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Paving the way for heavy duty electrification in India

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Centre for Science and Environment

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Contents

Why zero emissions electric trucks?

Ambitious clean air targets for public health protection and net zero goal for climate change mitigation require clean and low carbon pathways for the transportation sector and rapid acceleration of zero emissions trajectory. This transition needs to encompass all vehicle segments with a special focus on the heavy duty trucks.

Mounting evidence on the relative contribution of different vehicle segments to the overall pollution load from transportation in cities and regions show that the heavy duty trucks powered by diesel fueled internal combustion engines (ICE) are gross emitters of toxic local air pollutants including particulate matter and nitrogen oxides, major energy guzzlers and a major emitter of heat trapping greenhouse gas (GHG) emissions.

For instance, emission inventory of Delhi and the National Capital Region carried out by The Energy and Resources Institute and Automotive Research Association of India in 2018 shows trucks contribute about 29 per cent of particulate pollution load from vehicles. Earlier in 2016, similar estimation by Indian Institute of Technology-Kanpur showed that trucks contributed 46 per cent of the vehicular particulate load. Similarly, a Niti Ayog and Rocky Mountain Institute study of 2022 has estimated that trucking contributes 53 per cent of particulate emissions and 34 per cent of carbon-dioxide emissions from road transport.

The International Energy Agency (IEA) along with Niti Aayog has released a report on transitioning India's road transport sector in 2023 the report has estimated that due to the growing demand for freight transport and growing dependence on personal cars, the carbon dioxide (CO_2) emissions from the transport sector can double by 2025. Even though two-wheelers dominate the vehicle fleet in India, their smaller carbon footprint and potential for faster electrification can reduce their energy needs and emissions from the mid-2020s onwards. But trucks will skew the curve upwards.

For India to be on track with the 2070 goals of net zero, fuel efficiency of the ICE truck fleet needs to improve by more than 35 per cent in the coming decades, estimates this IEA report. But the largest additional reduction is possible with zero emission trucks – electric, hydrogen fuel cell, and other clean fuel technology trucks. The IEA estimates that electric trucks (henceforth e-trucks) can potentially reduce annual trucking carbon emissions by 46 per cent by 2050 and avoid 3 million tonne (Mt) CO_2 and more than 30 kilo tonne (Kt) NO_X emissions over the replaced trucks' lifetime.

The forecast is that a sizeable number of battery powered trucks can begin to arrive after 2030. But early initiation of its roll out needs advanced planning and action to develop adequate and appropriate products, infrastructure, regulations and standards and fiscal instruments.

This zero-emission trajectory needs to develop quickly in India as there is very high dependence on road-based freight that is driving the boom in diesel truck-based freight movement. According to the 2021 Niti Aayog report on transforming trucking in India, the road-based freight dominates the freight movement at 70 per cent mode share. It is encouraging that the matter of zero emissions trucking has drawn policy attention.

In March 2023, the Office of the Principal Scientific Adviser (PSA) to the Government of India released an outline of the technical roadmap for deployment of zero emissions trucking in India. This highlights the pathways and multitude of actions encompassing effective research, analysis, technology development for zero emission trucks, regulations, standards and notifications, charging standards, battery standard development, evaluation of rare earth magnet free motors, financing instruments, generation of field level data, among others. This has also provided budget estimates for each element of this roadmap.

Given the growing policy interest in this segment for electrification, Centre for Science and Environment (CSE) has assessed the opportunities for electrification of the heavy-duty truck segment – primarily the 12.5 tonne and above category. So far electric vehicle (EV) models have penetrated the lighter goods carrier category with some degree of commercialisation. But the mainstream mid to long range trucking requiring higher payload and goods carrying capacity have not seen EV penetration yet. But electrification of this segment is necessary to maximise the emissions benefits.

Given the fact that electrification of this segment presents a more complex challenge than the smaller vehicles and that there is no active real world project on ground to draw lessons from, a rapid perception survey of the key stakeholders – original equipment manufacturers (OEMs), logistic service providers, charging service providers, and power distribution agencies, has been carried out to capture their assessment of the possibilities, opportunities, barriers, market readiness and enablers of solutions for early adoption.

This is a greenfield area of growth. The OEMs have just come up with prototype models awaiting commercialisation. Charging providers are beginning to review and understand heavy duty charging options. A small segment of the logistic service providers are also beginning to understand and assess the possibility of inducting these vehicles for delivery services especially in shorter range of operations. This nascent beginning of policy conversation has connected the key stakeholders with the agenda and their reflections provide important insight into what is needed to inform this policy trajectory as it takes shape.

For the purpose of this study, CSE, through a technical consultation process, reached out to a diverse group of stakeholders. Given the relatively limited number of respondents in the field, a qualitative approach was chosen to collect information. This method allowed for a deeper exploration of the subject matter, taking into account the nuanced views and experiences of the stakeholder groups involved. Each engagement was designed to elicit specific information and opinion relevant to the respective group. The target groups for the study include the representatives of the conventional and new OEMs and third-party and fourth-party logistic companies, particularly in the geographies of northern India with a focus on Delhi and the National Capital Region and Varanasi; and the representatives of the charging providers and power distribution companies in these geographies.

The objective has been to gather comprehensive understanding of the stakeholder groups' viewpoints and first-hand encounters with the subject matter. This offers a textured and case-specific analysis based on the consultation and engagement as well as the emerging information from the available literature and relevant global experiences around these issues.

Summary findings

Perception of the original equipment manufacturers (OEMs)

Even though the OEMs have begun to develop prototype models in different gross vehicle weight (GVW) categories – ranging from 12 tonne to 55 tonne with the range varying between 150-200 km to 300-500 km, and the maximum battery energy capacity up to 276 kilowatt-hour (kWh) of the vehicles, the truck manufacturers are cautiously assessing the prospects of e-truck commercialisation. Industry is conservative about its market prospects.

Industry is weary of uncertain demand generation and a fragmented road freight market and the possible use cases. Industry is also cautious in view of the policy position that seeks to promote a mix of fuel types in the coming years. Currently, there is a small-scale niche deployment of e-trucks in port areas. At this stage there is little clarity about the possibility of scaling up this programme.

Industry does not have much clarity about the use case application for priority introduction. The industry representatives have broadly indicated that an operational range of approximately 1.2 lakh km a year for e-truck would be more viable to achieve price parity with ICE vehicles. Also, vehicles traveling interstate or intrastate, covering a minimum of 80-90,000 km, may show promise for electrification. The vehicle segments employed for transporting goods from warehouses to urban areas and transferring them to supermarkets or distribution centres following predetermined fixed routes are also suitable.

However, OEMs are unanimous that policy steps are needed to address infrastructure limitations, battery technology advancements, and customer acceptance among logistic service providers and individual truck entrepreneurs.

Moreover, large scale deployment of e-trucks will require a technology roadmap for robust product development and to achieve optimum performance of e-trucks. This needs to address more demanding duty cycle, durability, safety and thermal management, adapting to harsher environmental parameters (temperature, weather elements, shock/vibration, etc.) among others. This roadmap requires strong participation of OEMs in the transition phase and regulatory mandate. Currently, lack of localisation and high dependence on imported components escalate the costs. This will require well designed financing instruments and fiscal incentives.

Perception of the logistic service providers

Most logistic providers are not aware of what transitioning to e-trucks may entail. A small section of the logistic providers has picked up the information from the larger conversation in the country. Predictably, their perception borders around upfront capital costs, high total cost of ownership, charging requirements that may increase costs and delays, limited range, lengthy recharging times, strong desire for financial support, and high costs associated with vehicles and infrastructure.
At this stage there is strong interest in understanding the business case for e-truck adoption when there are limited financing, incentives, and limited leasing options. They want to know if there are cost-effective solutions for batteries such as using a battery leasing model, extended warranty etc. They also need better clarity about the real-world maintenance savings and technical glitches during the initial years of operations.

They expect regulators to evaluate soft incentives to encourage e-truck adoption, such as high-occupancy vehicle lanes, green loading zones, and preferential access. According to the logistics sector's representatives, the average distance covered by a truck in the country has increased by up to 100 – 150 km/day as compared to what vehicles were covering in the pre-Goods and Services Tax (GST) era. The average distance covered by a truck (long haul trucks) in India is between 400–450 km/day.

Most logistic providers are unclear how the freight and fare rates will play out and affect their cost recovery and earnings. The lack of organized data and standardization in the trucking industry makes it challenging to establish consistent pricing benchmarks. The absence of reliable information hampers the ability of industry stakeholders to accurately assess market dynamics and make informed decisions. This initiative also requires intense outreach and demystification of the products.

Perception of charging service providers

Charging infrastructure upgrades for e-truck charging will be a significant area of intervention. The charging service providers are of the view that government mandates and regulations will be important to build infrastructure and market. Currently, the use case for charging of e-trucks is not clear and large-scale deployment of e-trucks charging is not yet well-understood in terms of cost, technology, grid services and impact on grid. High-capacity chargers would require heavy upfront investment. Several important components like rectifiers, connectors, and charging guns etc., are also not readily available locally.

The charging roadmap will require well framed incentive schemes and policies and operational cost support to make up for operational start-up losses. This will require robust standards for megawatt level new charging options and also standardisation of common charging connectors and protocols to help lower costs and optimize maturation of technology. They see collaboration with freight operators and OEMs important to understand their daily distance travel and vehicle battery design and power requirements, assess the optimal approach for specific needs of charging in depots and en-route.
It is necessary to prioritize convenient access to 3-phase power sources with either dedicated transformers or enough capacity reserve or dedicated feeders for charging, which are crucial for efficient charging operations while targeting heavy duty e-trucks. Demand management and load balancing will need to integrate network management and software companies. Consider this approach in sites with multiple chargers, adherence to open standards, energy storage and localised solar power generation.

They have also highlighted several other issues including the need for considerations for optimizing charging initiation protocols, collaborating with electric utility companies for infrastructure support, different charging paradigms and measures like energy storage and backup charging plans to enhance the reliability of charging operations for commercial vehicles, and access to land.

Perception of Distribution Companies (DISCOMs)

The DISCOMs have highlighted the costs associated with infrastructure expansion projects, upgradation of the grid at the distribution level, and data acquisitions. New load could require further distribution system upgrades and management of peak power increase/ charging demand pattern, power quality related challenges, megawatt charging integration with the distribution grid and associated regulatory challenges. Large investment is needed to meet load peak but there may not be consistent utilization. A road map is needed to address the lack of data and information to forecast the near future demand from electric vehicles. The distribution system upgrades will require corridor based new feeder lines, technology readiness to optimize the charging need through smart charging etc. The new capital investment will have to be attained within the restriction to socialize the cost amongst the users.

The power sector representatives pointed out the need for a roadmap for megawatt charger integration with the distribution grid and its management. There is a need for a preparedness for integrating the transport and power sectors.

