strategy** alleviate risk, improve access to credit, and ultimately help vital ecosystem participants finance their own business transition to ZETs, including original equipment manufacturers (OEMs), charging infrastructure providers, and fleet operators?

Box 2: Targeted investments and policy interventions to achieve TCO parity

The total cost of BET ownership can improve significantly as economies of scale improve. The TCO numbers outlined in the economics section earlier depicts how TCO parity is achieved when ZET production reaches economies of scale and there is optimised charging infrastructure utilisation. To reach economies of scale in a short period of time, targeted investments and regulatory measures that incentivise and encourage ZET manufacturing capabilities will be critical to drive down the cost of ZETs and reach TCO superiority sooner.

Scaled manufacturing

To overcome this nascency period and improve ZET manufacturing capacity, private and public investments are needed to begin ZET production and increase production volume to achieve economies of scale. The market cannot effectively grow without vehicle supply. Supply-side policies like sales targets can provide traditional OEMs incentive to innovate and encourage startups to enter the market. Supply-side policies have been the most effective regulatory tool used globally and have been the driving force behind sustained ZET adoption in the United States and Europe.

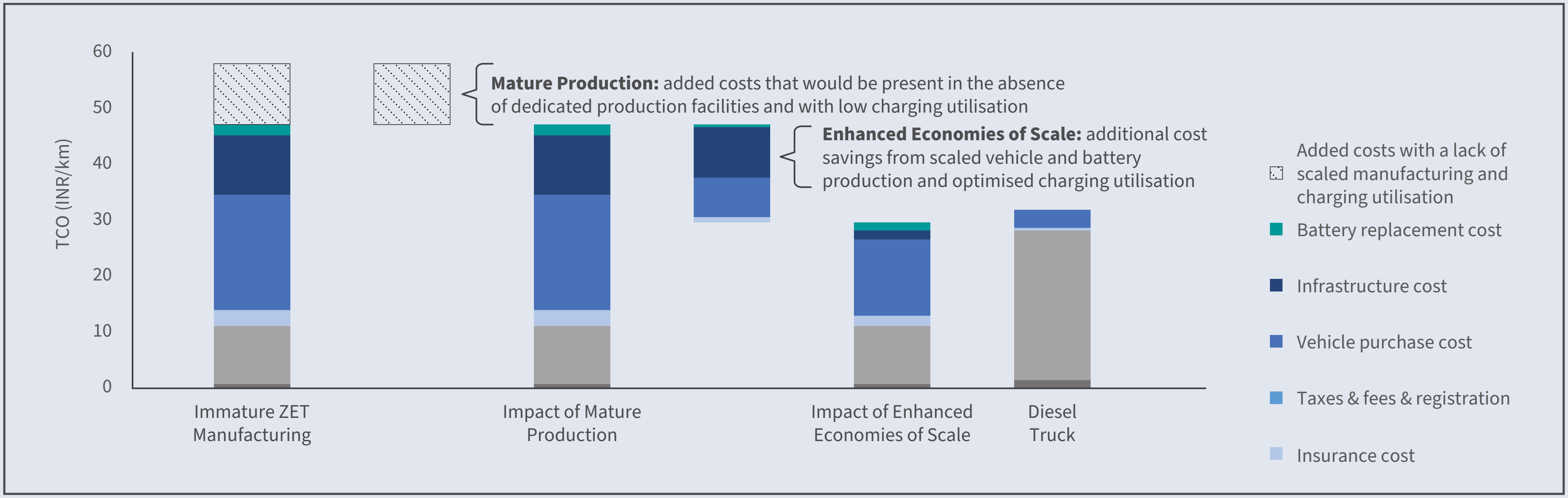
A three-pronged strategy is required for ZETs to reach TCO parity in the HDT sector:

1. Encourage manufacturers to increase ZET production, reducing per-unit costs through larger production runs.
2. Increase domestic battery production and reduce battery prices to achieve parity with the global market average price.
3. Increasing charger utilisation or subsidise public charging infrastructure development until achieving economies of scale.

Exhibit 25 depicts how these three tools can coalesce to continue to drive down costs until ZETs reach TCO superiority. This chart captures how improvements in vehicle production and battery manufacturing and increasing charger utilisation can further drive down the TCO of ZETs. The TCO of electric HDTs will remain high until ZET domestic production capacity is scaled. It also depicts the impact of mature market production and outlines how economies of scale can lead to near cost parity with diesel counterparts across all trucking use-case applications. Economies of scale can bring down the costs of the truck by an additional 20% due to production efficiencies. Dedicated investments to achieve high volume battery production can lower the cost of batteries in India from $220/kwh today to the global average price of $125/kwh.[17] And, Increasing infrastructure depot and end-route utilisation by 20% can lead to lower infrastructure costs resulting in near ZET TCO parity with diesel vehicles within HDT long-interstate use cases — the hardest sector to electrify.

Government investment to seed the nascent market can enable OEMs and charging infrastructure providers to increase production capacities. Failure to achieve economies of scale efficiently will lead to ZETs having a higher purchase price than equivalent diesel vehicles for years to come and will require prolonged government subsidy to incentivise ZET production. Targeted investments to help weather ZET technology's nascent period can drive production scale. Once market entrants overcome the R&D stage, their businesses can become self-sustaining, given ZETs potential for performance, economic, and environmental benefits. As vehicle costs decline and charger utilisation grows, the government will be able to withdraw support, and natural market forces will lead to ZETs growing in market share.

Exhibit 25: The effect of scaled production and improved charging infrastructure utilisation on HDT long-haul total cost of ownership



1.

Policy Interventions

Expanding current electric vehicle (EV) policies while shaping new demand- and supply-side policies will accelerate the road to truck electrification

India has already made meaningful progress fostering passenger EV adoption, creating opportunities to adapt existing policies as frameworks to support ZET adoption. For example, vehicle electrification policies, charging standards, and fuel standards have all helped spur the light-duty EV market in several ways, including reducing upfront costs of EVs and infrastructure, providing tax waivers, and establishing targets and non-fiscal incentives to spur market growth.

Broadening the scope of these current EV policies to include trucks while also introducing ZET-specific policies will be critical to speeding market growth and can motivate industry players to step up their own efforts by helping mitigate investment risks and reduce manufacturing costs.

Mapping out today's policy landscape, with a ZET lens

Exhibit 26: Overview of existing policy landscape

POLICY	DESCRIPTION
National-level EV policies	India's National Electric Mobility Mission marked the beginning of the nation's EV transition. Since then, FAME and FAME II have effectively promoted EV adoption by providing demand incentives for EVs and establishing a network of charging infrastructure. Several other initiatives such as the exemption of registration fees on EVs, the Go Electric campaign, and the Shoonya Campaign actively support the EV ecosystem in India.
Emission standards	Bharat Stage VI (BS VI) emissions standards are designed to improve air quality by reducing tailpipe emissions such as PM and NOx. The BS VI standards require trucks to emit 63% fewer PM emissions (g/km) and 88% fewer NOx emissions (g/km) than the former BS IV emission norms.
Initiatives to promote manufacturing	India has launched a series of initiatives to promote entrepreneurship and industrial development to ensure national companies and manufacturers remain globally competitive. For instance the Aatmanirbhar Bharat (Self-Reliant India) Campaign sets a vision for India to become self-reliant and enhance its domestic manufacturing capabilities and exports.
Initiatives to improve logistics efficiency	India is working to reduce logistics costs as a share of GDP from 14% to less than 10% by 2022. This includes development of road highway infrastructure, multi-modal logistics parks, dedicated freight corridors and warehousing infrastructure.
Incentives on battery manufacturing	The National Programme on Advanced Chemistry Cell (ACC) Battery Storage is designed to improve India's battery manufacturing capabilities and catalyse battery and ZET manufacturing. Additionally, the PLI Scheme for Automobile and Auto Components Industry provides incentives to enhance India's manufacturing capabilities for advanced automotive components and battery electric and hydrogen fuel cell vehicles.

POLICY	DESCRIPTION
Sub-national actions and initiatives on ZETs	States are committing to broader ZET deployment. Telangana has endorsed the Drive to Zero Campaign and has agreed to a Memorandum of Understanding with other global actors to have 100% of new truck sales be zero-emission vehicles by 2040. Additionally, the Maharashtra EV policy establishes a target to make four key highways fully EV-ready by 2025 and outlines how these corridors would have charging infrastructure suitable for long-haul electric truck transport. In addition, eighteen states or union territories have established EV policies to promote the electrification of urban transportation.

The launch of India's national- and state-level EV policies has introduced a wide range of fiscal and non-fiscal incentives and targets for manufacturing and adoption of EVs and associated charging infrastructure. To date, these policies and schemes have helped accelerate EV market growth and strengthened fuel security — but their focus is primarily limited to two-, three-, and four-wheelers and buses. While these policies do not specifically mention MDT and HDT electrification, they do provide a framework for policymakers to expand existing programs or craft similar initiatives to foster ZET manufacturing and adoption in India.

India has already set fuel-economy and emissions standards for trucks, which will evolve over time, and the Bureau of Energy Efficiency currently requires trucks to improve their fuel consumption (km/litre) incrementally.[18] Recently, Bharat Stage VI Standards were also implemented to regulate vehicular emissions of air pollutants. As India continues to strengthen its vehicle emissions standards, manufacturers may find it more cost-effective to manufacture ZETs instead of investing in costly equipment to comply with vehicle emissions regulations. Gradually adopting more-stringent efficiency and emissions standards in this way can encourage manufacturers to transition towards ZET production.

With regards to FCETs, India has also started building the hydrogen ecosystem at the right time by laying the foundation stone with National Hydrogen Mission. In line with the mission, Green Hydrogen Policy was launched to help stimulate green hydrogen production for decarbonisation of hard-to-abate sectors.[19] India can leverage this existing momentum around green hydrogen, and draw learnings from global pilots to devise its plan to support FCET infrastructure.

Close-up on demand- and supply-side policy

Expanding existing EV policies to trucks and creating more-specific demand- and supply-side policies can catalyse the ZET market and set the sector on the pathway to high electrification. These policies can be designed to boost the demand and supply of both BETs as well as FCETs.

Demand-side policies to increase consumer demand

Incentives, subsidies, tax exemptions, rebates, and adoption targets can all help seed the nascent market and accelerate fleet operators' transition to ZETs. The policies outlined below can help bring down the upfront cost and ultimately increase the uptake of ZETs:

- **Purchase subsidies can help bring down the upfront cost of ZETs** to unlock their TCO advantage for more adopters. Extending existing incentives or creating all-new schemes for MDTs and HDTs can help spur adoption and lower the purchase price for fleet operators looking to adopt ZETs.
- **Feebates can incentivise ZETs with rebates, while disincentivising diesel trucks with fees.** This self-financing scheme does not work like taxes that add to government revenue. Instead, fees from diesel vehicle sales go towards funding ZET rebates. Fees are defined based on their fuel emissions, calculated in litres/km. Imposing additional fuel cess, pollution cess, and road tax can also fund feebates schemes and help disincentivise diesel.
- **Interest subvention can alleviate high ZET interest rates to propel adoption.** Interest rates for ZET purchases are currently high due to the perceived business and market risk associated with this nascent market. National or state government and other public-sector undertakings can help remove this market barrier by subsidising part of the interest rate on ZETs — an approach that has often proven effective in bringing down monthly payments as well as interest rates for purchasing ZETs.
- **Fleet purchase requirements can establish a fleet electrification timeline for commercial freight operators.** The purchase requirements can be incremental, and over time the government can require that an increasing percentage of medium- and heavy-duty vehicle fleets are electric. This program can encourage ZET adoption by fleet aggregators.
- **Scrappage policy and incentives can help eliminate high-emitting, old, and unfit trucks from India's roads.** The existing national Vehicle Scrapping Policy mandates scrappage of commercial vehicles, including trucks older than 15 years if they fail to pass the fitness test. Per the policy, a consumer is provided a scrap value on de-registration of an old vehicle, and an upfront discount and motor vehicle tax rebate on purchase of any new vehicle.[20] Effective implementation of such a policy for freight trucks can act as an incentive for fleet operators to buy new ZETs. Moreover, the government can provide additional scrappage incentives for buying ZETs on submission of scrappage certificate.[21]
- **Zero-emissions zones (ZEZs) provide unrestricted access to zero- or low-emissions vehicles and restrict polluting vehicle use.** A demarcated zone could be as large as a few streets or even an entire city (e.g., Rotterdam).[22] Whatever the size, these zones incentivise ZETs by easing traffic conditions, and in turn encourage fleet operators to incorporate more ZETs into their fleets in order to meet their delivery demand within these jurisdictions.
- **Waiving entry restrictions for ZETs.** Several Indian cities restrict truck travel during specific hours of the day. Waiving these restrictions could provide an additional incentive and operational advantage for ZETs, thereby improving the business case for shifting to ZETs.

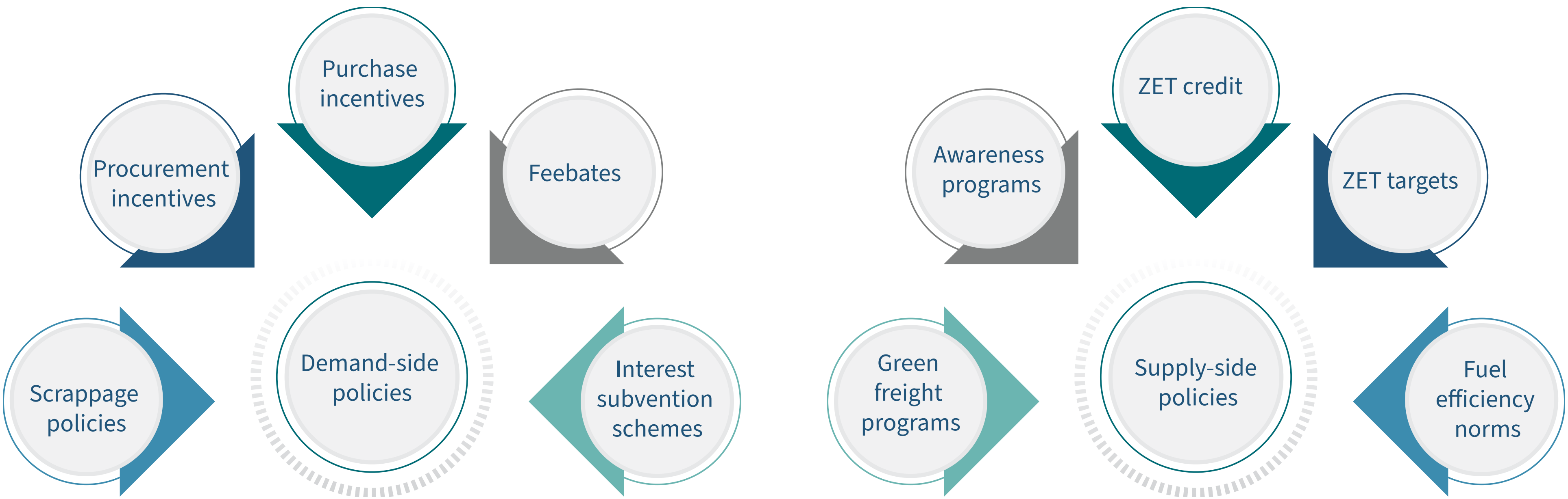
Supply-side policies to encourage traditional OEMs to innovate and startups to enter ZET manufacturing

Clearly defined targets and goals set by the government can send market signals while boosting ZET manufacturing and deployment efforts. Implementing emissions standards can also disincentivise the sale of inefficient trucks. Each of the policies outlined below can encourage ZET manufacturing and help OEMs achieve economies of scale for ZET production.