Spotlight on charging infrastructure of e-trucks

The conversation with the charging providers and DISCOMs have brought out the importance of deeper understanding of the charging requirements and renewable energy integration. Therefore, a more detailed review has been added to capture the dimensions of this challenge.

Several issues related to charging has come up:

- The rise in peak demand poses a potential strain on electrical distribution systems, necessitating the upgrade of networks to handle the increased load.
- Different charging strategies and smart charging frameworks to address uncontrolled charging of a large number of electric vehicles that can imbalance the distribution systems.
- Managed charging technology: DISCOMs convey that this may involve exploring alternative energy sources, improving grid infrastructure, and adopting advanced load management techniques. Management of charging optimizes various factors such as grid stability, electricity demand, charging cost, smart charging technologies and strategies. This needs to be coordinated

and controlled to avoid overloading the power grid during periods of high electricity demand to mitigate the impact of large numbers of EVs charging simultaneously, which could strain the grid infrastructure and dynamically modify the charging behaviour.

- Technical and safety standards for any connectivity with the grid are under exclusive control of the Central Electricity Authority. These may be further updated including harmonics, Flicker, DC Injection, etc. into the grid under control, as well as preventing voltage imbalance. The same standards are extended to electric mobility charging stations also. Central Electricity Authority (CEA) further to incorporate safety of supply has accordingly modified the CEA (Measures relating to safety and electric supply) Regulations, 2010. The charging stations need to comply with the safety requirements of the IEC 61851 standards.
- Regulations regarding connectivity with the grid including power factor, load factor, harmonics, voltage deviations etc. For supply of quality of power, it is essential that power factor, load factor, harmonics, voltage deviations etc. are kept within the prescribed limit as defined by Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations. CEA has already amended the regulation to incorporate necessary changes with respect to safety condition requirements of EV charging stations. CEA has further amended the regulations to include Vehicle to Grid (V2G) in aforementioned regulations.
- Communication protocols are required for communication and control between electric vehicles, charging stations (also known as Electric Vehicle Supply Equipment (EVSE), and a Central Management System (CMS).
- DISCOMs need to collaborate to develop grid integration plans that facilitate the seamless integration of zero-emission trucks and renewable energy sources. This involves assessing the capacity of the existing grid infrastructure, identifying potential areas for grid upgrades, and developing strategies to accommodate increased renewable energy generation and charging demands.
- Facilitating knowledge sharing and technical collaboration between zero-emission trucks stakeholders and DISCOMs may include providing DISCOMs with information on zero-emission trucks technologies, their charging characteristics, and any grid integration requirements. Conversely, DISCOMs can offer expertise on grid infrastructure, electrical codes, and safety considerations relevant to the zero-emission trucks integration.
- Since the load profile of public charging stations (PCS) as observed is usually erratic, the surplus generation may be used by the respective DISCOMs to offset their Renewable Purchase Obligation (RPO) mandate. If allowed so, the PCS up to 500 kW may get benefitted.
- Irrespective of the available framework for green open access, there is a need

for adoption of the green open access rules by respective states. Further infrastructural requirements need to be thoroughly investigated for availing of open access as part of technical requirement. This needs to be assessed and duly amended to allow green open access.

- There is a need to amend existing supply code regulations to ensure time bound issuance of connectivity as well as required technical specifications. This needs to be ensured by the PCS within distribution licensee jurisdiction. It has been observed that various states apply either Parallel Operation Charges or Self Generation Tax on entities who own and operate their renewable energy plants. This has a cost disadvantage for the PCS as this increases the landed cost under open access and eventually discourages public charging stations from opting for Green Open Access.
- DISCOMs often highlight the capex requirement to augment their distribution network. The state electricity regulators need to encourage capex for system augmentation - specifically for EV charging stations led network optimization.
- Within the recommended measures of renewable energy (RE) banking provisions with the distribution utilities, the modalities of settlement and adjustment of RE plays a big role in maximizing the RE usage by the EV charging infrastructure provided within the scope of MoP's Green Open Access Rules. Very recently, Maharashtra Electricity Regulatory Commission has issued draft guidelines to enable green open access, and they have relaxed the metering specification from Availability Based Tariff (ABT) to time of day (TOD) meters. This acts as a significant cost advantage for entities eager to avail green open access. The same needs to be uniformly adopted across states.

Way forward

Need a detailed roadmap for e-truck roll out: The Office of the Principal Scientific Adviser, (PSA) Government of India, has already provided a guidance on the roadmap for deployment of zero emissions trucks integrating the scope of field research, standard and regulations, technology assessment and development and pilot project preparation for implementation. A wide range of tasks, methodology and deliverables along with budget have been identified. This needs to be taken forward with appropriate directions to the concerned ministries and departments. The implementation of the pilot projects along with the stakeholders to support deployment strategy for e-trucks needs to be prioritized.

Drive product development with appropriate standards: While OEMs are in the process of developing products, more evolved and comprehensive regulations and technical standards are needed for safe and durable operations of e-trucks. The PSA roadmap has identified standardisation of battery communication protocol, appropriate drive cycle for range/energy assessment, interoperability among others as some of the critical areas of interventions. Battery standards as well as standardised format for recycling and repurposing format for batteries are also needed.

Strengthen fuel economy standards for ICE trucks for quicker electrification: Provide the timeline for successive improvement in fuel economy improvement targets and advancement in testing protocol to give a longer-term policy visibility of the pathway. This may be supported by a suitable timeline for zero emissions mandate while modifying the EV super-credit multiplier and disclosure of test data.

Implement carbon credit trading system to mobilise resources and investment: There is already a regulatory provision of carbon trading system under the Energy Conservation Act and Bureau of Energy Efficiency is developing this mechanism for the vehicles. Bring e-trucks within the scope and enable companies operating e-trucks to earn credits based on their reduced carbon emissions and meeting of the emissions reduction obligation.

The national policy needs to unify highway planning with obligatory EV infrastructure: This can be placed every 80 km on both sides of the highway. Additionally, locating RE projects in proximity to charging infrastructure is essential to enhance the renewable energy share in the energy mix, a critical factor for optimizing GHG reduction advantages.

Need standardized protocol for managed charging strategy and demand response: The utilities are required to invest in upgrading and designing the network to cater to peak system demand, which is capital-intensive. The regulator ought to create a mechanism for demand response products in the ancillary market, allowing charging service providers to participate in it. Several new technologies related to managed charging of EVs have initially been introduced through pilot platforms. These require large-scale technology deployment. While standards and guidelines in India include provisions for communication protocols between EVSE and other stakeholders, there has been a lack of pilot initiatives on large-scale managed charging projects. To promote the adoption of managed charging of EVs, it is crucial for DISCOMs and regulators to undertake pilot initiatives to demonstrate the potential advantages and challenges.

The CEA, in conjunction with DISCOMs, also need to generate short and long-term demand projections for EV penetration based on available charging data. There is currently no regulatory mandate for DISCOMs to incorporate the CEA forecasts into their planning processes.

Design a suitable tariff that increases feasibility of operation of charging infrastructure facilities even at low asset utilization level: Electricity demand charges i.e., "Fixed Demand Charges in EV tariff" pertain to fixed fees imposed on charging station operators, determined by the connected load, regardless of the actual usage of the charging station facility. For chargers located along highways and expressways, initial phases might witness low asset utilization, and the application of electricity demand charges can present challenges for high-capacity chargers to achieve break-even points.

Allow recovery of network investment cost through regulatory provisions and tariff determination. Adapt energy utility rate structure to accelerate the cost-effective electrification of e-trucks. The cost of supply is higher than the approved EV tariff (accrual of EV tariff subsidy committed by government). Even if this allows recovery of utility capital costs it may discourage the electrification of the e-trucks. Innovative EV tariff should be adopted to be an enabler. The state EV policies can make changes specifically concerning road freight vehicles and define specific tariff rates for the megawatt chargers for e-trucks.

Smart charging techniques: This may also enable new services to optimize the cost of charging, mitigate the secondary peak, encourage to utilize clean source of energy, and delay the infrastructure augmentation, if compensated appropriately. Assess the resilience and requirements of infrastructure along highways and key locations. Ensure connectivity and safety measures.

Leveraging policy support for charging of e-trucks: The government has implemented favourable policies and regulations to incentivize DISCOMs to create a supportive environment by offering various incentives for supporting zero emission vehicles and their engagement in renewable energy-based power generation and the establishment of charging infrastructure. These incentives can take the form of tax benefits, subsidies, or grants. The Ministry of Power (MoP) has issued guidelines and standards for public EV charging infrastructure on 14th January 2022. Under phase-II of FAME-India Scheme, Rs. 1000 Cr. has been allocated for the charging infrastructure development. The MoP has sanctioned 2,877 electric vehicle charging stations in 68 cities across 25 states/UTs. Further, 1576 charging stations across 9 Expressways and 16 Highways under phase-II of FAME India Scheme has also been sanctioned.

Introduce point-of-sale incentive for e-trucks: Incentive and subsidy, and policy support schemes for e-trucks need to be integrated in the upcoming FAME III (Faster Adoption and Manufacturing of Electric Vehicles) program.

Financing e-trucks: Need a combination of financing instruments and insurance policy including viability gap funding of e-trucks. Coordinate with the financial institutions to design appropriate financial products and specially address risk mitigation.

It is very clear that the State Electricity Regulatory Commissions (SERCs) ought to permit the spreading of capital expenditures (capex) to enhance e-truck Infrastructure. The central and state governments need to include the exemptions of cross subsidy surcharge and additional surcharge and this exemption should be mandated by the State Government through Section 108, directing State Electricity Regulatory Commissions (SERCs) to formulate regulations that encompass the project's entire useful lifespan.

Tax measures to reduce operational costs: During the initial phase, incentives, road tax credits, and rationalisation of GST etc can help to lower the operational and charging expenses of e-trucks.

Enable stakeholder collaboration for establishing charging network: The vehicle OEMs, start-ups involved in e-truck development, financial institutions, logistic service providers, charging equipment providers, and infrastructure companies need to align and coordinate to plan charging locations, upgradation of grid along highways, expressways, logistic hubs, and economic corridors. This also requires empirical estimation of investment required for both charging infra and procurement of electricity.

Also, logistic service providers, fleet operators, and OEM's have the opportunity to engage with private sector stakeholders and financial institutions to create innovative business models, partnerships, and institutional mechanisms. By doing so, they can effectively leverage financing resources required to achieve their transportation electrification objectives.

Charging infrastructure and data analytics: The vehicle electrification programme brings with it a significant increase in data related to vehicle and energy usage. This is an opportunity to design effective policy measures based on data to improve vehicle performance, charging patterns, and overall energy consumption. This information can be utilized to develop targeted incentive programs and financial incentives. This needs seamless communication and data sharing standards, use of data analytics for performance optimization, enhanced fleet management etc. This can also enable environmental and safety reporting.

Capacity building and knowledge dissemination: Design and launch awareness campaigns around the benefits of electrification of trucking. Establish collaborative partnerships with market leaders to gain insights into effective deployment strategies for e-trucks. Promote skill development and training programs to equip the workforce with the necessary expertise to operate and maintain e-trucks. This will ensure a smooth integration of electric vehicles into the existing logistics ecosystem.

Advanced planning and roadmap for setting charging infrastructure for powering e-trucks: The conversation with the charging providers, and electricity distribution companies (DISCOMs) has brought out the need for advanced planning for charging infrastructure for e-trucks. Heavy power withdrawal for heavy duty e-trucks with large batteries require special attention to ensure uninterrupted and reliable energy supply and significant investments in new charging infrastructure capable of meeting high voltage and current flow from Electric Vehicle Supply Equipment (EVSE) to the vehicles. Charging time and reliable power will matter for timely deliveries and uninterrupted travel. These will require much more powerful charging equipment, relying on a network of ubiquitous, high powered direct current (DC) fast chargers ranging from 350 – 10000 kW.

The e-truck industry requires megawatt chargers and the Megawatt Charging System are being designed to deliver power up to 3.75 MW (3750kW) by 2024. These are capable of handling the higher power demand effectively and efficiently. Standardization of both hardware and software becomes crucial. By establishing standardization, compatibility between different charging systems can be ensured, enabling interoperability. Although every project may require unique engineering solutions due to variations in sites and specific requirements, there are certain common elements that should be taken into account. This requires installing high-power charging infrastructure at the commercial facilities, including depots, yards, and hubs

Leveraging renewable energy for e-truck powering: Currently, EV charging stations with solar rooftop with loads above 10kW, are eligible for availing regulatory benefits in terms of net-metering, net-billing or net feed-in (gross metering). However, since most of the state electricity regulatory commissions identify eligibility for net-metering by consumers' category, this creates a regulatory ambiguity over eligibility of EV charging stations to avail net-metering benefits. The EV charging infrastructure providers may be allowed to install solar/micro wind systems with regulatory incentives of net-metering and net-billing. This can also reduce the cost of running the electricity infrastructure. A clarification is needed to be issued by the Ministry of Power (MoP) to consider EV charging stations to be classified as eligible consumers as part of the net metering/net billing incentives. This classification would not only facilitate a more dynamic and efficient use of energy resources but also incentivize the adoption of renewable energy sources for EV charging stations.

Allowance for yearly Renewable Energy (RE) banking should include the flexibility for adjustments within both peak and off-peak time of day (TOD) periods.

Upgradation of distribution grid and timeline: Nowadays, practically all DISCOMs in every state demand that consumers pay for system expansion. To save customers money and avoid wasteful infrastructure, electric utilities are regulated to respond to service requests. While shared infrastructure can be built as load forecasts increase, generally regulations require that utilities respond to customers' electric service requests rather than anticipate them. The electrical infrastructure to be upgraded by electric utilities can include distribution lines, local stations, breakers, transformers, and switchgears. Electricity grid upgrades are necessary where on-site power availability is not sufficient. Grid upgrades can range from minor, such as only upgrading the breaker and distribution transformer, to major upgrades of the distribution lines and substation. It is necessary to illustrate the tentative cost for new infrastructure upgrades and average timelines for each set-up.

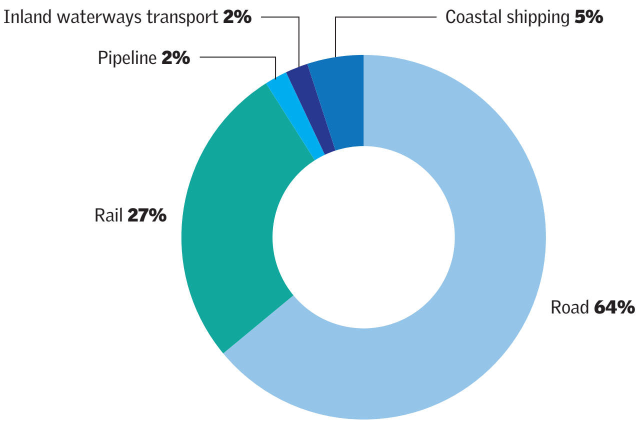
Enable third-party aggregators to engage in the aggregation of distributed energy resources, encompassing EVs, through regulatory measures. This participation aims to facilitate grid services, which in turn promote the effective deployment of Vehicle to Grid (VG) projects, optimizing a wide array of resources for enhanced efficiency.

Remedial solutions to prevent the stress: Addressing the grid challenges posed by e-trucks requires multiple solutions rather than a single fix. Fleet operators, logistics service providers, and charging service providers must acquire new skills related to power procurement, charger installation, and managing charging power and time.

SECTION 1
Heavy duty trucks and zero emissions pathway

The volume of truck traffic is expected to increase substantially in the coming decades given their very high modal share in the overall freight traffic and due to economic growth. While Niti Aayog in its 2021 report has estimated that the road-based freight forms 70 per cent the freight mode share, the Ministry of Road Transport and Highways (MoRTH) data shows that road transport is around 64 per cent of the total freight traffic in India in 2019. Rail transport, which is considered to be more energy efficient and cost-effective for long-distance movement, accounts for around 27 per cent of the freight traffic, while inland waterways contributes a mere 2 per cent (see *Graph 1: Modal split of freight movement in India in 2019 (per cent of tonne-km)*).

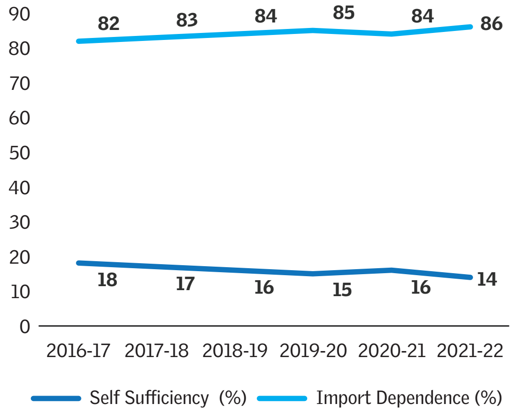
Graph 1: Model spilt of freight movement in India 2019 – per cent of tonne-km



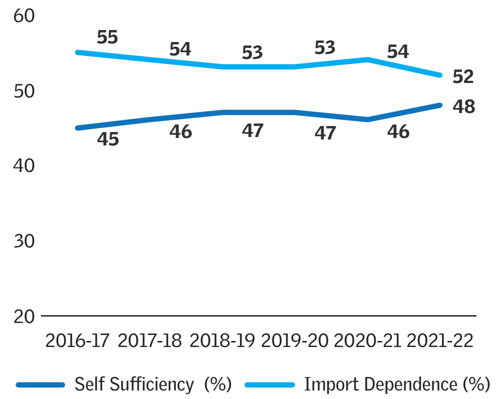
Source: Based on data from Ministry of Road Transport and Highways (MoRTH), 2019-20

The Niti Aayog has further estimated that India transports about 4.6 billion tonnes of freight annually, generating transport demand of 2.2 trillion tonne-kilometres (tonne-km) at the cost of Rs 9.5 lakh crore. The number of trucks is expected to more than quadruple, from 4 million in 2022 to roughly 17 million trucks by 2050. This growing demand would require over US $1 trillion crude oil imports for diesel production cumulatively by 2050. As per the Petroleum Planning & Analysis Cell of India (PPAC), the import dependency of India on crude oil has increased from 82 per cent in FY7 to 86 per cent in FY22. For natural gas, this has decreased from 55 per cent to 52 per cent during the same period (see *Graph 2 & 3: India—Import dependence on crude oil and natural gas*).

Graph 2: India—Import dependence on crude oil



Graph 3: India—Import dependence on natural gas

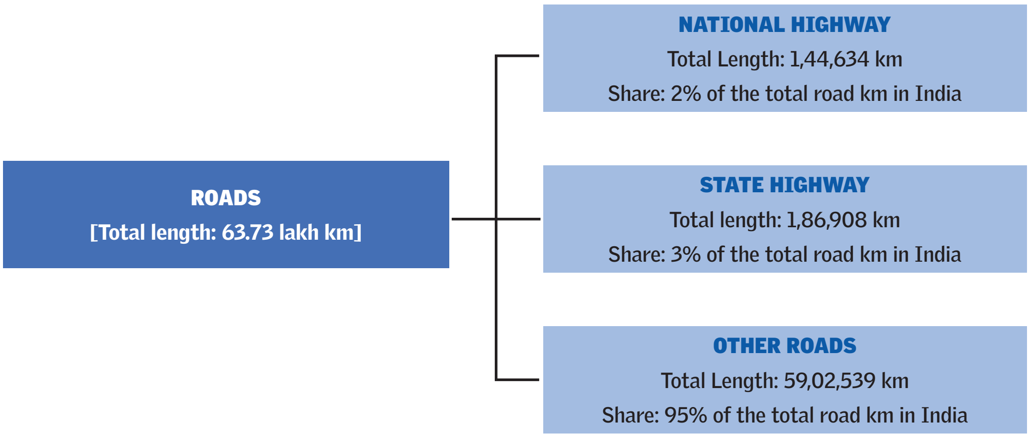


Source: Analysis based on data from PPAC 2021 report

Road freight is encouraged with massive and rapid expansion of roads and highway infrastructure. The Indian Road network, now the second largest in the world, covers a total length of ~ 6.3 million (see *Figure 1: Road network in India*). This plays a pivotal role in transporting over one third of the country's goods. India's road infrastructure has witnessed a 59 per cent growth over the past nine years.

The highway construction has increased at 17 per cent compounded annual growth rate (CAGR) between 2016-2021 in India. As per the information available from MoRTH, the road freight in India has increased from 467 billion tonne/km in 1999-2000 to 2927 billion tonne/km in 2019-2020 which is above 600 per cent increase. Another estimate from the Economic Survey 2020-21, shows that the total road freight movement in India has reached 3,595 billion metric tonne kilometres (BMTK) in 2019-20. This is a significant increase from the previous years' figure of 3,344 BMTK . There is also interest in building smart highways with inbuilt features of electric mobility in the future but there is no implementable roadmap yet. Various greenfield expressways totalling to 2489 km are also being added.