- **ZET credit schemes ensure a certain percentage of an OEM's new truck sales are zero emitting.** To earn credit, OEMs must sell a certain number of ZETs or purchase credits to fulfil the quota from a ZET manufacturer, which can be increased over time. If an OEM sells more than the policy requires, then they may trade excess credits, incentivising first adopters and new market entrants alike by providing an opportunity to earn revenue.
- **ZET targets send a market signal that the government is committed to electrifying the trucking sector.** Such policies galvanise OEMs to set production targets to achieve specific adoption timelines. Several countries/states including Austria, California, Cape Verde, and more have already established their own ZET targets (see Box 4).[23]
- **Fuel efficiency (FE) norms reward OEMs manufacturing vehicles with low emissions, while penalising those with high emissions.** Fuel standards can be designed as a regulatory standard or take a market-based approach. Thus far, India has taken a regulatory approach, implementing fuel consumption standards for commercial vehicles. Continuing to strengthen fuel consumption standards can spur market innovation and nudge manufacturers to shift to ZETs. For instance, some fuel standards have been designed as a cap-and-trade program to limit the emissions of fuels, and reward OEMs who overachieve targets by allowing them to sell their extra credits, creating an additional revenue stream. India's market-based Perform Achieve Trade (PAT) scheme involves a similar market mechanism for exchanging credits (EScerts) across high-emitting industries and has already successfully reduced emissions in regulated industries.

Public-private collaboration is key to the effective implementation of any of these outlined schemes. The Indian government and its strategic partners should engage with the private sector to understand on-the-ground challenges, gain different perspectives on the impact of any potential policy, and ultimately co-design mechanisms that enable these actors to overcome market barriers and build a sustained demand and supply of ZETs. Throughout, streamlined logistical processes and clear coordination across state and national government bodies will be critical to smooth operationalisation. For instance, the successful adoption of Bharat Stage VI and the FAME II schemes stemmed directly from coordinated private engagement and public awareness initiatives, as well as sustained policy implementation and monitoring. A similar spirit of public-private partnership can support implementation of demand and supply policies for ZETs in India.

Exhibit 27: Examples of supply- and demand-side policies to facilitate ZET growth



From concept to practice: Policy leadership in other major economies

Box 3: California Charges Ahead on a ZET Sales Requirement

In California, the world's fifth-largest economy, emissions from the transportation sector represent over 50% of the state's total carbon emissions. In order to meet 2030 climate targets, state leaders have adopted a series of targets to transition to zero-emissions passenger and freight vehicles — and made California the first jurisdiction to enact zero-emissions freight vehicle sales requirements.[24]

In June 2020, the California Air and Resources Board (CARB) adopted the Advanced Clean Trucks (ACT) regulation, a sales requirement for manufacturers to sell an increasing percentage of ZETs. The enacted sales mandate is divided into three vehicle groups, each with differing sales penetration requirements. By 2035, 55% of new class 2b–3 (3.8–6.3 tonnes) pickup trucks and vans, 75% of class 4–8 (6.3 tonnes and above) rigid trucks, and 40% of class 7–8 (11.7 tonnes and above) tractor truck sales are required to be zero-emissions vehicles. The state has devised an accounting process to track credit compliance. Manufacturers accrue deficits based on the number of vehicles sold within California, beginning with the model year 2024, and the number of vehicles sold is then multiplied by the percent sales requirement and a weight class modifier. Each manufacturer must incur credits by selling vehicles that meet California's standards for emissions criteria to offset their accrued deficits.[25]

Moreover, CARB has developed Advanced Clean Fleets regulation that promotes the demand of ZETs, as California plans to enact complementary rules to drive demand. The state is currently deliberating on zero-emissions fleet requirements for drayage trucks and commercial fleet vehicles.[26] This policy would spur the demand and reassure manufacturers that there will be sustained demand for ZETs. The implications of the ACT regulation and advanced clean fleet electrification regulations will likely have national, even global, effects as truck manufacturers cater to the new rule. Given California's global market share, this progressive policy will help increase the number of ZET models offered in the global supply chain, helping spur the transition to ZETs well beyond California's borders.

Box 4: Global momentum to ZET adoption

Countries across the globe are using policy mechanisms to help stimulate a ZET market shift. Several countries have introduced ZET targets (Exhibit 28) and/or strengthened or adopted new policies and mandates to seed the market and incentivise OEMs to manufacture ZETs. Policymakers and industry leaders are also beginning to explore opportunities to spur ZET development to remain competitive in global supply chains.[27] Technology advancements, carbon-reduction targets, and policy schemes aiming to reduce trucking-related emissions have initiated the shift to ZETs in locations from California to Cape Verde, and many in between.

Exhibit 28: Countries/states with targets aimed at accelerating ZET manufacturing and demand [28]

COUNTRY/STATE	TARGET
Austria	100% of newly registered HDTs less than 18 tonnes by 2030, and 100% of those weighing more than 18 tonnes by 2035
California	100% of MDT/HDT by 2045
Cape Verde	100% of new MDT/HDT by 2035
Norway	50% of new MDT/HDT by 2030

The European Union initiated a CO_2 corporate standard, and OEMs will need to meet fleet-wide average CO_2 emissions standards to be compliant. The policy targets a 15% reduction in CO_2 emissions for MDT and HDT fleets by 2025 and a 30% reduction in average fleet CO_2 emissions by 2030. The UK recently announced that it will ban the sale of diesel trucks in the country beyond 2040 and all new trucks sold will be zero-emissions based.[29]

As part of the international Drive to Zero Campaign, Austria, Canada, Chile, Germany, Greece, the Netherlands, Norway, and Sweden all signed a memorandum of understanding (MoU) in May 2021 to foster leadership and international coordination to accelerate ZET adoption. The MoU aims to ramp up ambition towards 100% ZET adoption before 2050, foster collaboration, and send a clear market signal to investors and manufacturers.[30]

2.
Charging Solutions

A menu of versatile charging options is available now — along with clear pathways to implementation

Achieving widespread charging infrastructure is crucial to enabling ZET adoption. Fleet operators, governments, electricity distribution companies (DISCOMs), and charging infrastructure providers must establish short- and long-term strategies for assessing and addressing charging infrastructure needs. Infrastructure, particularly at depots and along freight corridors, is required to electrify long-haul and regional-haul freight applications. The first step is to understand the array of charging solutions available to India's trucking leaders today.

Today's charging strategies

Providing the right mix of charging strategies and types of chargers is critical for enabling ZETs to travel a range of distances and for charging infrastructure providers to maximise charging station utilisation. Fleet operators will also need to consider how any potential charging strategy aligns with dwell times, business operations, and vehicle model types. For example, a fleet operator that has already made significant investments in warehouses, truck yards, and depots may benefit form a different charging approach than companies that do not operate on a return-to-base model.

Exhibit 29: Charging Strategy[31]

CHARGING STRATEGY	DESCRIPTION	BENEFIT	DRAWBACK
Plug-in Charging			
Depot charging 	Charging occurs at an operator's hub, such as a truck yard or warehouse. These privately owned chargers typically charge overnight when a fleet is not operating.	• Supports overnight charging and can align with existing fleet operating schedules. • Users will pay less on a per-charge basis.	• Fleet operator will be responsible for deploying charging assets, including hardware, electrical, and soft costs. • Access to dedicated depots might only be available to larger fleet operators, whose market share is much lower compared to owner-operator trucks.
En-route charging 	Chargers are located along commonly traveled corridors to enable fleets to top off a depleted battery. These chargers could be public charging or battery swapping assets, and should offer high-capacity, high-speed charge to reduce downtime.	• Enables ZETs to travel longer distances. • Users need not make a capital investment in charging infrastructure; instead, they can pay per charge.	• The driver will need to wait with the truck to charge, and en-route charging times will likely affect driving schedules. • The costs of a single-vehicle charge may be more expensive than depot charging.

CHARGING STRATEGY	DESCRIPTION	BENEFIT	DRAWBACK
Battery Swapping			
Battery swapping 	Instead of using a plug-in charger, drivers trade out batteries for fully charged replacements at conveniently located swapping stations.	• It takes far less time to swap a battery than to charge a depleted one. • The time it takes to swap a battery is comparable to diesel truck refueling times.	• Differing battery-pack configurations could lead to additional costs. • This solution requires significant capital outlay to cover extra batteries and stations that can service large ZET batteries.
In-Motion Battery Charging			
Catenary charging 	Electrical lines help charge trucks while they are en-route. Charging can take place via overhead wires, embedded wireless power transfer systems, or underground power tracks.	• Batteries recharge while the truck is in motion, eliminating charging downtime. • ZET batteries could be much smaller.	• Building overhead electrical charging involves substantial capital and maintenance expenditure. • Trucks would only be able to travel along routes with overhead charging infrastructure.
Inductive charging[32] 	Also called dynamic charging, this method uses coils installed under the asphalt. These coils transfer energy through electromagnetic induction to provide electricity to charge a small truck battery.	• Requires smaller truck batteries as the truck is recharged during route. • Eliminates the need for plug-in charging and waiting to recharge.	• Requires major roadway infrastructure maintenance. • Is capital-intensive and any maintenance associated with the coils would require road cutting.

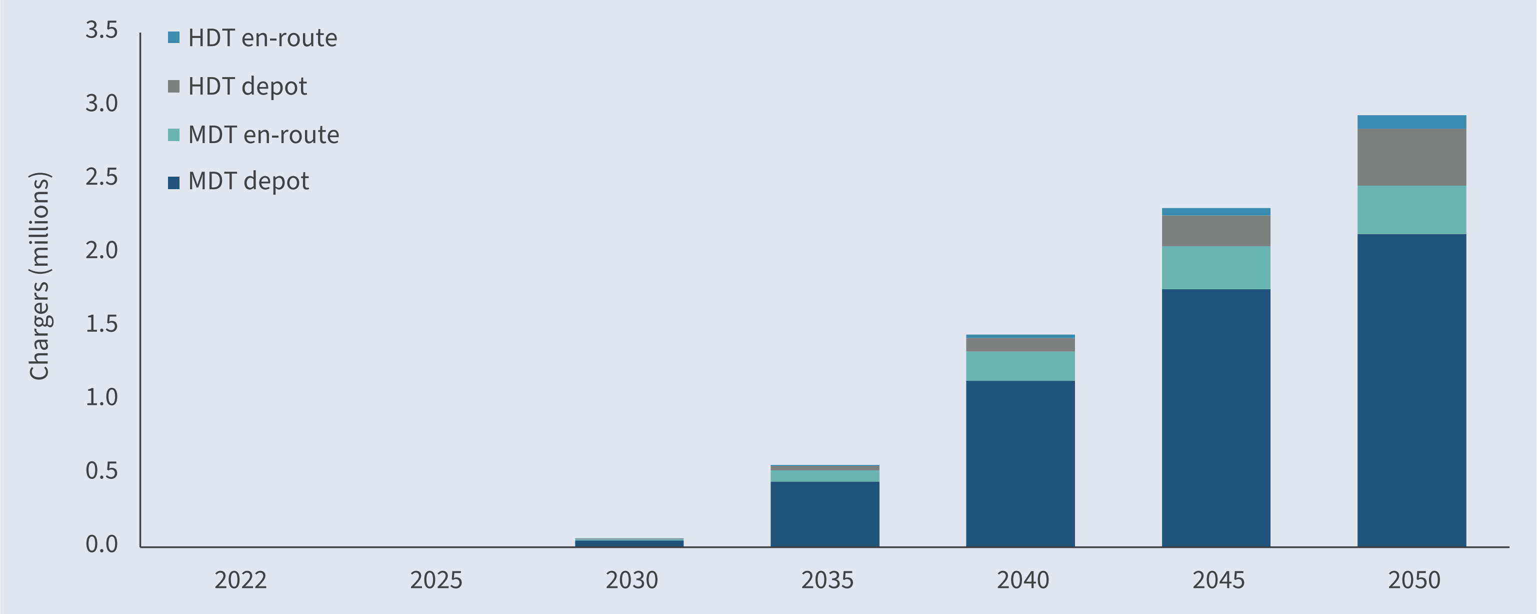
Given that plug-in charging is a mature technology, existing infrastructure is already underway to facilitate EV charging. Therefore a likely scenario is that **fleets will utilise a mixture of plug-in depot charging and en-route fast charging.**

- *Depot charging will give fleets a secure location to charge vehicles overnight.* Lower power depot chargers will allow fleet operators to manage their charging costs, and as such these chargers will likely provide the bulk of daily charging in regional and urban duty cycles.
- *En-route fast charging will enable ZETs to travel farther during the day, enabling the electrification of more trucking applications.* Since the dwell time for en-route charging is limited, powerful fast chargers will be better suited for en-route charging.

However, en-route charging means ZET operators pay a higher energy price, as charging operators need to charge a cost premium to recoup the cost of deploying fast chargers. Fleet operators will likely choose to maximise depot charging when possible. Yet in many instances, this will not be possible, such as when a truck is not returning to a depot base or when operators do not own the land they park on overnight. These conditions lend themselves to a greater reliance on en-route charging.

The exhibit below estimates the number of chargers to meet the demands of BETs in India through 2050. From 2030 to 2040, the uptake of electric MDTs is expected to be greater given the operating patterns of these vehicles as well as their favorable economics. By 2040, even more rapid uptake of electric HDTs is expected as charging technology will have also likely evolved, and charger utilisation increased. Thus, the uptick in electric HDTs will require few chargers, but these chargers will have a higher power capacity of 150 Kw and greater.

Exhibit 30: Total charging units required



Box 5: How battery size affects charging needs

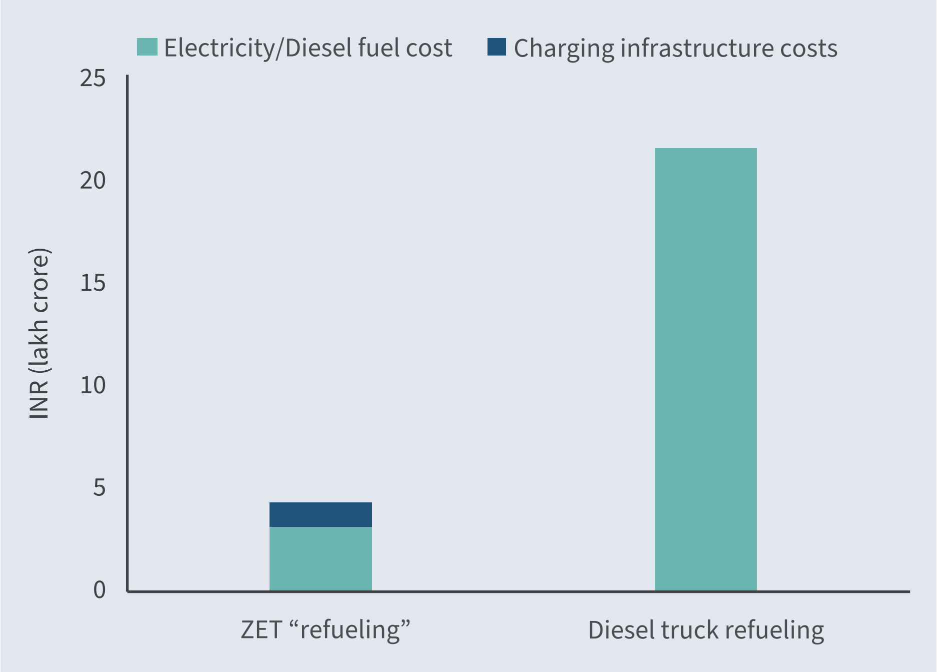
Given the size of ZET batteries, a Level 2 or moderate-power charger is likely the smallest charger feasible for MDT charging. A Level 2 charger, which operates at 208–240 volts/22 kw and uses a three-phase current to deliver AC charge to batteries, will likely be common for depot charging.[33] HDTs require a higher capacity charger at a minimum DC charger with 50 kW.

For en-route fast charging, a direct current fast charger (DCFC) is forecasted as the best option. DCFC chargers currently operate at 415 volts/50–500 kW and deliver DC charge. However, research and development on megawatt (MW) charging is currently under way and will likely become available in several years.[34] Already in the United States, for example, Portland General Electric and Daimler Trucks have installed a public fast-charging station for HDVs with a power level of 1 MW.[35] As the technology evolves, fast charging can play a key role in en-route charging to minimise charging times. However, the most economical charging will continue to be lower power capacity charging as it will require significantly less investment in electrical infrastructure.

Cumulative annual charging infrastructure investment costs are projected to reach approximatley 3,000 crore by 2030 and 1.2 lakh crore by 2050. Infrastructure investment accounts for hardware, installation, and maintenance costs over a unit's lifespan. These costs do not include land, construction, or grid infrastructure costs, which vary considerably based on local conditions.

The bottom line: Different businesses will have different demands for charging, and no one charger or charging utilisation strategy will fit every use case. The deployment of private depot vs. public en-route chargers will depend on the changing needs of fleets, existing electrical infrastructure, and the ability of private and public sector stakeholders to develop comprehensive charging solutions that understand and meet those needs.

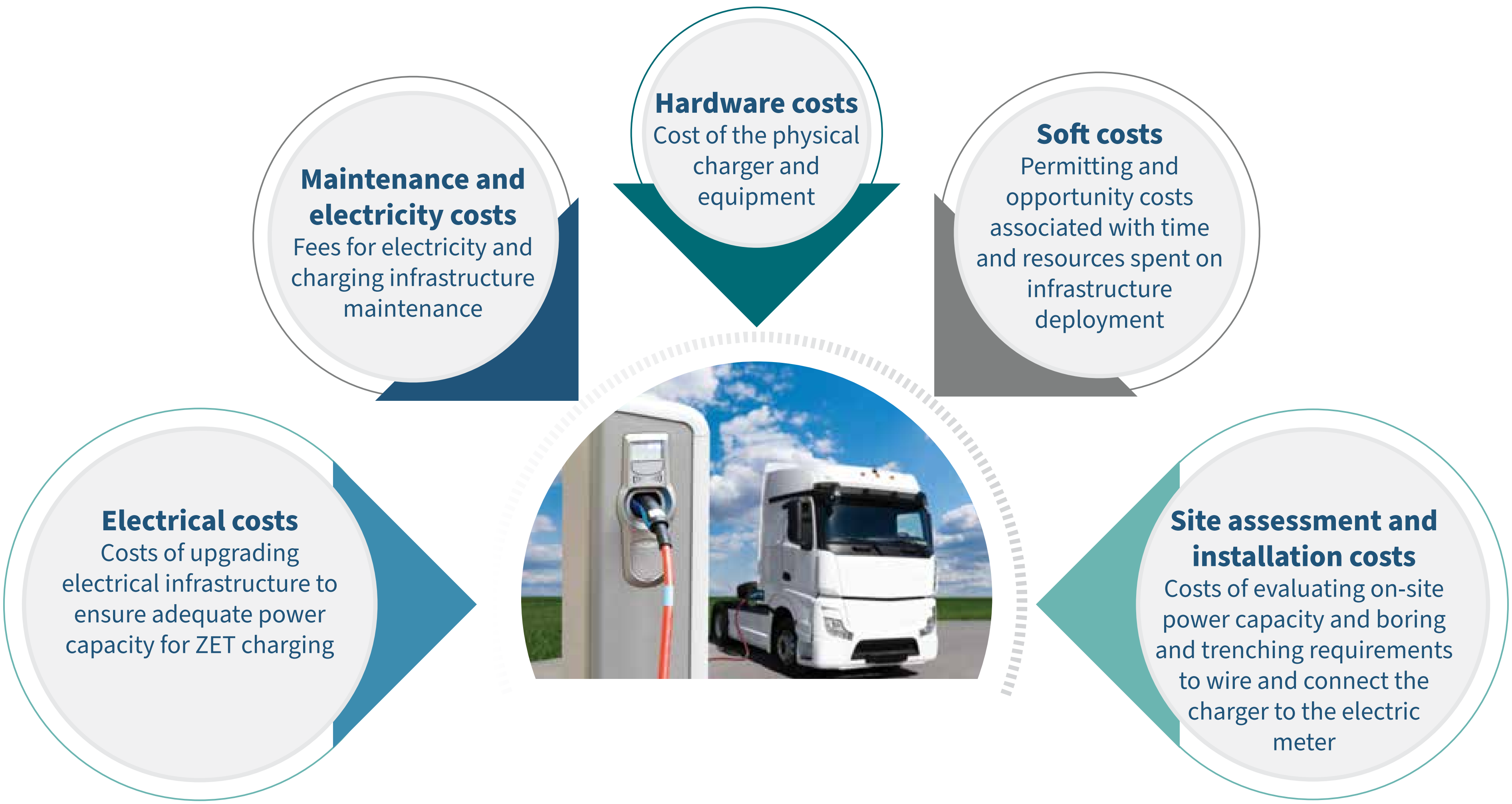
Exhibit 31: Cost of chargers and electricity to power 2050 EV stock vs. the cost of diesel to fuel equivalent vehicle stock



Pathways to delivering a widespread charging network

Strategic cost management is essential to promoting infrastructure development for the urgent transition to ZETs. Typically, the cost to charge BEVs includes hardware, maintenance, electrical, site, and soft costs as shown in Exhibit 32. Each of these components can be managed strategically to reduce the overall cost of charging.

Exhibit 32: Components of charging cost



Pathway 1 Leveraging policy intervention to reduce charging costs

Charging costs vary widely based on factors like the hardware itself (i.e., the size of the charger and its power capacity rating) as well as on operational costs like the cost of electricity and maintenance. For example, hardware costs for purchase and installation of a 22 kWAC charger are roughly ₹0.75 lakh, whereas the cost of a 150 kWDC fast charger can be upwards of ₹18 lakh. Many of the larger 300 kW and 500 kW chargers have yet to be deployed in India and will be more expensive to purchase and install. Land costs are also critical to consider.

As part of the 2022 Union budget, the Indian government announced plans to increase funding for charging infrastructure. The government has also encouraged private players to develop innovative business models to increase the availability of charging. Business models that help distribute the cost of charging infrastructure development and incentives to promote early market entrants to deploy charging infrastructure along highways and business models which distribute the cost of charging infrastructure development can help increase charging availability.

The table below provides a list of interventions that can decrease overall charging costs:

The table below provides a list of interventions that can decrease overall charging costs:

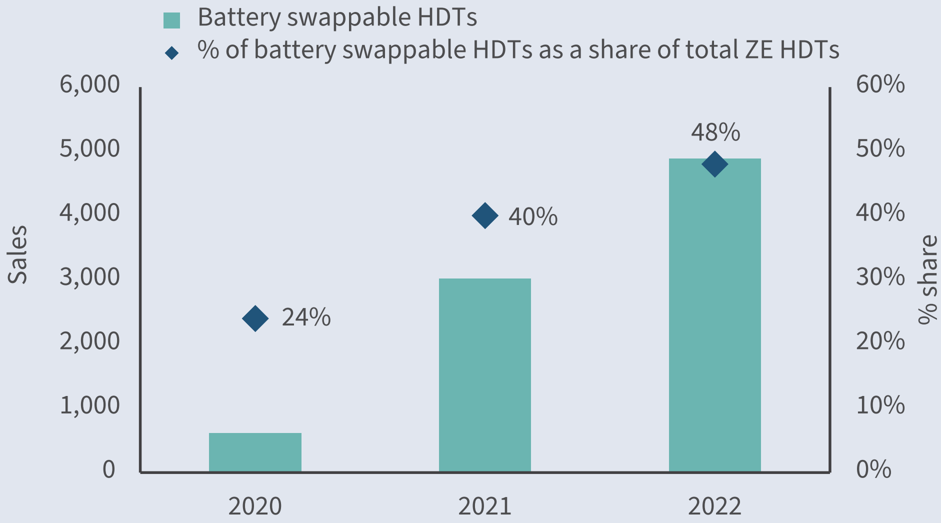
Exhibit 33: Interventions to encourage innovative business models for charging infrastructure

INTERVENTION	DESCRIPTION
Removing demand charges for ZET charging	Specific tariffs that remove demand charges in the near term for ZET charging can reduce the total electricity cost of charging while ZET uptake increases.
EV tariffs	National and State Governments can introduce a special EV tariff that would offer lower electricity prices for charging electric trucks.
Concessional land	Government can provide public land for the installation and operation of charger at bare minimum lease rentals. They can also consider providing public land on a revenue-sharing model, wherein the concessionaire pays a pre-determined share of electricity sold to the government agency.
Enact time-of-use (ToU) or time-of-day (ToD) tariffs	A ToU or ToD tariff for charging could incentivise vehicle charging during off-peak hours — times of day that typically see lower energy demand coupled with high renewable energy generation. Such a tariff structure can be a more effective mechanism for DISCOMs to minimise peak loads, manage costs, and reduce the need for additional distribution capacity.
Subscription-based charging models	Subscription models offer drivers the opportunity to pay one flat (typically monthly) fee to charge their vehicles. This model may be useful for trucking fleet operators that do not want pay the upfront costs for depot chargers and want a means to manage variable charging rates. This type of model can also help charge point operators better manage their revenue flow and can be a means to increase charging availability.
Public Private Partnerships to fund charging infrastructure	Public Private Partnership (PPP) models offer a promising solution to fund the deployment of charging infrastructure. Under such a scheme, both the public and private sector could bear some of the upfront investment cost for charging infrastructure development.

Box 6: Battery swapping for heavy-duty trucks in China

Battery swapping technology provides an alternative strategy to charging electric vehicles. It allows EV operators to swap their battery near the end of its state of charge with a new battery at battery swapping stations. China has witnessed a growing momentum of battery swappable HDTs over the past two years.

Exhibit 34: Number and share of battery swappable HDTs sold in China[36]



Note: 2022 figures are from Jan–Jun 2022

Sales of battery swappable HDTs in China reached close to 5,000 by the first half of 2022, rising from just 600 in 2020. Moreover, these battery swappable HDTs represented half of the zero-emissions trucks sold in China in the first half of 2022. This astonishing growth can be attributed to the following factors:

- **Faster recharging times:** Battery swapping allows the fleet operators to recharge their ZETs quickly (in less than 6 minutes), reducing operational delays and lost revenue from the time spent charging the truck otherwise.
- **Lower upfront cost commitment:** A battery swappable truck is sold without a battery, which can reduce the purchase price by 37.5%, allowing fleet operators with better financing options to procure the vehicle.[37]
- **Shifted responsibility of battery ownership to swapping operator:** The battery is the single most expensive cost element of a ZET. With the swapping model, the onus of battery maintenance and operation is passed on to the swapping operator.
- **Policy support:** The central government in China has allowed battery swappable EVs to be eligible for subsidies. Moreover, local governments such as the Jiangsu province is in the process of standardising batteries for the swapping use case.[38]

Most of China's battery swappable HDTs are deployed in closed-loop systems like industrial parks and ports — where trucks run short distances on specific, predictable routes multiple times a day. This allows swapping operators to accurately size the battery stock and increase station utilisation, eventually reducing costs and maximising revenue.

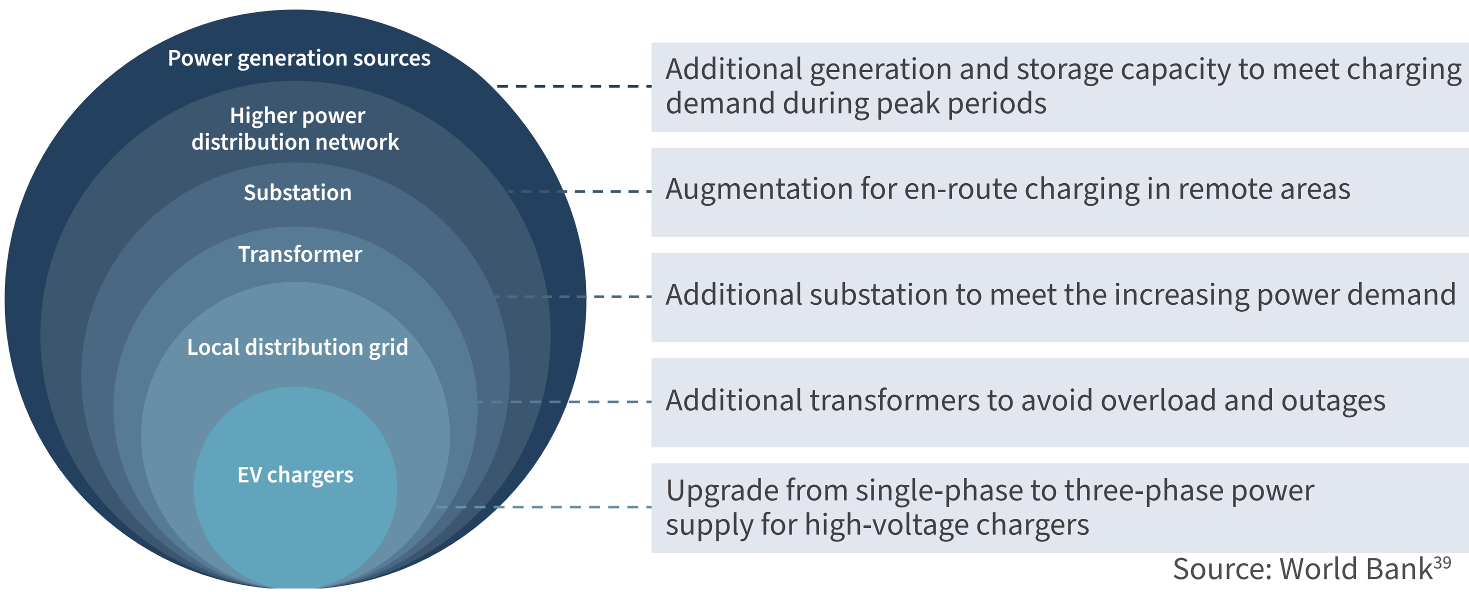
Drawing from the experience in China, battery swapping is most effective for HDTs running on a shorter route with multiple trips. India can look to explore the battery swapping technology through pilots in the near term for specific use cases like port or mining operations to test the feasibility of the technology and eventually scale based on the learnings from the pilot. In the future, with the decreasing costs for vehicle batteries and the increasing commercial viability of ultra-fast charging stations, a combination of charging and swapping can be explored.

Pathway 2 Strategically build adequate power infrastructure

As more ZETs come into the market, evaluating the distribution and transmission capacity of the grid will be a prerequisite for mass electrification. If India achieves an 86% ZET sales penetration in the MDT and HDT segments by 2050, the energy demand from charging the BET stock in 2030 is estimated to be 8.8 terawatt-hours (TWh). By 2050, the energy required for charging MDTs and HDTs could reach as high as 531 terawatt-hours (TWh). This level of energy demand requires investment in generation, transmission, and distribution to ensure power and current can be supplied to satisfy truck charging.

A charging station that draws power from the grid will need to relate to the broader electrical infrastructure network. HDT and MDT mobility requires more power than EV passenger transport and is more on par with e-bus needs. While charging can be managed to reduce the strain on local distribution grids as charging demand increases, electrical infrastructure investments will be needed when the sanctioned load does not meet the charging demand. Investment in upstream electrical infrastructure — such as converting single-phase to three-phase power, installing additional transformers, and re-cabling — is crucial to ensuring smooth charging operations. India is already building interstate bus electric vehicle supply equipment (EVSE), which ecosystem actors could consider planning in concert with HDT infrastructure to help facilitate reliable power supply for all transport needs.

Exhibit 35: How the charger fits with the broader grid network and potential reasons for upgrades



Source: World Bank[39]

Granular data on load availability, grid congestion, and capacity constraints will enable charging infrastructure providers, fleet operators, and DISCOMs alike to make more informed decisions regarding electrical infrastructure investments and charging station development. By projecting future power demand and performing grid analysis, DISCOMs can recommend sites for fleet operators that already have grid capacity. The table below provides specific recommendations that DISCOMs, governments, and fleet aggregators can adopt to prepare for and minimise electrical infrastructure costs.