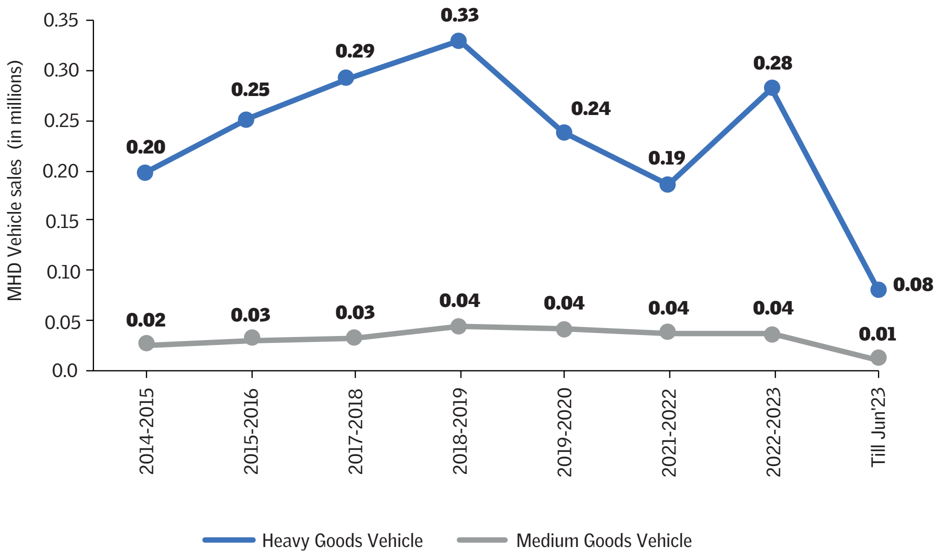
Figure 1: Road network in India



Source: Press Information Bureau (GoI) MoRTH

According to the data from Society for Indian Automobile Manufacturers (SIAM), as of June 2023, there are close to 2.12 million (cumulative as of 15-June, 2023) commercial medium and heavy-duty trucks operating in India. Over the past several years, until FY 2019-2020, the medium and heavy-duty truck sales have increased with a CAGR of 3.91 per cent and 11.51 per cent respectively. However, post FY 2020, there was a sharp decline in the domestic sales due to the pandemic. In 2020-21, domestic sales of heavy-duty trucks increased by 51.10 per cent but medium duty sales further declined by 1.11 per cent (see *Graph 4: Medium and Heavy-duty Vehicles Sales in India*).

Graph 4: Medium and Heavy-duty Vehicles Sales in India



Source: Based on data from Vahan Dashboard & SIAM

There is clear indication that a recovery in the industry after a two-year period of decline caused by the economic slowdown in 2019-20 and the subsequent impact of the COVID-19 pandemic in 2020-21.

Who is producing trucks in India?

Trucks come in all shapes and sizes and the Central Motor Vehicle Rules (CMVR) 1989 define the categories based on the body types, gross vehicle weight (GVW) and axle configuration (see *Box: Truck classification*). Technically, the focus of this investigation is the N3 category which is 12.5 tonnes and above, though the larger interest is in the heavier segment that include the multi-axle trucks and trailers with varying weight range.

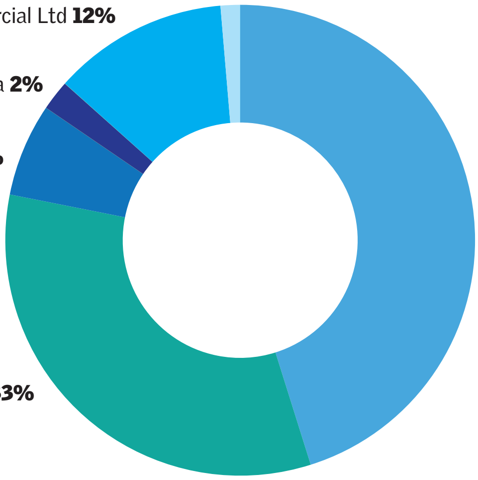
The gross vehicle weight (GVW) and the total permissible safe axle weight are specified as 49 tonne in case of rigid vehicles, and 55 tonne in case of semi-articulated trailers and truck-trailers except modular hydraulic trailers. The GVW of a two-axle truck has increased to 18.5 tonne from 16.2 tonne and GVW for a three-axle truck has increased to 28.5 tonne from 25 tonne. For a five-axle truck, the vehicle weight has increased from 37 tonne to 43.5 tonne.

The conventional OEMs including Tata Motors, Ashok Leyland, Mahindra & Mahindra and Daimler India commercial Vehicles (DICV) – Bharat Benz, have long been dominant players in the internal combustion engine (ICE) truck market. These OEMs have just started to develop e-truck prototypes. On the other hand, the emerging new players such as PMI, Olectra, BYD, and IPL Tech*, are more strident towards electrifying the heavy-duty segment.

In the conventional ICE truck segment, the shares of the manufacturers in the truck sales for the 2019-20 and 2020-21 show that Tata Motors is ahead with 46.5 per cent of the market in 2019–20 and 49.42 per cent in 2020–21 and maintains a market share that is more than twice that of the second largest shareholder, Ashok Leyland. Despite experiencing a decline of 1.8 per cent in market share between 2017-18 and 2019-20, Ashok Leyland still held nearly a quarter of the market in 2019-20. However, in 2020-21, its market share was 20.6 per cent. Available data for heavy-duty truck sales during April and July 2023, show the market share of Tata Motors at 45 per cent and Ashok Leyland at 33 per cent (see *Graph 5: OEM's market share in heavy-duty goods vehicles*).

*Now owned by Murugappa Group TI Clean Mobility

Graph 5: OEM's market share in heavy-duty goods vehicles (April – July, 2023)



Source: Based on data from Vahan Dashboard Vahan Dashboard, Author Compilation

TRUCK CLASSIFICATION AS PER CENTRAL MOTOR VEHICLE RULES (CMVR) 1989

In India, the Central Motor Vehicle Rules (CMVR) 1989 categorize the commercial vehicle segment into light, medium, and heavy goods vehicles and classify based on Gross Vehicle Weight (GVW) and different axle configuration, that essentially address vehicle's weight and payload.

N1 category: Gross vehicle weight less than <3.5 tonnes,
N2: Gross vehicle weight > 3.5 to < 12.5 tonne;
N3: > 12.5 tonnes[20].

Configuration by body type
Body type 1 – Rigid trucks that carries cargo on the same chassis as the power unit and cab.

Body type II - Tractor-trailer is a power unit (engine and transmission) and cab is used in combination with a semitrailer. When combined together it is labelled as a tractor/trailer unit (referred to as a 'semi').

Axle configuration denotes the number of wheels where traction force is applied by the powertrain in relation to the total number of wheels present on the vehicle. For example, the difference between a 6x2 and 6x4 HDT is that in a 6x2 wheel configuration, only one of the two rear axles receives power. In a 6x4 configuration, both the rear axles are drive axles.

Table 1: Maximum safe axle weight of each axle type

Maximum Safe Axle Weight	
Axle Type	Maximum Safe Axle Weight
Single Axle	
Single Axle with single Tyre	3.0 Tonnes
Single Axle with two Tyre	7.5 Tonnes
Single Axle with four Tyre	11.5 Tonnes*
Tandem Axles (Two Axles) (where the distance between two axles is less than 1.8 Mtr.)	
Tandem axle for rigid vehicles, trailers and semi-trailers	21 Tonnes*
Tandem axle for Puller tractors for hydraulic and pneumatic trailers	28.5 Tonnes
Tri-axles (Three axles) (where the distance between outer axles is less than 3 Mtr.)	
Tri-axle for rigid vehicles, trailers and semi-trailers	27 tonnes*
Axle Row (two axles with four tyres each) in Modular Hydraulic trailers (9 tonnes load shall be permissible for single axle)	18 Tonnes

* Note: If the vehicle is fitted with pneumatic suspension, I tonne extra load is permitted for each axle

Source: MoRTH notification issued dated on 7th August 2018 on "Revision of safe axle weights for Transport Vehicle" (GoI, 2018)[21].

Who is producing electric trucks in India?

Battery operated zero emissions trucks are still a low maturity technology in India. However, it's encouraging to see that the major producers have started to develop prototypes in different GVW categories – ranging from 12-55 tons with range varying between 150-200 km to 300-500 km. There is also a variation in energy capacity of the vehicles (see *Table 2: Prototypes of zero emission trucks in India*).

Tata and Ashok Leyland have so far not demonstrated a commercially viable electric heavy-duty truck, although they have recently indicated plans to accelerate development of electric variants[22].

The non-conventional entrant like the Olectra, PMI, IPL Tech, and BYD have taken steps. Olectra's e-tipper is certified heavy-duty electric tipper engineered and manufactured indigenously. The company received homologation certification for its 6×4 heavy-duty electric tippers with a load capacity of 28,000 kg and a maximum range of around 150 km per charge[23]. Other examples include Propels 45 CED, the electric dump truck specially designed for off-road mining application, Infraprime Logistics' 60 tonne Rhino 55336 e-truck and Tresa Motors' Model V0.1. These OEMs are leveraging their international supply chain for local manufacturing.

Table 2: Prototypes of zero emission trucks in India

Model	GVW (tons)	Range	Energy Capacity	Power Train
Ashok Leyland boss EV	11.9	300-350	284 kWh NMC	235 KW motor peak-140kW motor.
VCEV fuel cell truck	16-19	NA	350 bar 4 tanks	NA
Tata prima E.28K	28	150-200	453 kWh	245 kW motor
Ashok Leyland FCEV	28	NA	4-350 bar tanks, 33.6 kg H2	250 kW motor continuous, 80 kW stack
Ashok Leyland H2 ICE 4125 HN	41	NA	Type 4 carbon-fibre composite cylinders, 350 bar system	6-cylinder 180kW H2 engine
Tata prime E.55S	55	350-500	350 bar tanks	220-270 kW fuel stack, 470kW peak power motor
Tata prime H.55S	55	350-500	TYPE-3 cylinders with fuel storage total capacity @350 bar-50kg	Cummins B6.7L H B56. 2300rpm, 290HP 1200Nm 1200-1600rpm
BYD Q1R Truck (400 units ordered by the Adani Group)	42	100	LFP 217 kWh	180 kW motor
FCET Pilot (Agreement between Adani, Ballard power, and Ashok Leyland)	55	200	3 H2 tanks	120 kW fuel cell stack

Source: International Council of Clean Transportation (ICCT)

At this moment, battery operated light and medium duty commercial vehicle models have started to emerge. However, the heavy-duty models – with more than 12.5 gross vehicle weight and going close to 50 tonnes, are still not operating commercially on the road. The original equipment manufacturers (OEMs) have begun to develop prototype models.

There are uncertainties related to this segment and their prospective market entry. Battery operated zero emissions trucks are known to have much higher upfront cost compared to diesel trucks. Nevertheless, their operational costs per kilometre is epxxted to be much less. Several international studies have indicated total cost of ownership (TCO) (see *Table 3: International Studies to estimate TCO*). There is a favourable correlation compared to diesel trucks. With adequate support this can become a scalable programme.

Table 3: International studies to estimate total cost of ownership (TCO)

Author Names	Year Published	Region	Diesel TCO ($/km)	T	D TCO	Battery Price (($/ km)	Range (km)	Battery Capacity (kWh)	GVW
Chad Hunter et al. (NREL)	2021	USA	0.28	0.25	-9%	100	483	682	Class 8 (~ 36t)
Chad Hunter et al. (NREL)	2021	USA	0.45	0.25	-44%	100	193	155	Class 4 (~7t)
Sripad and Viswanatha (CMU)	2018	USA	0.37	0.12	-67%	150	805	1000	Class 8 (~ 36t)
Ear et al.	2018	Europe	0.99	0.90	-9%	77	800	1000	40t
Phadke et al. (LBNL)	2021	USA	0.60	0.47	-23%	135	604	375	Class 8 (~ 36t)

Source: Based on various research paper, compiled for this study[24]

OEMs: Perception survey

- The perception survey conducted with automobile OEMs has aimed to obtain comprehensive information about the types of medium and heavy-duty electric vehicles (MHD EVs) that are currently being developed for future roll out. The industry spokespersons have talked under the conditions of anonymity.

- This perception survey has attempted to gain insights into the rapidly evolving landscape of the industry. During the market survey, representatives from OEMs were asked to provide their perspectives and candid opinions on various topics related to freight electrification. This has kept within its purview the conventional truck sales of the OEMs during the last three years and the forecast of sales.

The OEM survey has engaged with the OEMs who are either in the process or have planned for near future manufacturing of e-trucks. This consultation has considered the following issues.

- Barriers to market adoption of e-trucks: infrastructure, charging standards, service and support, business case, customer appetite, regulations
- EV product availability and development: models commercially developed, announced to the public, and intended for future years
- Preferences regarding e-truck chargers: standards, charging rates, modes of charging

Investigation and perception: key highlights

The truck manufacturers are cautiously assessing the forthcoming changes in the road freight industry. In the heavy-duty segment, there is a diverse mix of established market leaders and new entrants, including start-ups, all diligently working on developing various e-truck models ranging from 12 to 60 tonnes. Notably, some companies are exclusively dedicated to e-trucks in their product portfolio. Despite the clear potential for heavy-duty e-trucks, predicting which specific type of vehicle will transition earlier in the near future remains a challenge for OEMs, inform industry experts. As a result, they expect a conservative growth rate in the vehicle market, with a mix of fuel types prevailing over the next 5-10 years.

It is also somewhat complicated for OEMs due to government directives and advisories during meetings and forums instructing them to explore different fuel mix options, including ethanol, LNG, hydrogen, and fuel cell vehicles. This has made the OEMs hesitant to fully commit to any particular type of vehicle segment. They are adopting a more cautious approach while piloting road freight vehicles in the market.

The lack of active engagement in forums to investigate the necessary changes needed in transport regulations and policy support schemes for promotion of road freight electrification is contributing to this conservative approach. The established OEMs are currently taking their time to develop specific e-truck models for piloting in the market.

Several OEMs foresee a bigger shift in the freight market with a certain level of distance travelled by the vehicles that can help to achieve better price parity vis a vis the ICE vehicles. According to the OEM representatives, vehicles (>12.5 tonnes) covering approximately 1.2 lakh km a year would be the ideal and most suitable candidates for transitioning to e-trucks. Additionally, vehicles traveling inter-state or intra-state, covering 80,000-90,000 km, are an opportunity for electrification. The rising diesel fuel prices, coupled with continuous improvements in battery efficiency and cost can make e-trucks a preferred choice.

Vehicles in this segment, commonly employed for transporting goods from warehouses to urban areas and transferring them to supermarkets or distribution centres, usually follow predetermined fixed routes with known stop times at each end. These vehicles can be charged both at the start and the conclusion of their journeys.

The cautious view on e-truck adoption is influenced by factors such as infrastructure limitations, battery technology advancement requirements, and customer acceptance (both logistic service providers and individual truck entrepreneurs).

These factors significantly impact OEMs outlook on the future of the market. The OEMs are also concerned about the uncertain demand generation and fragmented road freight market. This makes it challenging to estimate transitional demand, which OEMs see as the main obstacle in projecting their manufacturing efforts.

With respect to the changes needed in the regulatory environment or the implementation of specific Zero Emission Vehicle (ZEV) mandates, the industry representatives have mentioned the relevance of fuel efficiency norms. The Bureau of Energy Efficiency (BEE) is developing fuel efficiency norms for the trucking industry. The most recent and finalized fuel-efficiency standards for commercial heavy-duty vehicles were published in August 2017[25]. With subsequent amendment issued on March 22nd, 2022 (tipper shall be exempted with these norms), these standards are set to play a role. But the stringency of these norms needs to be assessed to see their effectiveness in pushing electrification of trucks.

Despite acknowledging the growth potential of e-trucks, most OEMs remain cautious in their projections, primarily because they require time to adapt to the transition. However, there is a rising interest in road electric freight among the established players, market leaders, and new start-ups.

Several major OEMs have already unveiled a restricted range of new models spanning different Gross Vehicle Weight (GVW) classes. They anticipate that the number of such models will exceed 20 by the year 2030. As technology advances and regulatory support for electrification gathers momentum, a more rapid adoption of e-trucks is expected in the coming years. This particular segment's landscape is characterized by a delicate balance between cautious optimism and ambitious innovation. The OEMs are exploring and developing various e-truck models to meet the evolving needs of the road freight industry.

Market feedback from respondents indicate that the light commercial electric vehicles (LCVs) in the range from 3.5 to 7 GVW, are witnessing high sales in the use cases related to regional shipping, food or beverage distribution, and transit services. The surge in demand is driven by the rise of e-commerce activities and the need for short-distance transportation of goods. Respondents, including top manufacturers and start-ups in the commercial EV fleet market, are optimistic about vehicle sales and future growth, contributing to the positive sales forecast for commercial EVs.

PRODUCTS IN THE MAKING IN DIFFERENT WEIGHT CATEGORIES

Here are some of the illustrative industrial initiatives to develop and market electric commercial vehicles in different weight categories – including light, medium and heavy duty commercial vehicles.

Tata Motors has unveiled models across the commercial vehicle spectrum. The tata Ace EV is an electric version of the popular diesel LCV(N1 category) powered by a 21 kWh battery with a range of 154 km and a 27kW (36hp) motor with 130 Nm of peak torque enabling a GVW 1840 kg. It is the only commercially available model currently. Tata motors unveiled prototypes in the MHDV categories at the Auto Expo earlier this year. The Ultra E.9 is a intermediate category truck(N2) with a 110-140kWh battery, 120-150 km range and 250kW motor producing 950Nm torque enabling a GVW of 9000 kg. The Prima E.28K is the first prototype model in the Heavy Duty category(N3). It is a tipper concept for mining and closed-loop applications with battery capacity of 453 kWh, which provides an operating range of 150 to 200km. It is equipped with a 245Kw traction motor providing max torque of 2950Nm and a GVW of 28000 kg.

Ashok Leyland is all set to introduce two new variants within the Light Commercial Vehicle (LCV) segment, namely "Electric Dost" and "Electric Bada Dost," during this fiscal year. They are also actively working on developing alternative fuel technology for launch of Medium and Heavy-Duty (MHD) vehicles in the fiscal year 2025.

Olectra Electric Mobility has unveiled Meghaetron Electric, an all-electric tipper truck in the heavy-duty segment. This represents Olectra's debut into the tipper market in India and is the first homologated electric tipper. This is a robust 28-tonne 6×4 electric tipper that is equipped with a Li-ion Phosphate battery pack with peak power output of 362 hp and maximum torque of 2400 nm. Its gradeability is 18 per cent for challenging terrains.This offers a range of 120 to 150 kilometre per charge and can achieve a maximum speed of 80 km per hour. They have also introduced 30 eTrucks in their subsidiary companies, specifically targeting shallow mines. These eTrucks have a Gross Vehicle Weight (GVW) of 28, with a range of 150 kilometre on a single charge. It plans to launch bigger electric trucks in the fiscal year 2025.

While some respondents have publicly announced their plans to develop e-trucks, it is essential to note that these vehicles are not yet commercially available. A few OEM respondents have disclosed their intentions to release a diverse range of vehicles across different tonnages and types, such as refuse trucks, regional haul trucks, and 55 & 40 GVW HD e-trucks. This reflects the OEMs' commitment to expanding their product portfolios and catering to a wider range of freight transportation needs.

The insights provided by the survey shed light on the specific segments driving sales, the reasons behind the positive sales forecast, and the upcoming vehicle releases from certain OEMs. This information is valuable for industry stakeholders and decision-makers to understand the dynamics of the commercial EV market.

OEM's perspective in terms of barriers for developing charging infrastructure for MHD EVs (eTrucks).

The BYD Q1R eTruck is a tractor trailer, approximately six meters in length, with an unladen weight of eight tons and a Gross Vehicle Weight (GVW) of nearly 42 tons. It is primarily designed for distribution and logistics operations rather than long-distance travel. For its intended use, a 217kWh battery (typically equipped with LFP cells at BYD) is sufficient to provide a range of 100 km. Charging can be done using a 40 kW AC charger, taking approximately six hours, or a 120 kW DC charger, taking about two hours. The truck's permanently excited synchronous motor generates 180 kW of power and offers torque of 1,500 Nm. The Adani group has placed an order for 400 BYD eTrucks, and 304 eTrucks have been dispatched. These electric trucks are intended for deployment at various ports, including Ennore, Katupalli, Hazira, and Mundra. At present, five of these eTrucks have already arrived at Katupalli port and are actively in operation.

PMI Electro Mobility Solutions, is expanding into the eTruck market over the next three years. They have partnered with China's Beiqi Foton Motors, their technology provider, to manufacture a comprehensive range of eTrucks. The PMI aims to develop and offer up to 15 different vehicles, spanning across light to heavy categories. They will partner with Foton. The construction of the plant is expected to be completed within the next 18 months. They may double their annual output to 5,000 vehicles.

Infraprime Logistics Technologies (IPL Tech), is utilizing modified Tata Signa trucks (49 tonnes) equipped with lithium-ion batteries to transport freight for Tata Steel and Bhushan Steel. The IPL Tech is introducing its branded trucks called the 'Rhino 5536A', which have a larger capacity of 60 tonnes and are powered by a 276kWh battery. The IPLTech began retrofitting old Tata Signa trucks with Li-ion batteries in mid-2020. There are 200 retrofitted trucks. The IPL Tech has also conducted trials of sodium-ion batteries from Faradion in June 2020. The TI Clean Mobility Private Ltd. (TICMPL), the clean mobility division of Murugappa Group, has acquired a significant majority stake in IPL Tech Electric Private Ltd., a three-year-old start-up focused on electric heavy commercial vehicles based in Gurgaon.

- The cost and weight of batteries are barriers to match with the ICE vehicle operational characteristics
- Standardized infrastructure is needed for fast charging at MW and above rates to fuel MHD EVs in near future.
- Lack of coordinated effort to streamline the products to swiftly introduce in the market
- The lack of financial incentives and support from the (GoI) for the freight segment, coupled with easy access to affordable finance for operators and individual entrepreneurs, will hampers the transition process.

Product development for robust pathways

The policy discussion has started on this issue and the policy roadmap will play an important role in accelerating product development which is in a very nascent stage now. Technology roadmap is needed to build market confidence and scale up local manufacturing.