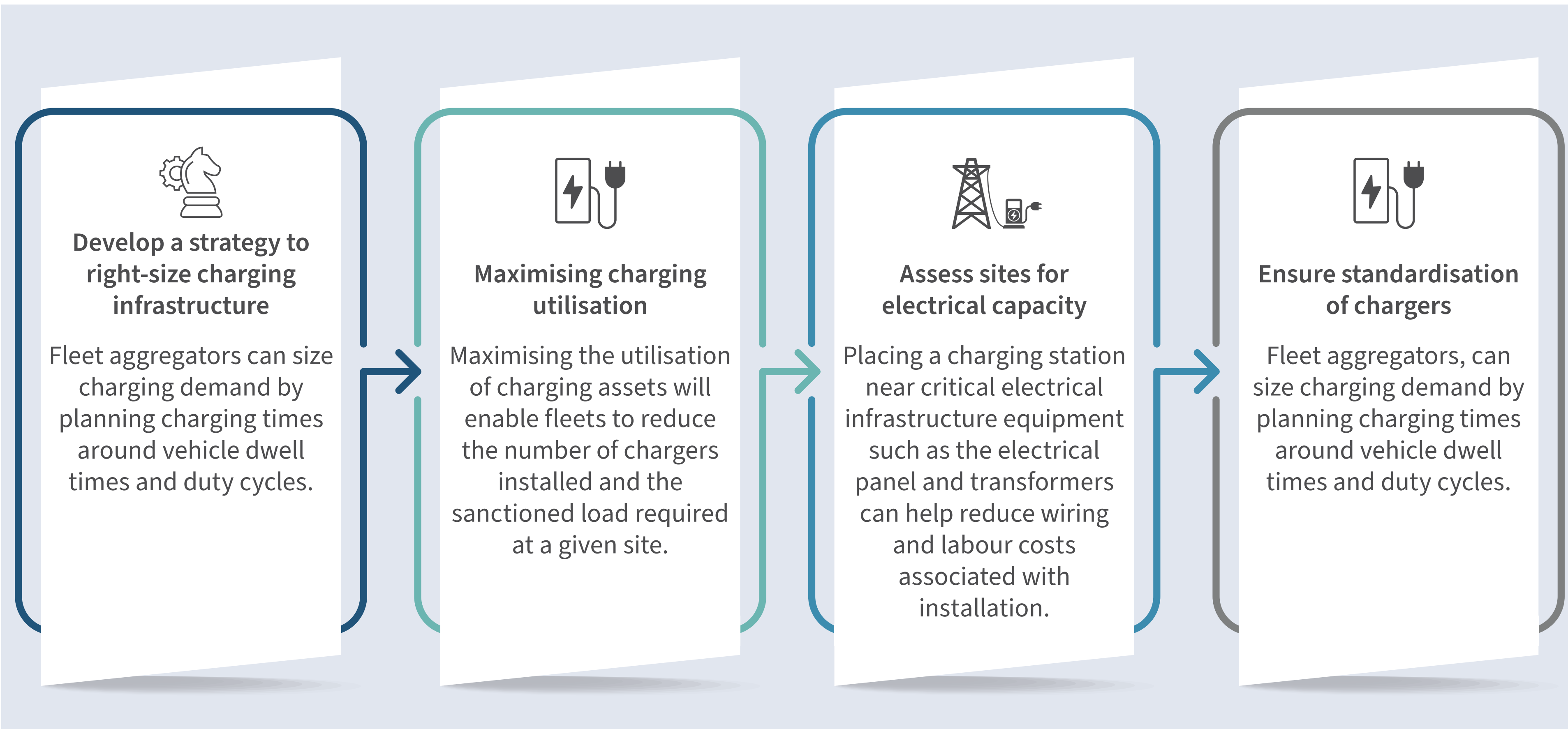
Exhibit 36: Interventions to reduce the electrical infrastructure costs of charging infrastructure deployment

INTERVENTION	DESCRIPTION
Load assessments	Publicly available analysis on load availability by DISCOMs can enable charging infrastructure providers and fleet operators to select charging sites with higher sanctioned loads and minimise electrical infrastructure investment.
Extending the Integrated Power Development Scheme	Through initiatives like the Integrated Power Development Scheme, the Ministry of Power can provide funding for cities to plan for electrical infrastructure growth. With dedicated funding, DISCOMs will be able to more accurately forecast where ZET charging could cause grid congestion and where power draws may exceed the sanctioned load capacity.[40]
Dedicated funding for infrastructure buildout	By extending FAME II incentives or introducing new fiscal incentives, the government can help defray upstream electrical infrastructure costs.
A utility-ready infrastructure scheme	A concerted effort can be made to ensure DISCOMs follow Ministry of Power guidelines for revamping the distribution sector to deploy electrical infrastructure up to the meter. Under a utility-ready infrastructure scheme, DISCOMs would be responsible for maintaining and updating all electrical infrastructure except for the meter. To help DISCOMs pay for these upgrades, state governments or the Ministry of Power could offer grants and financial incentives to DISCOMs. Incentives can also be allocated explicitly for electrical augmentation along highly travelled corridors and within commercial districts.
Energy storage investments	A build-out of high-capacity energy storage can enable India to meet the growing demand for charging with as much renewable energy as possible, and with fewer grid investments. Increasing electricity demand together with falling battery prices will make storage technologies more economically viable and can help pave the way for even greater renewable penetration.[41]
Demand-side management schemes	Managed charging utilises infrastructure assets to optimise the grid by controlling time, power draw, and charging duration to align with times of day when excess grid capacity is available. Under such a scheme, fleet operators and public charging providers could opt into the program to receive preferential electricity rates when they charge their vehicle during off-peak periods. The implementation of smart charging can enable participation in demand response or time-of-use tariff programs. Additionally, installing chargers that can provide reactive power support while pulling real power heavily from the grid can help with grid stability.

Fleet operators must strategically plan infrastructure deployment to reduce capital hardware costs. Sizing infrastructure around vehicle dwell time, ensuring high utilisation of every installed charger, and ensuring interoperability between chargers will all increase demand for charging infrastructure and in turn reduce costs.

Considering future demand growth for fleets and associated charging can enhance infrastructure planning. For instance, to determine whether a site will be suitable for charging, an electrical evaluation is likely needed to assess current capacity and determine whether upgrades are needed. It may be necessary to upgrade electrical panels and wiring to ensure adequate current capacity — key factors in effective infrastructure planning.

Exhibit 37: Strategies for charging infrastructure buildout



Pathway 3 — Streamline infrastructure installation process to reduce soft costs

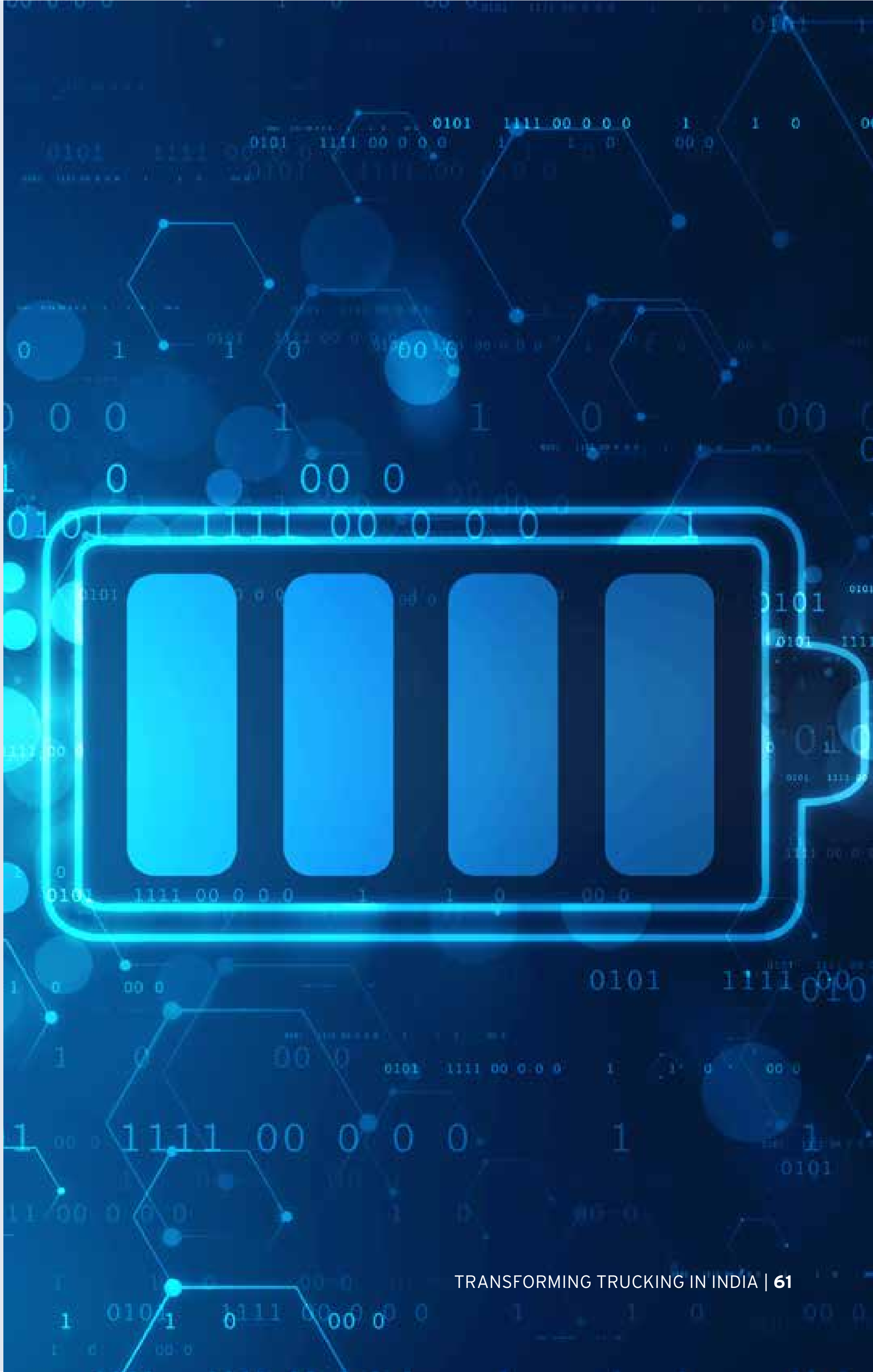
Soft costs comprise of process costs, permitting costs, and opportunity costs associated with charging infrastructure development. Given the power demand that electric MDT and HDT charging will require, sites might have to execute a new or updated electricity connection agreement with their local DISCOM. The time and logistical process of executing a connection agreement can significantly delay a charging infrastructure project. If additional grid upgrades are required, further correspondence with DISCOMs and municipal departments can add costs and delays. Additionally, charging infrastructure providers and fleet operators need to consider the amount of time and money it will take to secure permits for procuring or leasing the land to develop charging infrastructure.

To minimise soft costs, DISCOMs should develop more transparent processes and proactive communications that include notifying fleet operators and infrastructure providers of the status of interconnection applications. Streamlining the interconnection process will help fleet operators and charging infrastructure providers reduce overall costs as well as become more efficient in their capital planning.[42] Providing customers with a single-window process to procure and install charging stations will also reduce processing time and cost. User-friendly online platforms will enable customers to submit a request for load assessment, and ultimately help streamline the process for installing electrical infrastructure.

3.

Technology and Manufacturing

Positioning India as a ZET leader with enhanced vehicle performance and production solutions



To emerge as a global leader in zero-emissions trucking, India should expand its pursuit of innovative technology, localised manufacturing, and a resilient ZET supply chain ecosystem in the following high-level ways:

- Improve battery chemistry, energy density, and fuel cell efficiency to increase the range of electric trucks.
- Enhance performance characteristics such as payload capacity to ensure ZETs across the board are at parity with diesel counterparts.
- Foster a domestic manufacturing strategy to help build a robust supply chain of ZETs, in turn helping fulfil India's long-term trucking demands.

Overall, by purposefully advancing ZET technology, India can drive ZET performance improvements and manufacturing capabilities, eventually bringing cost reductions, too.

Vehicle Performance: Boosting range, payload, and efficiency

Technology innovation is needed to ensure that ZETs' performance characteristics — specifically vehicle range and payload capacity — equal that of their diesel counterparts. Only then will operators have the confidence to transition fully to ZET fleets.

Range: ZET trucks must be able to travel longer distances. Improved range performance will require technological investments in battery energy density (i.e., the energy potential stored in a battery relative to its weight). The past decade has seen significant improvements in battery technology, with automakers shifting from lead-acid to high-density lithium-ion (Li-ion) batteries boasting six times higher density.[43] In the next decade, the energy density of Li-ion batteries is expected to improve by an additional 63%.

Additionally, further advancements are being made in alternative battery chemistries. For example, solid-state batteries are at an early development stage but may facilitate higher energy density. Using solid electrolyte materials also offers enhanced safety and thermal stability.[44] Given the advantages of this next-generation battery technology, several OEMs (e.g., viz., Daimler, Toyota, and Ford) are already undertaking R&D and testing. More recently, Daimler deployed electric buses with solid-state batteries in Germany.[45]

Improvements in vehicle efficiency can also improve range performance, from investing in more aerodynamic body shapes and designs to reduce drag and the energy required for propulsion, to lowering tire-rolling resistance and light-weighting vehicles.[46]

Payload: The weight of batteries in BETs can compromise a truck's payload capacity by nearly 13%. Reducing battery weight leads directly to increased payload capacity, particularly in the HDT segment. Additionally, other light-weighting techniques such as reducing the tractor, trailer, and axle suspension system and frame weight and removing diesel engine components can recoup the "lost" payload.[47]

Charge time: The time a truck spends charging is time spent off the road. Minimising charging time is critical to enabling ZETs to compete against, and ideally outperform, diesel counterparts. To expedite charging in general, onboard charging systems need to be able to handle higher currents. Battery chemistry will also play a major role in bringing trucks greater ramp rates and charge efficiency. India can further research and invest in adaptive fast charging and thermal management to accommodate fast charging, reduce the deterioration of batteries, and increase battery life.[48] Such advancements can increase vehicle range and improve the operational viability of India's long-haul ZET segment.

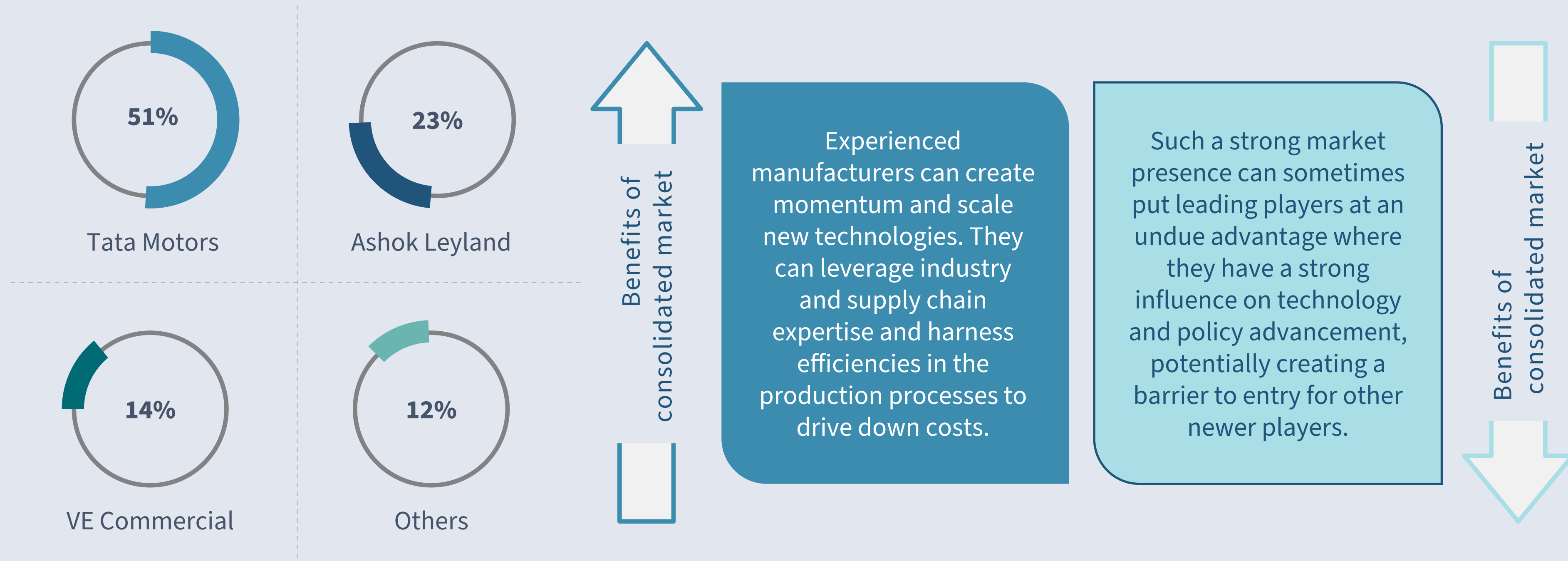
Manufacturing: India's ZET transition demands the domestic manufacturing of ZET models designed for a range of duty cycles. The country is indeed primed to meet growing trucking demand with ZETs, considering its well-established automotive and manufacturing sector and exemplary leadership from logistics and vehicle manufacturing firms currently supporting a strong passenger and light-duty-freight EV ecosystem. Similar engagements from industry actors coupled with India's strong domestic manufacturing capacity can enable India to fully transition to ZETs. Lastly, creating economies of scale in ZET production will drive down costs and inefficiencies.