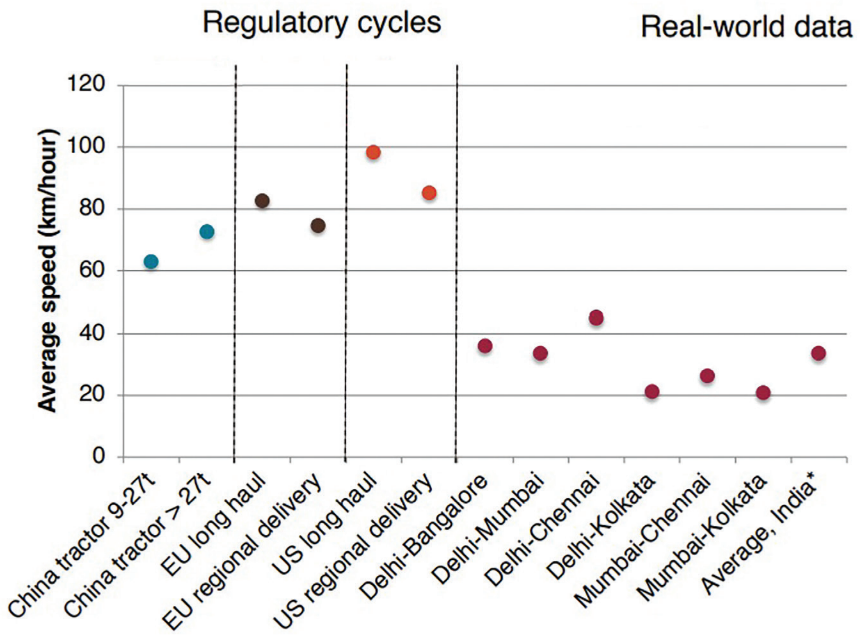
It is important to note that the office of the Principal Scientific Adviser (PSA), Government of India (GoI) has recognized that the transition from extant ICE-based trucks to zero emission trucks will require certain preparatory activities and due diligence. The PSA recently released a technical roadmap for deployment of zero emission trucking in India[26]. This is expected to influence the technology pathways for zero emissions trucks in India.

Battery for electric heavy-duty trucks: Optimization of battery system design lies at the heart of the electrification challenge of heavy-duty trucks. The choice of battery chemistry for heavy-duty trucking depends on a trade-off based on the performance of a particular chemistry over several key parameters.

India poses some unique challenges in the context of heavy-duty truck electrification. Rigid trucks* account for a larger share of the Indian truck market and will therefore have to rely on smaller belly-mounted battery packs due to lack of available chassis space. They cannot accommodate large battery packs as possible in tractor-trailer trucks.

Average speeds are lower in India in comparison to other major markets which will also affect battery sizing (see *Figure 2: Average heavy duty truck speeds*).

Figure 2: Average heavy duty truck speeds



Source: Felipe Rodrigues 2018, Market segmentation and duty cycles, ICCT as available at https://theicct.org/sites/default/files/Market-Segmentation-and-Duty-Cycles_Rodriguez_ICCT.pdf

*Rigid trucks carry cargo on the same chassis as the power unit and driver cab.

Indian driving conditions present peculiar issues like having an overloaded truck crawl up a crowded flyover without rolling back.

Battery weight: The payload capacity of a heavy duty truck defines its commercial value. Both weight (dependent on gravimetric energy density) and volume (dependent on volumetric energy density) of the battery will influence the payload capacity. In other words, lighter and smaller batteries can facilitate higher payload capacity.

For heavy duty trucking, increasing the gravimetric energy density (or specific energy) of battery packs is more of a challenge than volumetric constraints. For example, a Class 8 truck can accommodate the volume of a 1000 kWh battery pack. However, this will result in a significant reduction in payload capacity. The weight of batteries in battery operated e-trucks can compromise a truck's payload capacity by nearly 13 per cent. That payload penalty is expected to reduce in coming years, as more energy-dense cell chemistries (like solid state batteries) are introduced.

The battery pack design also offers tremendous opportunity for increase in energy density. Although cells can theoretically store about 260 Wh/kg, specific energy can reduce to about 150 Wh/kg at the pack level. Specific energy is the amount of energy a battery stores per unit mass. The loss in specific energy is often explained in terms of resistance losses, load current and internal impedance of the cells.

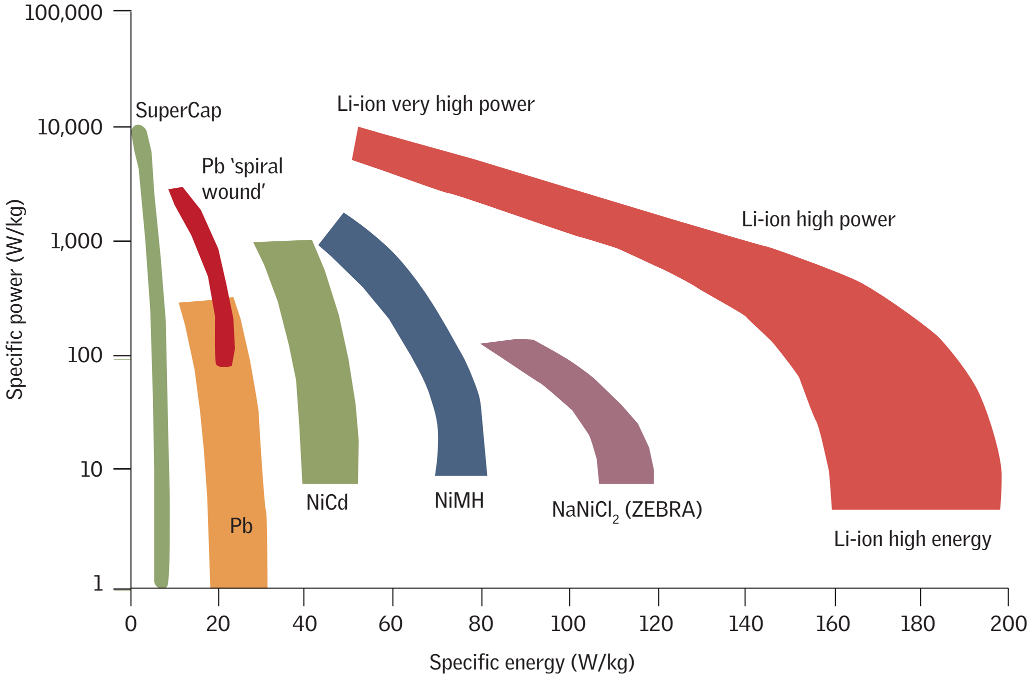
Some strategies to mitigate weight issues include using large format cells, tab-less technology and cell-to-pack designs. Additionally, within the Indian context, truck manufacturers must be prepared for overloading and incorporate a corresponding design margin while specifying battery capacity.

Furthermore, manufacturers also use a light weighting strategy to maximize payload capacity to compensate for the weight of the battery. It is used to reduce curb weight by using lighter materials like aluminium instead of steel and minimizing use of fasteners by incorporating additive manufacturing techniques (3D printing). Rolling resistance can be reduced by integrating more innovative tire designs and tread patterns and more aerodynamic designs could be incorporated for about 15 per cent gains in efficiency.[30]

Range: Heavy duty trucks have a demanding duty cycle which translates to longer range requirements due to long haul inter-city trip runs. Current state of battery technology falls short of meeting the demand of long-haul duty cycle on a single charge (less than 300 km). Long range can be achieved either by using a larger battery or by using a smaller battery with the capability of fast charging. Thus, range is a critical parameter which will need to be traded off against weight and C-rate*.

Higher range can be achieved by high energy density cells whereas fast-charge capability requires a high-power energy storage device. Lithium-ion batteries offer solutions for this kind of performance demand. However, these batteries exhibit a well-known trade-off between energy and power, often expressed as the power-over-energy (P/E) ratio, and typically represented in a Ragone plot (power as a function of energy) (see *Figure 3: Comparison for various rechargeable battery chemistries showing the wide range of performance offered by various Li-ion chemistries (Ragone plot comparison)*. High-energy cells have typically thicker

Figure 3: Comparison for various rechargeable battery chemistries showing the wide range of performance offered by various Li-ion chemistries (Ragone plot comparison)



Source: Heide Budde-Meiwes, et al. 2013, A review of current automotive battery technology and future prospects, Journal of Automobile Engineering

*the speed at which a battery is fully charged or discharged, Charging at a C-rate of 1C means that the battery is charged from 0-100% in one hour.

electrodes with a higher volume fraction of active materials, while High Power cells have thinner electrodes with a higher volume fraction of electrolyte and conducting additive.

Range can also be impacted by driving style, making it critical to train drivers on ways to maximize the benefits of regenerative braking, which can potentially add 5-15 per cent of power back to the battery.

Gaps in charging infrastructure and range challenges point at focusing on regional haul applications representing shorter routes. According to one estimate, about 60 per cent of all truck journeys are shorter than 500 km[31] and are therefore within the range achievable by battery e-trucks on a single charge. Electrification could therefore start with short haul trips. These are in fact low-hanging fruit for electrification because they have defined duty cycles which can benefit from predictability of charging infrastructure availability at defined intervals.

Charging: The speed required for charging depends on duty cycle and route scheduling of a particular fleet application. Off-shift (overnight) slow charging is a feasible option for fixed duty cycle applications and is limited only by provisioning of charging infrastructure at truck depots. Fleets with variable routes and long-haul operations will need proliferation of public charging stations in remote locations.

Heavy duty truck electrification policy should promote megawatt charging system (MCS) that can ensure faster charging and minimum downtime for fleet operators. A MCS can charge six times faster than is possible with a 350-kW charger.

MCS are typically designed to operate at charging voltages of 1,250 Volts and a current of 3,000 amperes, which is theoretically equivalent to a charging power of up to 3.75 megawatts. To put that in context, a Tesla supercharger operates at charging voltages of 480 Volts and current of 300 amperes.

Trucks can also avail opportunity charging when loading and unloading goods or when the driver is resting. This strategy could allow a heavy duty truck to carry a smaller battery thus enabling higher payload capacity. A power optimised battery suitable for fast charging will improve competitiveness in the heavy-duty segment. Large battery packs may be needed to match the operational patterns of diesel trucks. But fast charging enables smaller battery packs and better leveraging of physical scaling benefits and improve economics[32].

The Indian trucking sector is dominated by small fleet operators (less than six trucks) who would prefer to spend less upfront and depend more on public charging infrastructure when the vehicle travels longer distances.