Box 7: The state of India's trucking market today

The trucking sector in India is currently composed of differing vehicle use cases, truck types, and payload requirements. MDTs have historically dominated the Indian trucking market, but within the past several years, there has been an increase in HDT demand. From 2014 to 2021, the market share of HDTs grew from 42% to 63%.[49] This trend is consistent with the global trucking market — as countries become more developed and wages increase, road networks improve, and the share of loads carried by MDTs declines while HDTs loads increase.[50] The growth of hub-and-spoke networks — a delivery network that connects every location through a single intermediary location — coupled with the need for cost reductions can also contribute to the increasing share of heavier trucks.

The supply side of the trucking market in India is highly consolidated. This consolidation presents opportunities for scale but can also lead to specific players having an outsized influence on technology advancement within the sector. Three OEMs — Tata Motors, Ashok Leyland, and Volvo-Eicher — have 88% of the market share (Exhibit 38).[51]

Exhibit 38: Market share of MDT and HDT by OEM in 2021



While ZET manufacturing is in a nascent stage, some models are available today. The models currently in production domestically in India are Tata Ultra T.7 Electric (MDT) and Rhino 5536 IPLT by Infraprime Logistics (HDT).[52] Additionally, several organisations have begun converting diesel trucks to electric drive trains, and retrofitted electric MDT trucks are expected to hit Indian roads this year. While there are no FCETs manufactured domestically, prototype FCET trucks have been deployed globally, and it is expected that HDT FCET trucks in particular may gain market traction.

Bringing today's market momentum and ingenuity to tomorrow's supply chain

India has a proven track record when it comes to scaling EV manufacturing and is also already a global leader in electric two-wheeler manufacturing due to its extensive network of local suppliers of raw material and components, advanced logistics system and distribution network, and integration of suppliers using unique information technology.

Targeted technology and strategy advancements in the following areas can help inform a similar scaled investment in ZET manufacturing capabilities:

Local supply chain: Developing localised ZET manufacturing and supply chains is an opportunity for India to serve both domestic and global trucking markets. Local manufacturing and robust supply chains will bring opportunity to both existing and emerging businesses, and drive economic expansion with new green jobs across the value chain. Local manufacturing can also help minimise the geopolitical risks associated with imported components' availability and price volatility. Moreover, the development of the local supply chain will also enhance the cost-competitiveness of ZETs.

Battery and Component manufacturing: For a vehicle to be eligible for the FAME II purchasing incentives, it must have domestically manufactured EV components such as the body panel, traction motor, and battery.[53] However, due to the dearth of raw material availability, insufficient technological expertise, and lower cost of imported components, India's battery localisation for electric cars stands at 20%. For some components like motor and power electronics, it is below 10%.[54] Dedicated investments are necessary to develop and deploy advanced technology and local manufacturing of ZET components.

Currently, key battery chemistries used in the FAME-approved models are lithium iron phosphate (LIP), lithium nickel manganese cobalt (LNMC), and lithium nickel cobalt aluminum (LCNA).[55] But overly relying on lithium-ion batteries can lead to an overdependence on domestic exports. Meanwhile import dependence for minerals like lithium and cobalt will also lead to supply chain risks. Further investment in alternative battery development will enable India to realise a stronger, more self-sufficient battery supply chain.

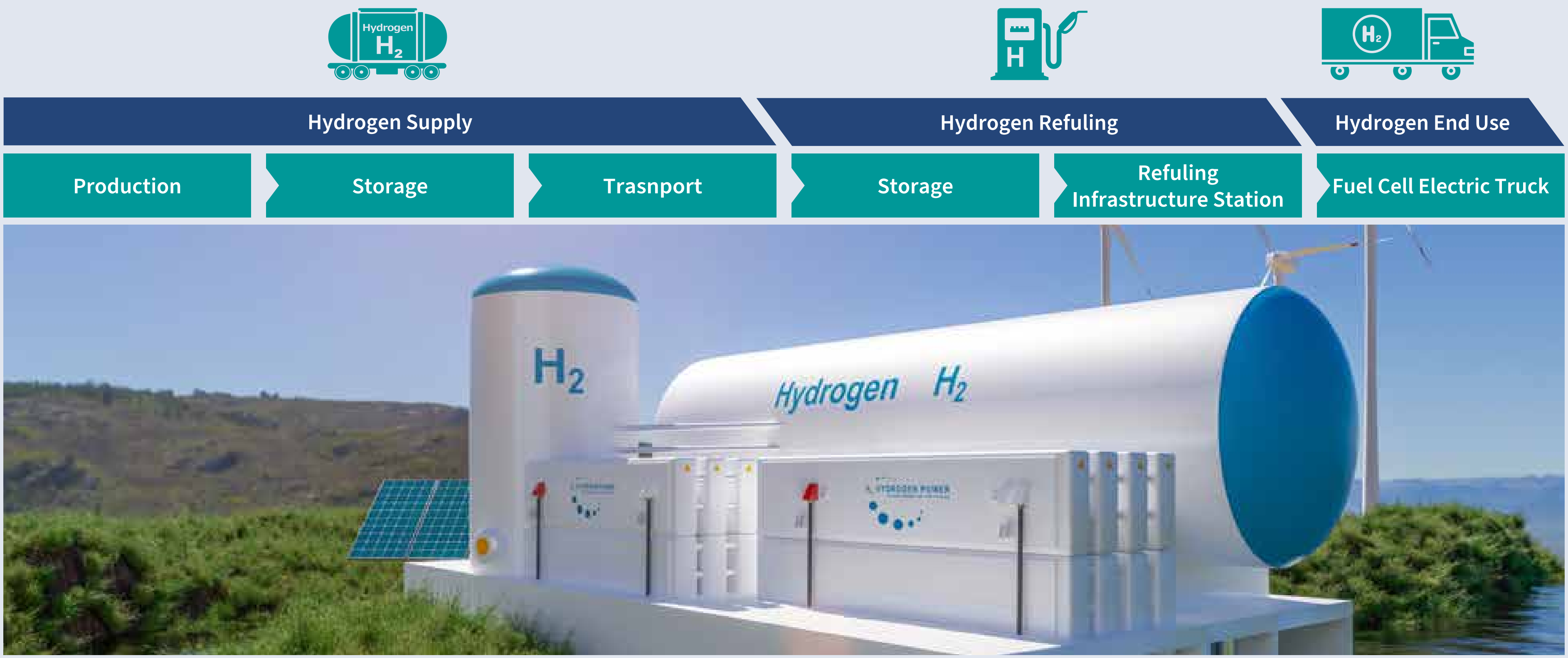
Battery recycling programs: Advancing recycling techniques can enhance efficiency in mineral recovery, promote the circularity of minerals in the economy, and help reduce import dependence to mitigate geopolitical risk.[56]

Box 8: Application of fuel cell technology to the trucking market

Fuel cell electric trucks (FCETs) use hydrogen as a fuel to produce electricity used to power an electric motor and the wheels of the vehicle. FCETs are primarily in the prototype and early demonstration stage globally. FCETs have a key role to play in India's transport sector, particularly for long-haul applications that are difficult to electrify today from a battery range standpoint.

The most significant impediment to the commercial adoption of FCETs is the high total cost of ownership compared with other technology options such as BETs. Before hydrogen can be used as a fuel, it must first be produced, stored, and transported to the refueling stations, just like conventional trucks that fill up at the diesel pump today. Different considerations and strategies across the entire hydrogen value chain will be critical for cost reductions and in helping FCETs achieve market maturity.

Exhibit 39: Flow of hydrogen from production to end use for FCETs



Hydrogen supply considerations

While hydrogen can be produced in a variety of ways, to ensure FCETs contribute to zero emissions, hydrogen used for fueling should be green hydrogen (i.e., produced via electrolysis powered by renewable energy or thermochemical water splitting). Given the abundance of domestic renewable energy, India is well-positioned to be a competitive producer of green hydrogen in the near future, but it will require large-scale investment in green hydrogen production to drive down costs.

One potential production pathway is producing hydrogen off site, storing it, and then transporting it over longer distances. This can be advantageous because hydrogen can be produced in areas with rich renewable resources in large capacities, enabling scale and higher efficiency, leading to lower unit costs. The second pathway involves utilising regional production clusters where the hydrogen off-take could be shared among different end-uses, for example, key industrial clusters with rich renewable resources and significant trucking activity. Hydrogen would still need to be stored but would not need to be transported over long distances. This pathway will be most economical when large-scale hydrogen demand exists within a particular regional cluster.

Similar to other fuels, hydrogen must be transported from its production site to refueling stations for use, adding substantial costs to the production process, especially if produced off site. Hydrogen has a low volumetric energy density and must be condensed to be moved economically. Once condensed, hydrogen can be transported via maritime ships, rail, pipes, or trucks.[57] The most economical solution will likely be pipeline transportation with final mile delivery completed by trucks.

Hydrogen must be stored after production and again once it is transported to the refueling station. Currently, hydrogen is the most economical when stored in its gaseous state in pressurised canisters and in small volumes on-site. India should undertake studies and invest in storage methods that require less equipment and space to reduce the cost of hydrogen storage.

FCET refueling infrastructure considerations

The stations include expensive equipment ranging from compressors, storage vessels, and dispensers, adding to the overall cost of owning and operating an FCET.[58] Maximising hydrogen refueling station utilisation will be one of the best short-term solutions to reduce these costs. Trucking operators and hydrogen refueling station providers need to consider where FCET trucks will need to refuel and how much fuel they require to operate their fleets to ensure stations are placed in optimal locations. These stations should be sized in proportion to the FCET fleet serviced.

FCET technology and operational considerations

The fuel cell propulsion system is one of the main cost drivers of FCETs. Investing in scaled production can lead to significant manufacturing advancements and reduce the upfront costs of FCETs. Additionally, efficiency improvements can lead to operational cost reductions.

For FCETs to have a viable pathway for scaled growth, India must pursue mainstream research and production activities in hydrogen supply, refueling, and fuel cell propulsion. Initial progress is underway with the launch of the National Hydrogen Mission.[59]

Recognising the need to accelerate technology innovation and supply chain development for ZETs, India can provide funding for research and development (R&D), enable public-private partnership, facilitate technology transfer and collaboration, and invest in skill-building to help electrify the nation's truck sector at the speed and scale needed to address both the geo-economic opportunity, and climate urgency (Exhibit 40):

Exhibit 40: Measures to drive innovation and supply chain development in India

FINANCING R&D AND MANUFACTURING	• Government grants to support R&D can facilitate technology breakthroughs. • Production-linked incentives, discounted loans, and subsidised lands can reduce investment requirements for new or retrofitted truck manufacturing units. • Government financing can accelerate development of prototypes, running pilots, and commercialising ZETs.
ENABLING PUBLIC-PRIVATE PARTNERSHIP (PPP)	• Cohesive efforts by government and industry can enable research and technology development. • Public-private partnerships can reduce the risk borne by either party and encourage innovation and the scaling of new technologies. • Government agencies can partner with truck manufacturers and corporates in piloting ZETs.
KNOWLEDGE SHARING AND COLLABORATION	• Global OEMs such as BYD, Volvo, and Daimler are testing and developing components and charging technologies to serve ZETs. • Forming a consortium to share knowledge and experiences with ZET technology to promote collaboration between global and national OEMs can spur the ZET ecosystem in India.
TRAINING AND SKILL DEVELOPMENT	• Skill-building and training of potential researchers and workforce can enable advanced research in ZET and associate components. • Strengthening industrial training institutes (ITIs) and government universities can facilitate creation of skilled workforce for manufacturing, assembly, and recycling ZETs. • Upgrading existing curriculums and creating new courses can equip students and researchers with more tools to undertake R&D and manufacture ZETs.
LEVERAGING EXISTING INFRASTRUCTURE	• The existing supply chain of electric LDVs and passenger vehicles can be leveraged, transferred, and forged into new and heavier applications to support ZET manufacturing. • Chargers set to be deployed under the FAME scheme can also be targeted to serve ZETs. • Upcoming liquefied natural gas (LNG) stations can be transformed to serve long-haul FCETs.

4. Financing and Business Models

Overcoming market barriers to mobilise ZET finance

Lack of financing is one of the critical barriers to EV adoption. EV capital costs, including for ZETs, are much higher than diesel counterparts. At the same time, the interest rate offered on loans for EVs is much higher than diesel vehicles. The loan-to-value ratios are low and loan terms are short. Innovative financing schemes and business models to operate ZETs can catalyse the market and spur deployment by helping would-be ZET fleet operators overcome upfront capex hurdles and access ZETs' superior opex and total cost of ownership.

Trucking market overview: Dominated by smaller companies and perceived credit risk

The demand for goods and freight movement in India is not centralised. While there are a few tier-one hubs like Delhi and Mumbai, tier-two and -three cities comprise nearly 60% of the country's total demand for goods and freight traffic volume.[60] Drivers also prefer to travel along routes where they are familiar with the local language and road network. Limited regulation and a low barrier to entry have led to a crowded market with many small fleet operators and unskilled drivers — in fact, over 75% of the freight market is made up of small owner-operators who own fewer than five commercial goods carriers.[61]

This disproportionate amount of smaller regional aggregators creates a high degree of fragmentation, resulting in unsustainably low returns. Those low returns and high competitive pressures make the small carriers unattractive to creditors because their businesses face high risk. At the same time, those price pressures can lead to behavior such as overloading — which larger, more compliant companies cannot engage in — precluding consolidation. As a result, only small operators can survive, but they often lack access to the information, capital, or level of sophistication it takes to fully invest in modern trucking technologies.

Revenue uncertainty in the market raises even further the credit risk associated with a borrowing owner-operator, which means that most new freight vehicles are financed through non-banking financial companies (NBFCs). These companies are less risk-averse than banks but charge higher interest rates. The loans stand at an average interest rate of between 12% and 16%, tenures of three to four years, and loan-to-value ratios often exceeding 80%, altogether driving the market towards low-cost business models seeking to minimise upfront costs.[62]

Barriers to growth of ZET financing, from purchase to production

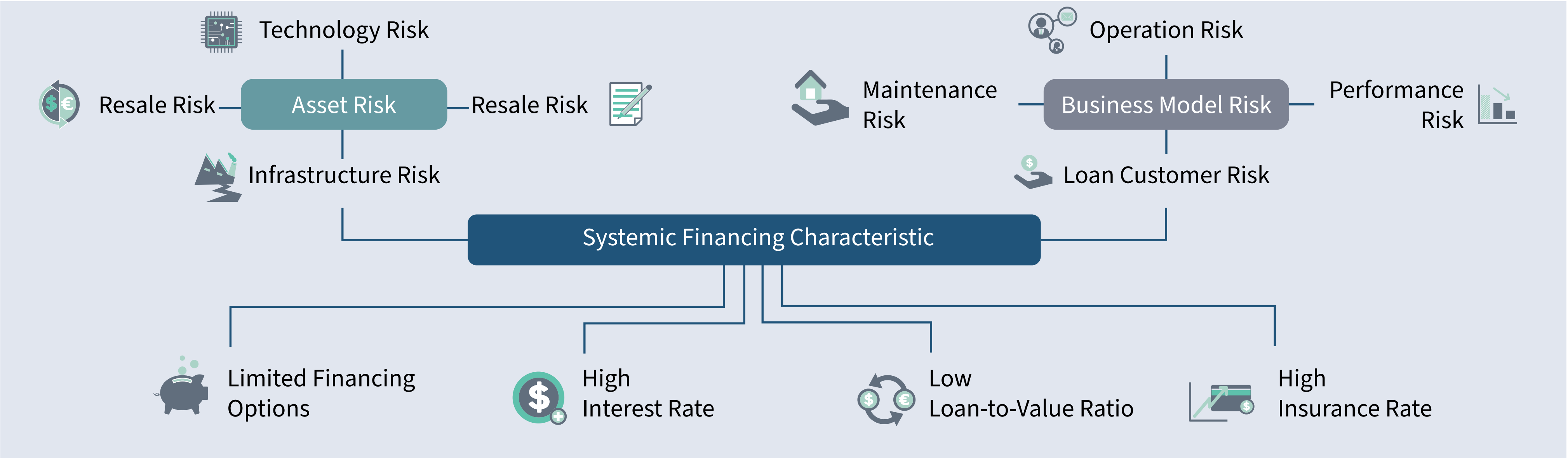
The critical role of financing in the trucking system makes it an important consideration in growing the penetration of ZETs.

This is exemplified on the purchasing side by the fact that buying an MDT ZET costs two to three times more than a similar-sized diesel vehicle, and an HDT ZET costs four to seven times more than a diesel HDT.[63] This relatively high upfront cost presents a significant barrier for already capital-constrained small fleet operators. Without access to affordable financing, it will be difficult for most operators to modernise their fleets.

Lending institutions may consider ZET financing to be higher risk than conventional truck financing, because ZETs involve introducing a much more expensive asset, and one with less certain residual value, into a market where financing even a less-expensive, more-familiar asset is already a risky proposition. If they offer any loan product at all, financing institutions typically offer only high interest rates, short loan tenures, and low loan-to-value ratios in order to hedge against two primary categories of perceived risk: 1) asset risks that are related to the value of the asset underlying the loan, and 2) business model risks that are related to the ability to generate sufficient revenue to service the loan.

- **Asset risks** stem from the lack of performance history and the nascent nature of the vehicle. While EV technology is rapidly evolving, lenders and vehicle operators have persistent concerns over ZET durability, range, supportive policy, and infrastructure. Furthermore, there is no established residual value of a ZET (as few if any have reached end of life), which compounds risk for lender and borrower alike. And with no established secondary market for EVs, ZETs, or batteries, the inability to predict how these markets will evolve only compounds uncertainty. Finally, technology developments within the coming years could dramatically improve ZETs and further deteriorate the value of older electric trucks — adding to the overall complexity of determining the residual value of battery and vehicle assets.
- **Business model risks** also affect bankability. There are operational concerns as well as market pressures, given that the entire road freight ecosystem was built to accommodate diesel vehicles. Considering ZETs are a new asset class, lenders and operators are uncertain about ZETs' ability to meet the demands of freight delivery. Lenders are wary that operators will be unable to generate enough revenue to pay off their loans, given the need to manage charging schedules, train staff, and restructure operations to accommodate the benefits and limitations of ZETs.

Exhibit 41: Key barriers with ZET finance



Customer risks also compound lenders' hesitancy to finance trucks. A high upfront cost corresponds to higher equated monthly instalments (EMIs), which may be even more difficult for operators to afford. In the instance of default, the lender would then be liable to cover the loss. Lenders subsequently use high-interest rates and shorter loan tenure to counterbalance customer risk, often even requiring additional collateral. Hence, smaller fleet operators may find it difficult to secure favorable loan terms to upgrade to ZETs.

Opportunities to mobilise finance: How government actors, industry leaders, and financiers can advance ZET financing and utilise innovative business models

Financing schemes and business models explicitly designed to address asset and business model risks, distribute customer risk, and expand access to credit can effectively spur ZET adoption. To help address financial risks and extend access to credit, government leaders, lenders, and industry actors can all play a role in managing risks and expanding access to finance. Below are a series of measures that different actors can take to mobilise finance for ZETs:

1 National and state governments

Government at different levels can accelerate the ZET transition by working to enact policies that, individually, help mobilise finance, and incrementally, help provide a stable and market-encouraging policy environment for the foreseeable future. Following are a few key examples of policy actions that will help pave the way for a ZET future in India:

- **Stable policy environment:** At the early stages, while the market develops, policy provisions, incentive schemes, and clearly laid out government commitments can help gain the trust of private financiers in the new technologies.
- **Public-backed loans:** Offering loans with more favorable terms can be one way to help borrowers attain more affordable debt. Using public finance at lower interest rates can help fleet operators manage high interest rates. Already, several existing schemes at the national and state level provide or facilitate financing for small road transport operators — and could be pivoted to start prioritising ZETs in a manner that creates awareness of and interest in the technologies, offering preferential loans for them.
- **Interest subvention schemes and risk-sharing mechanisms:** Discounts on interest rates of loans for buying ZETs can allow financiers to develop a learning curve on the technology without taking on high risk or delaying adoption. On the other hand, dedicating loan reserves to provide guarantees for ZETs helps distribute risks for lenders in case of loan default. In both cases, the government facilitates funds. Multilateral and bilateral development banks can also be brought in as funders of risk-sharing facilities, with public sector banks acting as facility managers. In lieu of dedicated schemes for interest subvention or risk sharing (e.g., credit guarantees), governments can incorporate ZETs into existing programs for enterprise owners and small road transport operators.

- **Demand aggregation:** These schemes can facilitate larger EV procurement contracts and minimise upfront costs. Currently, demand for ZETs is sizable among e-commerce providers. These businesses are heavily reliant upon third-party providers transporting goods to customers. Aggregating demand for ZETs can help create economies of scale for both manufacturing and financing ZETs. Bulk procurement orders can also help create economies of scale for financiers such that their learning curve on ZETs is steeper, and their confidence in the technology develops faster.

- **Market-based credit programs:** Market-based mechanisms can be used to put a price on emissions externalities. Such a tool can be leveraged to create additional revenue streams for the development of zero-emissions technologies. These schemes can target different points of the supply chain, such as the production of energy, production of the vehicle, or use of the vehicle.

2 OEMs and fleet operators

ZETs are a new asset class and present a differing risk profile than diesel vehicles. Differing risk portfolios require tailored financing approaches. To distribute the risk of ZET ownership, mechanisms need to transfer risk from purchaser to seller. Two primary mechanisms can achieve this 1) leasing and 2) explicit risk acceptance by seller in forms of warranties and buyback guarantees.

- **Lease purchasing and as-a-service models:** The decision to buy a vehicle outright or lease a truck varies for each company and largely depends on fleet size, anticipated duration of ownership, and financing options. Leasing adds flexibility to the business model and helps fleet operators increase vehicle utilisation. For instance, the operator can initiate short- or long-term leases. Short-term leases could be seasonal to meet peak demand periods. Leasing also enables operators to lease vehicles for specific use cases, strategically utilising vehicles based on delivery quotas and routing.

  Leasing a ZET eliminates the risk of unknown resale value, as the lessee is not liable for reselling the asset.[64] It also leaves room for purchased technology eventually reaching obsolescence in a continuously innovating market, such that when newer models arrive, leases may be transferred to another vehicle. Some leasing schemes are all-inclusive and include financing, maintenance, and in some cases, even insurance and operational staff. This type of model reduces the upfront risk for the operator, as they no longer need to invest in maintenance or staff training.

  Volta Trucks and Volvo Trucks are both, for example, exploring trucking-as-a-service models where a fixed monthly cost will give customers access to trucks, charging infrastructure, insurance, maintenance, and driver training.[65] Pay-per-mile leasing, wherein the leasing payment is calculated based on the usage of the truck, is currently being explored by Daimler. This could be an innovative business model to ensure access to ZETs for small road operators that cannot guarantee demand and do not wish to commit to longer-term leases.[66]

- **Battery leasing or financing:** Batteries represent 50% to 70% of the cost of ZETs, and separating the battery from the overall price makes the purchase of ZETs less capital intensive. The ZET and battery can be financed separately so that the battery can remain a liability for the OEM, and operators lease the battery from the OEM. As under a battery-leasing scheme, the OEM is liable for battery maintenance. This type of program reduces risk and upfront costs, while yielding maintenance savings. Batteries may also be financed separately, if needed. In the medium term, as other types of electric vehicles become more mainstream to finance, batteries may also be financed separately as they may become more lucrative due to the possibility of resale and ability to be repurposed outside of the application within the truck (e.g., as a backup for decentralised renewable energy).

- **Performance guarantees and more robust warranties:** Performance guarantees are typically structured as an agreement between the OEM and the financier; the OEM guarantees specific performance characteristics and is liable for replacing the vehicle or vehicle part if the ZET does not operate to specifications.

Warranties primarily help the vehicle operator manage risks and enable the operator to maintain and replace the battery or other vehicle parts during the duration of the warranty period. Such measures increase confidence and reduce buyer risk. However, there will be a requirement on the OEM's end to have the financial health necessary to provide guarantees and warranties, should the vehicle need to be replaced or maintained.

- **Secondary market development:** There is no established secondary market for ZET assets or batteries, which adds to both borrower and lender risk. However, this can be addressed if the OEM can offer a buy-back guarantee. A buy-back guarantee by the OEM would guarantee that the buyer can sell back the ZET at a minimum resale price based on depreciation. Extending a similar guarantee to lenders can reduce their risk. In the instance of borrower default, the financier will have an established guarantee from the OEM on a minimum resale price, thereby enabling the financier to recoup at least a portion of their loss. Similar to a performance guarantee, an OEM will need to ensure that its balance sheet strength can lend credence to a buy-back agreement with the borrower and be trusted by the financier.

3 Financial institutions

Lenders should invest in their research capabilities to adequately evaluate ZETs and gradually build trust in the technology. From there, lenders can work on structuring more favorable financing for ZET loans by shaping a new mechanism to reduce counterparty risks.

- **Robust depreciation criteria:** Banks lack expertise in evaluating the electric vehicle (EV) market and consequently price risk highly. Banks need to invest in their capacity to better evaluate the ZET and EV market to bridge the gap between perceived risk and actual risk. Traditional financing models that use upfront cost and residual value of diesel trucks to evaluate depreciation need to evolve for ZETs. For ZETs currently, higher cost and unknown residual value result in more rapid depreciation and higher financing costs.[67] As the financing market for EVs develops, however, the end-of-life value of batteries may start to be determined and can be incorporated for the case of electric trucks even if they are at a nascent stage of adoption. Also, with global and national targets around net-zero emissions and climate-aligned lending emerging rapidly, financiers may increasingly consider the climate transition risks of financing diesel trucks compared with ZETs. This would reduce the difference in risk between financing diesel trucks and ZETs. Given the long useful life of trucks in India, decisions taken today to finance ZETs today may be vital in helping financiers align to future industry standards on financed emissions even past the decade, and help create an early learning curve that sets financiers up for greater market share when ZET adoption picks up. Developing this knowledge and capacity may additionally help banks and NBFCs gain access to cheaper credit lines from institutional financiers through sustainability-linked loans, green bonds, and other similar financial instruments.
- **Tailored loan products:** Given high capital costs and high interest rates, ZET financing requires significantly higher loan principal compared with diesel truck loans. Yet current loan products do not account for ZETs' unique financial benefit of incurring operational savings and thereby making EMI repayments easier to afford. Offering ZET-favoring features like grace periods, higher loan-to-value ratios, lower interest rates, and longer loan tenures can all help borrowers secure and repay loans that better correspond to TCO savings. To evaluate ZETs with more accuracy, and offer more dedicated loan products, banks and NBFCs can leverage partnerships with OEMs that could include third-party quality assurance, financing pilots, and product guarantees. Creating a synergy between borrowers, financiers, and manufacturers of ZETs will translate to information symmetry on the real value and risk associated with a truck, and prompt novel preferential financing products.

In the near term, government policies like upfront subsidies, public-backed loans, and interest subvention will catalyse the market and encourage more OEMs and fleet operators to manufacture and operate ZETs. Capitalising on the supportive policy ecosystem, OEMs must step forward with leasing products with more attractive guarantees and warranties. Finally, financiers must build out institutional capabilities in the initial stages of adoption to provide more attractive financing for early market entrants.

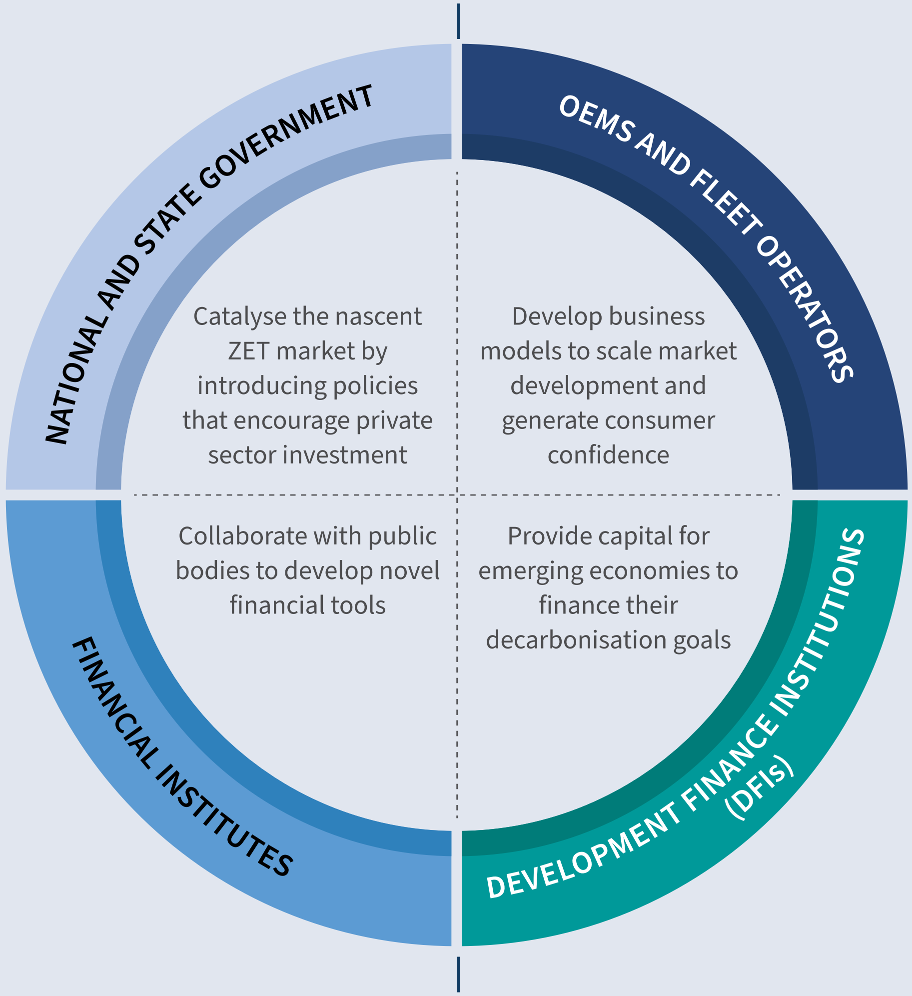
4 Development finance institutions and multilaterals

India is well-positioned to leverage concessional financing from multilateral trust funds or development finance institutions (DFIs). A considerable amount of funding by development institutions is set aside to promote innovation and sustainable energy breakthroughs, and the deployment of ZETs aligns with these development objectives. Additionally, DFIs have played an instrumental role in raising capital for India's power and rail sector. While these sectors are highly regulated, parallels can be drawn to mobilise similar capital flows to decarbonise the automotive sector and provide funding for charging infrastructure development.

- **Partial loan guarantee:** DFIs and multilaterals can increase private sector lending for ZETs through guarantees. Under this type of scheme, the multilateral or DFI agrees to cover a percentage of the loan principal if there is a default enabling private lenders to hedge against counterparty risk. This mechanism can help ZET manufacturers and aggregators secure more favorable financing.
- **Concessional financing:** Concessional financing is below-market-rate financing. Given the high cost of borrowing for nascent technologies, concessional loans can be used to seed the nascent market and attract more private sector investors.
- **Green bonds:** To raise capital for ZET production, OEMs may be able to leverage green bonds. Similar to traditional bonds, green bonds are a debt financing instrument; however, they are allocated explicitly for sustainable development projects.