The Technical roadmap stresses on development of Overhead Automated Charging Device (OH-ACD) which is fully automatic and connects physically with the corresponding charging rails/receptacle present on the rooftop of the truck. The SAE J-3105 standard promotes the safe implementation of mechanized DC power transfer systems for recharging heavy-duty vehicles. Overhead automated charging devices are available.[33]

Battery swapping as an alternate strategy also presents significant advantages. Battery swapping stations in China, for instance, can repower the truck in a shorter time than with charging technology of up to 10 C of charging rate. It introduces the concept of Battery-as-a-Service (BaaS) which allows fleets to pay for the truck and battery separately. The high purchase cost of e-trucks could affect adoption of electric heavy-duty trucks for many local fleet operators. It is estimated that an e-truck could save up to 50 per cent of initial cost by using a battery swapping service. However, BaaS is accompanied with challenges of battery standardization.

Harsher environment: The ambient conditions in India vastly vary compared to the temperate climate of advanced economies. Battery systems need to be designed for safe operation on roads inundated during extreme rainfall as well as handle high temperatures due to back-radiation from roads during peak summer.

Heavy duty trucks experience harsher weather conditions (temperatures, weather, shock/vibration) with tougher duty cycles compared to light duty vehicles. Heavy duty truck batteries in India will be subjected to average ambient temperatures of greater than 35 degrees Celsius which is outside the optimal operating range of Lithium-ion cells. The batteries that power them have to be designed accordingly with high abuse tolerance features. The truck's range can be impacted by several factors, such as the length of the route between stops, topography (particularly in hilly and mountainous terrain), weather conditions (particularly, extreme heat or cold), road spray, dust and unmetalled roads. Thus, mechanical and thermal integrity of the battery system is critical to prevent degradation and ensure safe operation. Although currently most trucks in India lack air conditioning, cabin cooling load on the battery needs to be accounted for in next generation battery electric truck (BET).

Thermal Management: Heavy duty truck (HDT) batteries have a much larger power output which generates more heat in addition to high ambient temperatures, thereby necessitating an even larger need for liquid cooling.

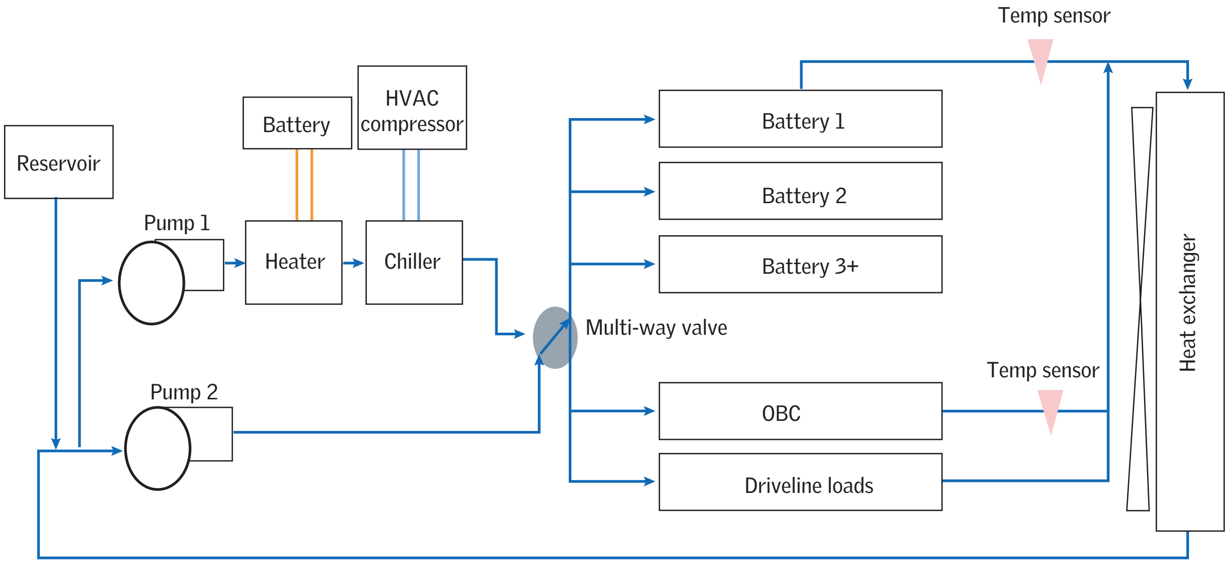
A liquid cooled Battery Thermal Management System (BTMS) consists of:

- Chiller / Heat exchanger which traditionally operates with the air conditioning compressor system to control the heat generated by the battery and power electronics.
- High Voltage or Low Voltage pumps which replaces the engine driven pumps to circulate fluid through the battery, power electronics and motor.

The thermal management system should also include a controlling point of egress for hot fumes and effluents and thermal barriers at the cell and module level to deal with potential overheating or fire events.

Thermal management becomes challenging when the power density of the cell increases. As the demand for fast charging grows and power density values increase, passive cooling* technologies such as two-phase immersion systems are gaining traction for efficient heat removal (see *Figure 4: Thermal management system of electric heavy-duty trucks*) and for avoiding battery failure. Other trends in cooling technologies include jet impingement** and spray cooling, which have

Figure 4: Thermal management system of electric heavy-duty trucks



Source: Anon 2021, E-Truck Virtual Teardown Study, ICCT and Ricardo

*evaporation and condensation within a closed system to transport heat from a concentrated source to a remote heat exchanger
**Flow of coolant as a jet in a perpendicular direction across the cold plate, that shoot across the hot surface to increase heat dissipation

received significant research attention in recent years, along with micro-channel heat sinks and heat pipes.

Cycle Life: Cycle life refers to the number of charge-discharge cycles that the battery can undergo without significant performance degradation. The capital cost of the battery will not only be determined by the battery cost per kWh but also by the lifetime of batteries. A longer battery life will increase the commercial value of a heavy duty truck. Short cycle life will necessitate battery replacements which will result in an increase in Total Cost of Ownership (TCO) values.

Battery Chemistry: Considering today's Technology Readiness Levels (TRLs) of the EV battery cell, Lithium iron phosphate (LFP) battery chemistry stands out as a promising candidate for heavy duty trucks. From a performance and payload maximization standpoint, Nickel Manganese Cobalt cathode chemistry (NMC) would be the chemistry of choice due to its high specific energy.

In comparison, LFP-based batteries have a lower specific energy (kWh/kg) and energy density (kWh/L), but because they are cheaper, more durable, and less prone to thermal runaways, they are an attractive choice for heavy duty trucking in India. LFP-based batteries are also less dependent on global supply chains since they contain neither Cobalt nor Nickel. In addition, energy density can be enhanced by using Silicon blended Graphite anodes.

Several developments are being reported globally. Northvolt, a Swedish battery manufacturer, which set up Europe's first gigafactory - have unveiled an EV battery cell designed specifically for long-haul electric trucking applications. The cell, which was developed in partnership with truck maker Scania, is a nickel cobalt manganese (NCM) battery cell with capacity to power heavy electric vehicles for 1.5 million km over their lifetime, implying large cycle life. This indicates that while LFP cell chemistry is increasingly becoming the technology of choice in Asia, high-Nickel chemistry is the more preferred chemistry in Europe and the US[34].

Beyond lithium-ion batteries, supercapacitors can be used in applications that require quick bursts of energy. They offer specific power that is five to ten times greater than that of batteries (around 10kW/kg). They can be used in conjunction with the primary battery for heavy duty trucks for requirements such as high peak current (high torque) and for harvesting regenerative braking energy.

With regard to charging technology for trucking, fast charging can be best utilized for trucks operating with power dense anodes like Lithium Titanium Oxide

(LTO). Exceptional charging rates is because of LTO nanocrystals which increase the surface area for electrons to flow in and out at a much faster rate compared to Graphite. LTO anodes also exhibit high thermal stability. However, these advantages come at the cost of reduced energy density.

Transitioning from diesel to electric heavy-duty trucks: The switch to electric addresses three primary issues - efficiency gains, reduced energy consumption and managing weight.

One of the foremost challenges of deploying electric heavy-duty trucks is to maintain the same level of service as an equivalent diesel truck. This entails matching the convenience of a diesel heavy duty truck with an average driving range of 600-800 km on a full tank of diesel, the availability of a dense network of refuelling stations and short refuelling times. To ensure that Battery Electric Trucks can mimic the low downtime of commercial vehicles operating on diesel, significant financial, technical and regulatory efforts would be required.

Operating efficiency gains: The prime mover of a diesel heavy duty vehicles is a compression ignition engine with a conversion efficiency of around 40 per cent. In comparison, a battery-operated truck, which uses a battery, offers efficiency of 85 per cent (see *Table 4: Drivetrain efficiency of diesel and electric powertrain*). The battery provides high voltage DC current drawn from the chemical energy stored in the battery cells. This powers the electric drive unit consisting of the inverter, electric motor and transmission.

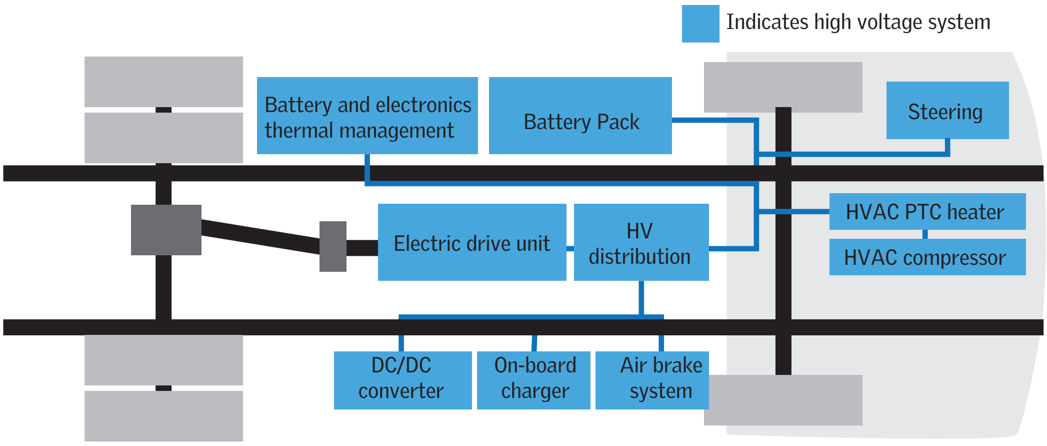
Diesel based powertrains comprise friction sensitive mechanical components such as pistons, pumps, valves, transmissions which result in considerably lower overall efficiency compared to an electric powertrain. This leads to lower operational efficiency and higher maintenance costs over the lifetime of the vehicle.

Table 4: Drivetrain efficiency of diesel and electric powertrain

Component Efficiency	Diesel HDT (in%)	Battery operated trucks (in %)
Battery charging		95
DC/AC inversion		95
Prime mover	Engine: 40	Motor: 95
Transmission	95	99
Total drivetrain	**40**	**85**

Source: Cunanan, Carlo, Manh-Kien Tran, Youngwoo Lee, Shinghei Kwok, Vincent Leung, and Michael Fowler. 2021. "A Review of Heavy-Duty Vehicle Powertrain Technologies: Diesel Engine Vehicles, Battery Electric Vehicles, and Hydrogen Fuel Cell Electric

Figure 5: Battery electric truck architecture



Source: Anon 2021, E-Truck Virtual Teardown Study, ICCT and Ricardo

Vehicles" Clean Technologies 3, no. 2: 474-489. https://doi.org/10.3390/cleantechnol3020028

In the electric powertrain, the motor is the prime mover and is the part that offers the maximum efficiency gains (95 per cent) relative to a diesel ICE.