A blend of strategies can be used to moblise finance for ZETs and each stakeholder group can play a key role:

Exhibit 42: Opportunities to mobilise finance for ZETs



- Public-back loans
- Interest subventions schemes and risk-sharing mechanisms
- Demand aggregation
- Market-based credit programs

- Lease purchasing and as-a-service models
- Battery leasing or financing
- Performance guarantees and more robust warranties

- Robust depreciation criteria
- Tailored loan products

- Partial loan guarantee
- Concessional financing
- Green bonds

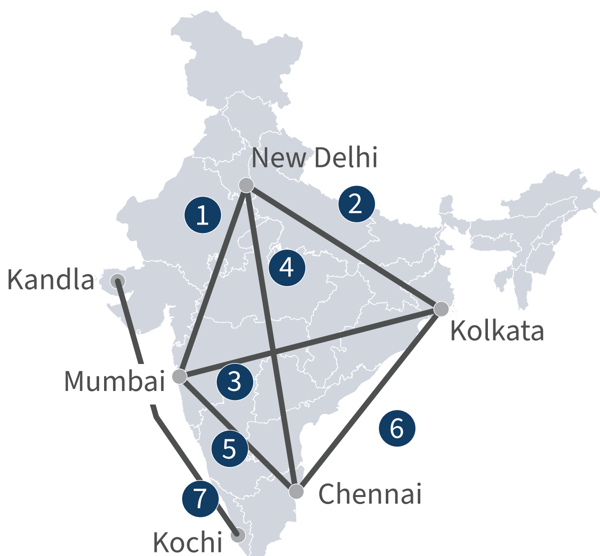
ZET Corridors as an Intersection of Solutions

Aligning policy, charging, technology, and finance innovation

Visionary, integrated partnership can unite solutions in all of the above categories to create not just a roadmap to a ZET future but also the physical infrastructure and conditions required to realise the benefits of ZETs on an accelerated timeline. Establishing a dedicated ZET corridor is a standout example of this potential. Featuring an appropriate selection of charging stations, a well-located ZET corridor can enable India to **pilot and unlock the market potential for ZET deployment** across the country.

Right now, 50% of India's vehicle freight traffic travels along seven major corridors, connecting Delhi, Mumbai, Chennai, Kandla, Kochi, and Kolkata.[68]

Exhibit 43: Freight traffic on seven high-density corridors in India



The amount of road freight travel and economic activity along these corridors presents an opportunity to strategically invest in charging infrastructure development along any of these road networks to scale ZET adoption.

- *Pioneering a demonstration ZET corridor can empower invaluable testing and refining of best-in-class solutions.* By electrifying a specific corridor, government and fleet operators can concentrate investments and test ZET adoption along a particular route. This intentionally chosen corridor can provide proof of concept and exemplify techno-economic feasibility of ZET use and widescale adoption. It can act as a learning ground and spark ZET adoption, while limiting risk. Moreover, ecosystem actors can use this ZET corridor to test the most promising charging, policy, technology, and financing solutions for electric truck adoption.
- *Committed government and favorable market conditions signal promise.* India already possesses the potent blend of **government resolve and market momentum** it will take to realise an effective electric trucking corridor and transition to zero-emissions trucking fleets. The Ministry of Road Transport and Highways (MoRTH) is outspoken on its intentions to facilitate a transition to ZETs and is actively considering developing an electric highway along the Delhi-Jaipur expressway or another highly travelled highway to facilitate the movement of heavy-duty trucks and passenger buses on electricity. Simultaneously, several Indian freight and logistics firms have committed to electrifying a portion of their fleets. Tata Steel has contracted 27 electric trucks to transport finished steel, for example, while Dalmia Cement Bharat has announced it would purchase 22 electric trucks as part of its e-truck initiative.[69]

- *Enabling zero-emissions trucking on the highest-use areas can build market momentum.* Trucks travelling along these corridors typically travel over 2,000 km to reach their destination, travelling as many as 500 km per day to carry goods between these hub cities. Given the length of these trips, reliable charging infrastructure is required to support ZET adoption along these trucking routes. By deploying adequate en-route public infrastructure, government and private stakeholders can maximise investment to meet the charging and refueling demand of ZETs. Alternatively, a ZET corridor could be built on an intrastate highway, like the Pune-Mumbai expressway, that would not require en-route charging. Electrifying a highly travelled corridor can enable the ZET market to reach economies of scale. Electrifying highways where there is a high concentration of freight travel can lead to optimised charging utilisation, and investments can enable cost-effective ZET travel along a critical freight route.

Ultimately, the successful deployment of ZETs along a strategic high-volume road freight corridor can catalyse the market and lead to scaled adoption well beyond its own geography.

Shaping a ZET steering committee to propel ecosystem development

Recognising the multi-stakeholder nature of ZET, policy development and infrastructure deployment must involve collaboration with fleet operators and OEMs. Effective deployment of ZETs will require national government actors to coordinate with the private sector and local government bodies. A ZET steering committee can have relevant stakeholders from the public and private sectors, including:

1. Government such as representatives from transport, commerce and industry, power, renewable energy, environment, and finance departments.
2. Private sector such as OEMs, logistics service providers, charging infrastructure providers, and financial institutions.

The committee is envisaged to undertake the following actions:

1. *Advisory planning:* Convene members to identify and act on solutions to scale ZETs, as well as help inform national and state policies to support a broader ZET and charging ecosystem.
2. *Stakeholder coordination:* Foster partnerships with a diverse network of industry, public, and civil society actors. Work together to increase public awareness around benefits and models, and dispel myths around associated risks.
3. *Technical assistance and capacity building:* Provide technical assistance support to ensure that financing, policy measures, and research and development investments are coordinated to scale ZET adoption. Undertake skill enhancement trainings to fulfil knowledge and capacity gaps amongst local bodies, DISCOMs, financial institutions, and potential and existing ZET workforce.
4. *Pilot deployment:* Identify and roll out pilots in partnership with relevant stakeholders.

Overall, this steering committee can help the Indian government and industry actors develop a framework for the deployment of a dedicated ZET corridor and assess the market outlook for ZET deployment.

Essential questions to ask on the road to a ZET corridor

Stakeholders across government, tech, infrastructure, and finance can contribute critical insights to inform development strategy. The following are high-level questions to ask and answer in the consolidated effort to harmonise ZET supply and demand with infrastructure investment, and together, drive market growth across India.

Exhibit 44: Market outlook queries to drive development

OUTLOOKS	QUERIES
Policy	• What level of investment or subsidy would help drive initial ZET demand? • What non-fiscal incentives could promote ZET adoption?
Technology and Manufacturing	• What level of demand (number of trucks purchased per year) would be required for OEMs to dedicate a manufacturing facility for ZETs to drive production scale? • How can ZETs support the PLI scheme and secure enough demand for battery manufacturing?
Infrastructure	• How can the government work with DISCOMs to ensure the electrical infrastructure is ready to support wide-scale ZET adoption? • What policy tools and concessions can be leveraged to reduce charging infrastructure deployment costs? • How can charging utilisation be maximised?
Financing	• How can actors come together to reduce the perceived and real risk of ZET adoption? • Can financing instruments be implemented this year to drive ZET adoption? • How can multilateral and concessional financing be leveraged to seed India's infrastructure investment in the ZET future?

Identifying the optimal ZET corridor

Choosing the right corridor location is an essential first step. Ideal corridors for electrification will support a high volume of economic activity and offer economic advantage for electrifying a specific freight flow. Below are five key parameters to help India identify a viable, high-impact demonstration corridor that optimises economic and environmental benefits.

Exhibit 45: Pathway for development of ZET corridor

CRITERIA FOR CORRIDOR SELECTION	JUSTIFICATION	KEY METRICS FOR CONSIDERATION
Road freight volume	A jurisdiction's industrial output, port activity, and state economic output is data that can be used to quantity the volume of cargo transported along a particular corridor to prioritise those that connect industrial districts and support regional economies.	• Industrial activity • Tonne/km
Trucking economics	Vehicle utilisation patterns and charging demands of MDVs and HDVs all affect the economics of electrification. A detailed total cost of operations can help ecosystem actors analyse various freight patterns as well as embodied transportation costs of certain freight use applications along a given corridor.	• Embodied transport costs • Total operating costs
Routing	Assess routing for ZET-optimal scenarios. For example, corridors that support bidirectional, closed loop, or return-to-base freight flows with clear rest stops or layovers for charging may support ZET use. Shorter routes may also be viable, if a truck could reasonably complete the route on a single charge.	• Point of origin • Distance travelled • Traffic density • Road feeder network
Policies	Understand existing EV and logistics policy landscape in states that the corridor will pass through. The states with favourable EV landscape will likely be early adopters.	• State taxes • Logistics policies • EV polices
Cargo diversity/ freight flows	The types of goods transported can determine if certain types of freight travel are better suited for electrification. Additionally, the type of container, such as bulk vs. non-bulk freight movement, should be assessed.	• MDT vs. HDT travel • Shipment diversity • Bulk vs. non-bulk • Product volume & weight

Strategic corridor development

Additionally, supporting conditions such as road infrastructure, land availability, electric capacity, and distributional infrastructure are also important factors in considering the feasibility and costs of developing charging infrastructure along a specific corridor to facilitate ZET travel.

In all cases, electrical and charging infrastructure investments will be required to ensure that ZETs can seamlessly meet a range of duty cycles along any prioritised corridor — but scope will vary based on unique corridor attributes. A thorough analysis of existing freight volumes and projected ZET traffic can provide the insight needed to assess infrastructure requirement, and inform strategy to maximise charger utilisation, minimise costs, and ensure ZETs have access to en-route charging to complete trucking routes.

Making a ZET corridor happen: It takes an ecosystem

Successful, efficient operationalisation of the ZET corridor will require concerted public- and private-sector collaboration (Exhibit 46) from the beginning and throughout the course of this impactful initiative.

In the early stages, national and state governments, DISCOMs, and charging infrastructure providers can work together to thoroughly evaluate road infrastructure network, grid capacity, and land availability, and from there, develop a strategy to streamline infrastructure development. By assessing the economics of vehicles and chargers, governments and development banks can allocate viability gap funding to overcome upfront cost barriers. OEMs and fleet aggregators can invest in developing technology and the supply chain to ensure deployment of trucks on the corridor.

India is well-positioned to leverage concessional financing from development banks to deploy a demonstration ZET corridor. A considerable amount of funding is set aside to promote innovation and sustainable energy breakthroughs, and the deployment of ZET fleets and a ZET corridor aligns with these development objectives. A detailed proposal on the feasibility, and market potential of developing a ZET corridor will be required to secure the necessary concessional financing.

The development of a first-of-its-kind ZET corridor in India will enable ZETs to garner market momentum. The successful adoption of ZET fleets along a designated corridor can help assure truckers and fleet aggregators that ZETs can be readily deployed to meet their delivery quotas and trucking demands. End-to-end zero-emission mobility along a dedicated ZET corridor can be achieved by meeting charging demand with renewable energy. Furthermore, learnings from the corridor development process can be leveraged to electrify all of India's major freight corridors. First-mover experiences can be documented to streamline ZET adoption and enable industry actors to overcome market barriers.

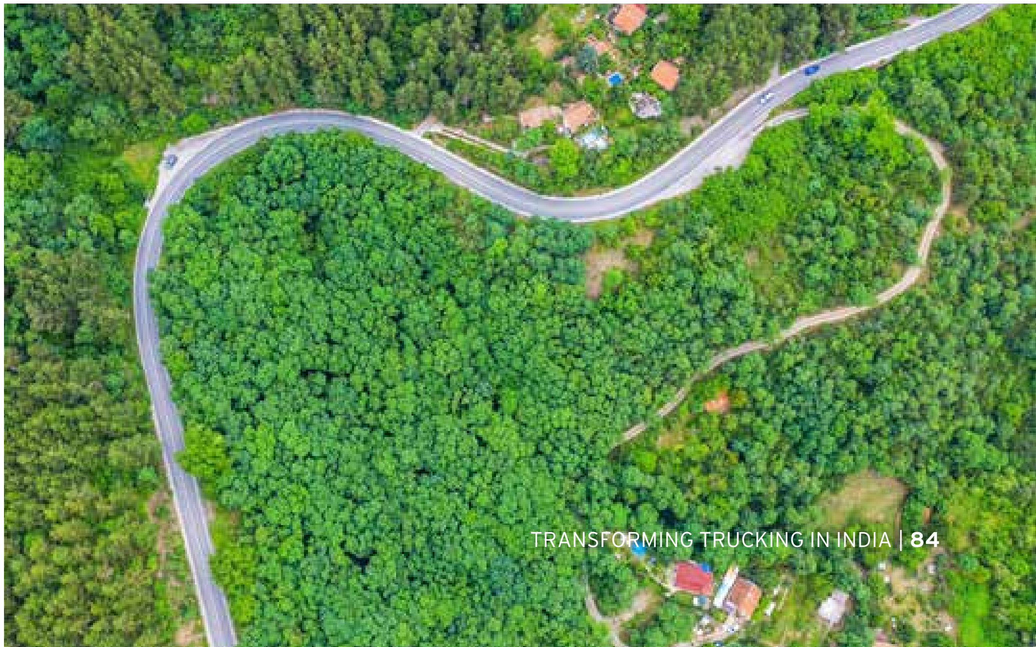


Exhibit 46: Stakeholder action to institute a ZET corridor

CHARGING INFRASTRUCTURE PROVIDERS & DISCOMS	NATIONAL AND STATE GOVERNMENTS	OEMS AND FLEET OPERATORS	FINANCING INSTITUTIONS AND DEVELOPMENT BANKS
• Estimate needed electrical infrastructure to facilitate charging of MDTs and HDTs along the corridor. • Determine the size and needed power capacity to adequately plan for electrical infrastructure upgrades.	• Provide funding/subsidies to ensure that the minimum viable number of trucks can be deployed. • Provide land concessions for charging infrastructure development.	• Invest in R&D for developing ZET models. • Set fleet deployment commitments along the ZET corridor. • Streamline supply chain for ZET deployment.	• Provide viability gap funding for infrastructure development. • Pilot financial products and build internal capacity to finance ZETs.

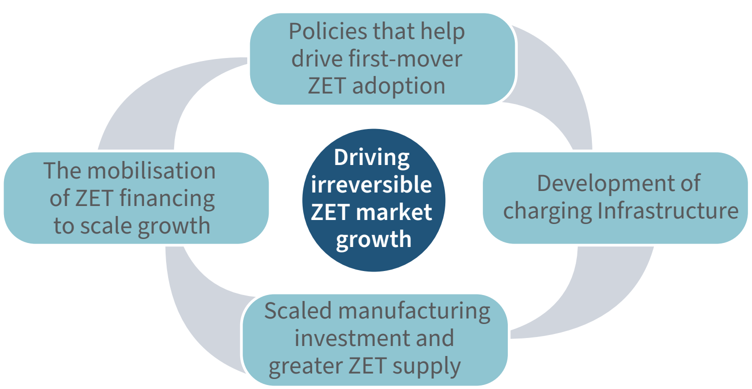
Conclusion and Next Steps

Turning ambition into coordinated action with a unified and systematic approach to the ZET transition

India is in a prime position to stand as a global leader in the transition to zero-emissions trucking. In order to realise the significant long-term economic and environmental benefits of ZET, however, government, technology, industry, and finance leaders must align decisively to develop and enact near-term, precise market and policy intervention.

At a macro level, accelerating today's positive ambition loop will help foster ZET market development. This cycle begins with the development of depot and en-route infrastructure along central highways and key freight corridors. Prioritising this infrastructure investment will be key to building market confidence as truck operations need assurance that ZETs can meet their operational requirements. The next step will be incentivising first movers to adopt ZETs through demand-side policy schemes and direct purchase subsidies to build a sustained level of ZET demand. Such demand can effectively encourage manufacturers to dedicate manufacturing facilities to ZET production. Lastly, scaled market development and supply-side policies can provide the leverage needed to mobilise banking and NBFCs to avail loans tailored to ZET procurement.

Exhibit 47: Pathways to ZET market growth



Moving the market towards tipping points

Despite their promise, ZETs will not be deployed at the speed or scale required to capture the benefits described in this report without a concerted and coordinated effort across stakeholder groups. These efforts should aim to realise critical thresholds of supply and demand that allow for market forces to become the primary driver of scale. One signal of this tipping point being close at hand would be industry commitments to establish dedicated manufacturing facilities for ZETs. According to India's heavy duty vehicle manufacturers, annual demand of 3,000–5,000 units would be sufficient to justify investments in commercial-scale manufacturing plants.[70] A whole-system approach designed to balance advanced demand with early supply can seed the market and lay the foundation for scaled adoption of ZETs.

To facilitate a ZET transition, active leadership is required from across the ZET ecosystem.

- Government can amend and adopt policies to support the emergent ZET market. Setting clear targets and developing schemes that support ZET adoption will send a clear market signal that India is serious about its energy security, economic advancement, and climate commitments.
- OEMs can invest in their ZET manufacturing capacity, and lenders can mobilise finance to drive adoption.
- Logistic providers can adopt ambitious zero-emissions vehicle adoption targets and drive ZET demand.
- Financiers can shape new structures that recognise the unique economics of ZET lending.

The countdown to ZET begins: Laying out the short-, medium-, and long-term steps to India's ZET future

A strategic course of action to scale ZETs with intermediate milestones will enable stakeholders to track progress against India's ZETs transition. The exhibit below outlines short-term, medium-term, and long-term measures that can be taken by policymakers, OEMs, truck operators, corporations, and charging station providers.

Exhibit 48: Measures to fast-track zero-emissions trucking in India

	POLICY	INFRASTRUCTURE	TECHNOLOGY	FINANCE
Near term (<3 years)	• Existing FAME or new scheme to subsidise the upfront cost of ZETs • ZETs as a priority in state EV policies • A ZET demand aggregation to promote deployment	• Roadmap for ZET charging and grid preparedness • Subsidised land for public chargers • Charging infrastructure along critical highway networks for en-route charging	• R&D grants and investments • Public-private partnership for joint research and technology development • Skilled workforce for manufacturing, assembly, repairing, and servicing ZETs	• Tailored lending products for lowering the cost of borrowing and increasing debt financing for ZETs • Strategic roadmap to mitigate and transfer the risk of ZET adoption
Medium term (3–5 years)	• A ZET fleet requirement and supply mandate • Interest subvention scheme for ZETs	• Subsidies for private depots and semi-public charging infrastructure • Smart charging solutions (time-of-day tariff, vehicle grid integration, etc.) for grid stability	• Domestically manufactured MDTs and HDTs at scale • Increased model availability in the market • Globally cost- and technology-competitive ZETs	• Dedicated reserves for loan guarantees • Increased performance guarantees and warranties • Innovative business models such as vehicle and battery leasing programmes
Long term (>5 years)	• ZETs as a priority in national manufacturing, logistics, and trade policies • Inefficient and polluting diesel trucks disincentivised with additional fuel cess, pollution cess, higher road tax, etc.	• ZET-ready upstream electrical infrastructure • Renewable energy integration to facilitate net-zero charging	• Shifted manufacturing focus to selling and producing only zero-emissions vehicles • Leading exporter of ZETs	• Low interest loans for ZETs • ZET finance is completely commoditised

Unlocking the full value of the ZET transition with immediate planning and committed collaboration

By aligning efforts now, government and private sector actors can help India maximise the economic and environmental benefits of ZETs. Supportive, ambitious policies at the national, state, and city level can advance charging infrastructure development and ZET deployment, while driving market growth by accelerating and synchronising ZET supply and demand. Private sector engagement and investment can play a vital role in stepping up to the challenge of high-quality ZET manufacturing and fleet deployment. Financing institutions will also play a critical role in mobilising the level of capital needed to support innovative business models around ZET deployment.

Through a consolidated effort coupled with favorable economics, a ZET future is well within reach for India. ZETs can deliver solutions to India's most significant national priorities. Replacing diesel with ZETs in India could mitigate 2.8 cumulative gigatons of greenhouse gas emissions between now and 2050 — one of the world's biggest decarbonisation opportunities in the transportation sector. ZETs have already reached cost parity with diesel on a total cost of ownership basis. Transitioning to ZETs would represent a long-term economic win for the country by lowering trucking costs, creating a globally competitive export industry, slashing economic risks by reducing oil expenditures by 116 lakh, and positioning India as a low-cost, low-carbon manufacturing hub.[71]

The nation's truck sector is growing fast; ecosystem actors have a historic opportunity to shepherd its growth towards a clean future that **can and will produce substantial economic, energy security, and emissions benefits for India — while establishing India as a global leader in zero-emissions trucking.** These opportunities are under active consideration by NITI Aayog, RMI, and partners — and entirely within our collective reach when supported by a community committed to ensuring an effective ZET transition.

Technical Appendix

A Truck classifications and use-case scenarios

Truck movements are typically categorised based on vehicle weight, freight movement, and make.

Gross vehicle weight rating (GVWR) of a truck is the maximum load it can carry plus the weight of the truck itself (curb weight).

- **Light-duty trucks:** <3.5 tonnes
- **Medium-duty trucks:** 3.5–12 tonnes
- **Heavy-duty trucks:** >12 tonnes

Trucks generally cater to the following freight movement use cases, characterised by distance travelled as well as origin and ending destination:

- **Short (intra-state) use cases** involve intercity travel or other short distances in the range of 100–150 km.
- **Regional use cases** involve freight movement along state highways (e.g., between a regional distribution center and local warehouses).
- **Long-haul use cases** typically involve interstate travel along major national highways (e.g., from a manufacturing facility or export-import terminals to regional distribution centers).

B Expected ZET sales penetration and associated carbon emissions reductions

NITI Aayog and RMI conducted an in-depth techno-economic analysis to understand and quantify the benefits that replacing diesel trucks with ZETs can bring to India, and to parse out the opportunity afforded by an urgent, proactive transition as opposed to letting market momentum occur naturally. A business-as-usual mode split trajectory based on the current freight split between rail, road, and maritime shipping was used to estimate the amount of freight moved via road and the truck stock. By assessing India's current stock of freight vehicles, researchers developed an analytical model to evaluate the impact of ZET adoption through 2050. From there, we compared two scenarios:

1) A high-electrification scenario in which India reaches 100% ZET sales penetration for MDTs and 75% for HDTs by 2050, and reduces its grid emissions in line with 1.5°C emission reduction targets.

2) A business-as-usual (BAU) scenario in which ZET uptake is slow and the grid emissions factor declines gradually at a rate of decline witnessed over the past decade.

	SCENARIOS			
	BAU 2030	BAU 2050	HIGH ELECTRIFICATION 2030	HIGH ELECTRIFICATION 2050
ZET MDT sales penetration	0.05%	27%	9%	100%
ZET HDT sales penetration	0.01%	14%	4%	75%
Grid emissions factors (kg CO_2/MWh)	683	480	382	21

C Total operating costs of four truck movements

A detailed analysis of capital and operating expenses was completed to compare the total cost of ownership (TCO) of ZETs against existing diesel trucks. The TCO calculations were derived based on a mature production scenario defined as the production of ZETs with a dedicated production facility and the achievement of reasonable scale and a competitive market price. Truck performance data was collected to inform this analysis and some high-level figures regarding truck operating characteristics are listed in the table below. Additionally, the following cost elements were derived and included in the TCO calculations:

- Vehicle purchase cost: derived from the average price of diesel trucks in the Indian market today for MDT and HDT use cases. BET and FCET vehicle prices were calculated by assessing the balance of truck price plus the battery pack and/or fuel cell cost to meet the required duty cycle.
- Maintenance costs: calculated as a portion of the vehicle purchasing cost.
- Fuel costs: for ZETs and diesel vehicles, fuel spend was derived by taking the product of the one-year average cost of diesel or current electricity rate, the average vehicle efficiency, and the annual kilometres travelled.
- Insurance: modeled as a percentage of the vehicle cost and depreciated over the vehicle's useful life.
- Tax: road taxes and tolls that are paid annually.
- Registration: the one-time registration cost at the time of purchase.
- Infrastructure (applicable to BETs only): the upstream infrastructure costs associated with vehicle charging are derived as the per-vehicle costs of charging hardware and charging station installation.
- Battery replacement (applicable to BETs only): battery life and cycling were evaluated to determine the need for battery replacement and the subsequent cost.

BATTERY ELECTRIC TRUCK SPECIFICATIONS (2022)	MDT SHORT	MDT REGIONAL	HDT REGIONAL	HDT LONG HAUL
Vehicle life (years)	15	15	15	10
Battery size (kWh)	78	147	205	1,042
Efficiency (kWh/km)	0.78	0.74	1.87	2.08
Average distance travelled in a day (km)	100	200	200	500

D Charging requirements of ZETs

NITI Aayog and RMI developed a quantitative model to analyse the impact of ZET charging and to estimate the required energy load and number of chargers needed to satisfy increasing ZET adoption. The process below describes how charging infrastructure figures were derived.

1. The number of chargers required is calculated based on each truck's actual electricity requirement, which depends on daily kilometres driven.
2. The electricity requirement is based on daily driving distance and vehicle efficiency in kWh/km.
3. Charger size is based on existing charging units available on the market. The charger appropriate for a given vehicle is calculated by comparing the charge time required at different charger powers for a given battery size. The analytical model then sizes the charger based on the lowest-power capacity that can achieve the minimum acceptable charge times (maximum 8 hours for depot and 2 hours for en-route; minimum 10 minutes for all types due to safety concerns).
4. The model accounts for charging utilisation rates, or the percentage of each day that a given charger is in use. As electric fleets and charging networks grow, and as logistics technology matures, utilisation rates for charging stations will improve. Thus, the ratio of chargers required per vehicle will decrease over time.

Policy Appendix

A Overview of national and state polices that can affect ZETs

- **FAME scheme:** The Department of Heavy Industry launched the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme in 2015 for a period of two years, which was later extended to March 2019. Based on stakeholder consultations and learnings from FAME, DHI launched phase two of FAME in April 2019.[72] The scheme was expanded to promote EV adoption through the three verticals; incentivising EV demand, establishing a charging infrastructure network, and initiating public awareness campaigns to inform the public on the benefits of EV adoption.[73] The initiatives outlined under the FAME scheme have been instrumental in increasing EV and component manufacturing and demand for EVs in India.[74] The success of the FAME scheme shows that policies that promote and incentivise vehicle electrification are effective and can accelerate EV adoption.
- **Charging standards:** The Ministry of Power issued guidelines outlining minimum requirements for public charging infrastructure in 2018. These requirements list specifications for infrastructure equipment, cabling, and charger models. The standards establish minimum density requirements between charging points, specifying that a charging station should be placed every 3 km^2, and a charging station should be set up every 25 km along highway corridors. Additionally, the standards outline that EV charging is a service and does not require a license to operate.[75] This means that charging stations are not subject to electricity distribution regulations that enabled more private charging infrastructure providers to enter the market. These can be elaborated to outline minimum charging specifications for ZETs, and require high-powered, ultra-fast chargers owing to their larger battery capacities.
- **Bharat Stage (BS) VI emissions standards:** Set by the Central Pollution Control Board under the Ministry of Environment, Forest, and Climate Change (MoEFCC), these standards are designed to improve air quality by reducing tailpipe emissions such as PM and NOx. Among the most stringent standards in the world, BS VI standards require trucks to emit 63% less PM emissions (g/km) and 88% less NOx emissions (g/km) than the former BS IV emission standards.[76] Successful adoption of these standards stemmed from a coordinated effort to increase public awareness, targeted advocacy efforts, and sustained policy and legal analysis. When considering how to implement policies to support ZET demand and supply in India, a similar combination of tactics (i.e. raising awareness around the benefits of ZET adoption and providing technical guidance for broader implementation) can deepen engagement on the issue.
- **Fuel consumption standards for MDT and HDTs:** Fuel consumption standards have been established for heavy-duty vehicles with a GVWR of 12 tonnes or more. Fuel standards are based on the vehicle's axle configuration and GVWR of the vehicle, and as the policy shifts from phase 1 to phase 2 there will be a 10% increase in fuel consumption standard stringency. In April 2020, a similar policy structure was also enacted for light- and medium-duty vehicles with a GVWR of 3.5–12 tonnes. Further tightening of standards will encourage more OEMs to manufacture ZETs.
- **Aatmanirbhar Bharat (Self-Reliant India) Initiative:** This initiative is a key focus of the Honorable Prime Minister, as he sets the vision for India to become self-reliant and minimise the risks posed by irregularities in the global supply chain. A focus on enhancing domestic manufacturing capabilities and tapping into the expanding export market is a key aspect of this campaign. To showcase the commitment towards enhancing local manufacturing, the government launched a production-

linked incentive scheme for 10 key sectors with a total outlay of ₹1.45 lakh crore over a period of five years.[77] The key sectors relevant to EVs such as batteries, auto components, and solar PV modules constitute close to 55% of the total outlay, signaling the government's intention to advance the transformation in the nation's automotive and energy sectors.

- **National Programme on Advanced Chemistry Cell (ACC) Battery Storage:** Recognising the dominance that battery technologies will play in advancing electricity grids, solar energy proliferation, and grid reliability, the Department of Heavy Industry initiated a national program to increase the manufacturing of advanced chemistry cell battery storage and the number of gigafactories producing batteries in India under the Production Linked Incentive scheme. The scheme allocates ₹18,100 crore to promote the manufacturing and export of advanced chemistry cell batteries. With this scheme, India aims to position itself as a lead manufacturer of batteries and other electric vehicle parts to become self-reliant and competitive in the global export market.[78] Domestic policies that advance energy storage technology will be critical for catalysing the domestic ZET market and catapulting India as a global leader in freight mobility.
- **Production Linked Incentive (PLI) Scheme for Automobile & Auto Components:** Launched in September 2021 with a capital outlay of ₹25,938 crore, this scheme provides fiscal incentives to enhance India's manufacturing capabilities for advanced automotive products, battery electric vehicles, and hydrogen fuel cell vehicles. The PLI scheme will create over 7.5 lakh jobs in auto and component manufacturing, and lead to investments of ₹42,500 crore and incremental production of ₹2.3 lakh crore in India. It will also boost localisation of EVs, facilitate investments, and strengthen India's EV manufacturing ecosystem, including for ZETs. Furthermore, dedicated production-linked mechanisms for ZETs can fast-track the transition.
- **The Draft National Logistics Policy:** To modernise India's logistics sector so that it remains internationally competitive, this policy calls for the promotion of more sustainable transport, deepened environmental consciousness, and cleaner logistical operations.[79] Trucking electrification can play a vital role in enabling India to achieve its logistics sector sustainability goals by reducing dependence on high-emissions vehicles. The draft policy also aims to improve India's ranking in the Logistics Performance Index (LPI) while reducing the cost of logistics by 5% over the next five years.[80] Owing to their lower operating costs, ZETs can help drive the policy's economic objectives, too.
- **The Logistic Efficiency Enhancement Program:** This program develops infrastructure solutions to address the high logistics costs and current inefficiencies in India's material handling infrastructure. The policy outlines steps to integrate digital delivery tracking, improve network capacity, and create a robust hub-and-spoke infrastructure system for deliveries.[81] Improving logistics efficiency can help modernise the trucking sector and enable freight operators to utilise ZETs in more use cases.
- **Digital India:** This initiative seeks to improve the nation's digital network capacity and connectivity, which could be leveraged by ZET fleet operators to develop optimal routes and monitor charging needs.[82]

B Notified state EV policies

X Signifies that the state EV policy makes a direct reference to a specific scheme or attribute

* Signifies this policy mentions charging infrastructure for trucking applications

STATE/CITY	EV ADOPTION TARGET/DIESEL PHASEOUT	RETROFIT/ SCRAPPAGE PROGRAM	CHARGING INFRASTRUCTURE	PURCHASE SUBSIDIES	TAX/PERMIT EXEMPTIONS
Andhra Pradesh[83]	X		X		X
Assam [84]	X		X	X	X
Delhi [85]	X	X	X	X	X
Goa[86]	X	X	X	X	X
Gujarat[87]	X			X	
Haryana[88]	X			X	X
Himachal Pradesh[89]		X		X	X
Karnataka[90]	X				X
Kerala[91]	X		X		X
Madhya Pradesh [92]					X
*Maharashtra[93]	X	X	X	X	X
Meghalaya [94]			X	X	X
Odisha[95]	X		X	X	X
Rajasthan				X	
Tamil Nadu[96]					X
*Telangana[97]					X
Uttarakhand[98]					X
West Bengal[99]	X				

Note: The table above lists the core components of state EV policies. While most EV policies do not directly mention trucking, a supportive EV ecosystem can facilitate a more seamless deployment of ZETs.

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RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621 USA

www.rmi.org