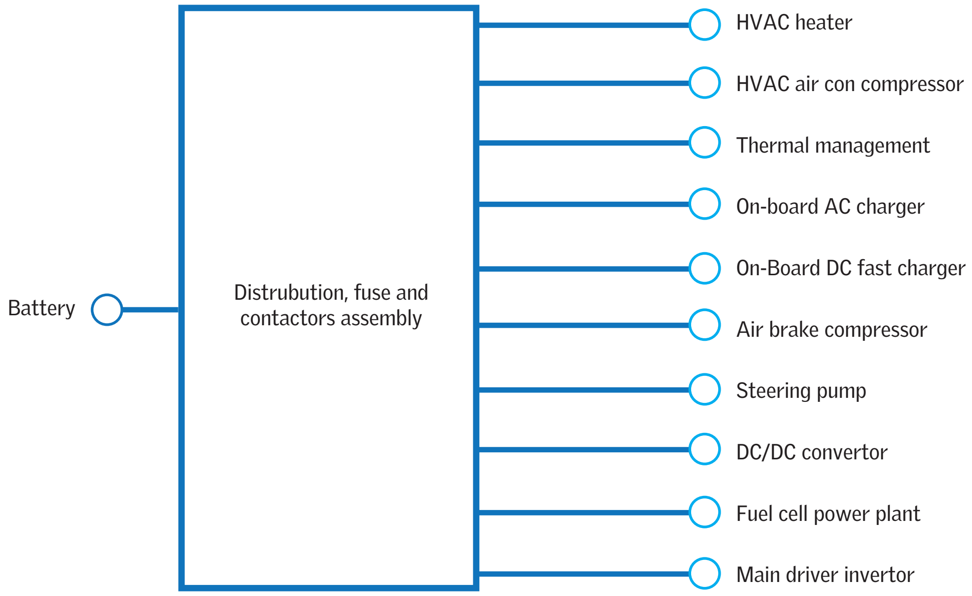
The motor is driven by the inverter which is a high voltage (HV) component. Other HV components in the vehicle typically include the DC/DC converters to supply energy to the low voltage system, on-board charger to facilitate battery charging and the HV distribution system to distribute energy from the battery to other components (see *Figure 5: Battery electric truck architecture*).

The battery system consists of battery cells, battery boxes for modules as well as the pack, battery management system and other subsystems such as high voltage contactors, busbars and wire harnesses (see *Figure 6: HV distribution system*).

Energy Consumption: The efficiency gains in battery electric trucks are quantitatively reflected in reduced energy consumption. CSE has conducted a comparative study of 'Tank to Wheel' energy consumption of diesel and electric powered heavy duty truck using data from an ICCT study on heavy duty trucks in India[35]. This is to provide visibility on saved fuel cost in battery electric trucks (provided by the ICCT study) compared to diesel heavy duty trucks as estimated by CSE.

The indicative assessment used five reference vehicle models to analyze real-world diesel technology performance and their virtual electric counterparts. The mileage

Figure 6: HV distribution system



Source: Anon 2021, E-Truck Virtual Teardown Study, ICCT and Ricardo

of these diesel heavy duty trucks was calculated using real-world drive cycle data. Raw energy content of 1 gallon of diesel fuel was assumed to be 37.358kWh[36] to calculate energy consumption.

Since India does not have battery operated e-trucks, the virtual models (used in the ICCT report[37]) replaced the ICE of the reference trucks with an electric motor and battery that could provide similar performance in terms of speed, power, and torque. Lithium-iron-phosphate batteries were considered for the calculation of energy consumption, as it is one of the leading chemistries used in heavy duty vehicle electrification today[38]. The analysis (see *Table 5: Tank to wheel comparison of energy consumption by diesel and heavy-duty e-trucks*) shows that the energy consumption of battery-operated e-trucks is significantly lower than their diesel counterparts.

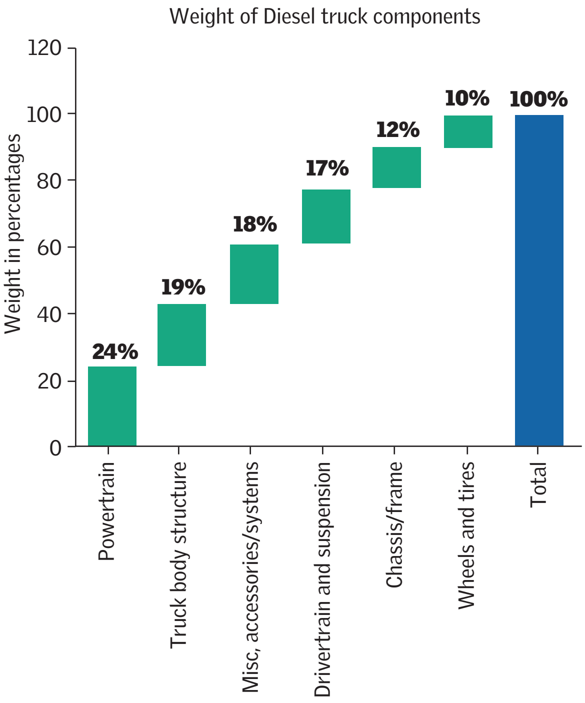
Weight: While battery operated e-trucks have simpler and more energy efficient powertrain architectures than diesel heavy duty trucks, the parameter which is a sticking point is weight. The curb weight of battery e-trucks on an average is 25-30 per cent more than their diesel counterparts. The biggest contributor to the increased weight is the battery - almost 45 per cent, (see *Graph 6: Weight distribution of diesel and electric HDT components*).

Table 5: Tank to wheel comparison of energy consumption by diesel and heavy-duty e-trucks

Truck Model		ICE			BET equivalent		
	GVW (kg)	Fuel tank (L)	Mileage (kmpl)	Energy consumption (kWh/km)	Battery size (kWh)	Battery weight(kg)	Energy consumption (kWh/km)
Tata 1212(rigid)	11,990	160	6	1.66	92	575	0.39
Ashok Leyland 1615 HE (rigid)	16,100	185	5.5	1.81	120	756	0.43
Tata 2818(rigid)	28,000	365	2.9	3.44	255	1593	0.8
Ashok Leyland 4220-5.7TD HM 10x2(rigid)	42,000	375	2.8	3.57	418	2612	1.07
Ashok Leyland 5525 (tractor-trailer)	55,000	375	1.9	5.26	471	2943	1.22

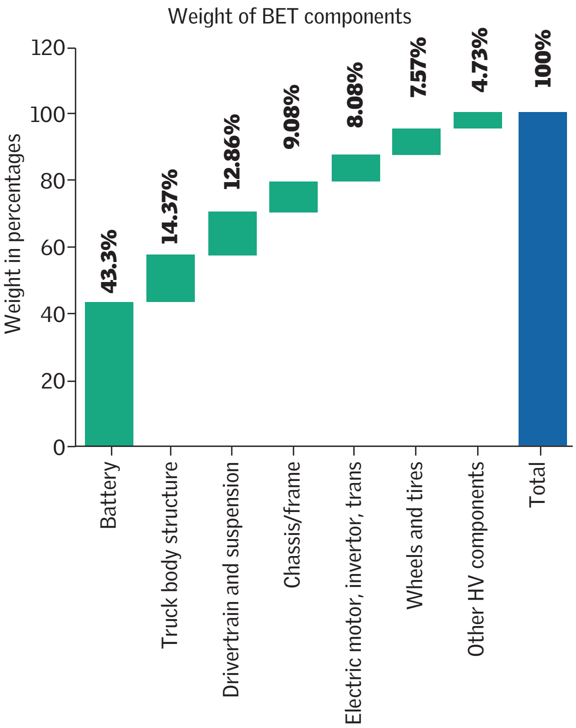
Source: Data from ICCT; CSE analysis

Graph 6: Weight distribution of diesel and electric HDT components



Diesel Powertrain, which includes engine, cooling system and transmission, typically accounts for a quarter of the truck weight, while components such as the fuel tank, pipes and exhaust system account for 18 per cent.

Source: Data from ICCT[39], CSE analysis



Electric powertrain includes battery, motor, inverter and transmission, all of which contribute to approximately half of the total weight of the vehicle.

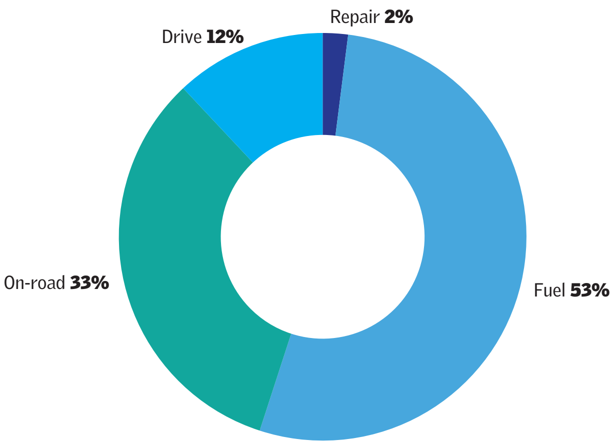
Source: Data from ICCT[40], CSE analysis

Going forward, the main barriers to larger adoption of battery electric trucks continue to be uncertainty of battery development and performance, long timeline for commercialization, provisioning of charging infrastructure and breaking the inertia of the diesel based trucking industry through regulations and success of niche markets. There is interest to first adopt battery electric trucks in high stop-start applications like refuse collection due to the advantage of regenerative charging in urban setting. Identifying ideal inter-city or regional routes for pilot operations and hub to hub long haul routes would be key to the success of electrification[41].

Cost of technology will be one of the biggest challenges that can impact adoption. Truck manufacturers would want to source batteries at affordable prices. Trucks are work tools that have to make economic sense for the buyer. A 2021 study from the Lawrence Berkeley National Lab estimated that an electric semi-truck with a 375-mile range would have a 13 per cent lower total cost of ownership (USD1.51 per mile) than a diesel model (USD1.73 per mile). From a technological perspective, energy density is the most important development goal that needs attention. Until battery prices and battery durability reach the point where e-trucks make economic sense, adoption will continue to be a challenge.

In India, the cost of fuel accounts for high share of the trip expense (see *Graph 7: Composition of trip expenses*). However, TCO parity with diesel can be achieved earlier in India compared to the advanced economies where fuel costs are comparatively lesser.

Graph 7: Composition of trip expenses



Source: Transport corporation of India 2016, Operational efficiency of freight transportation by road in India, available at https://cdn.tcil.in/website/tcil/Study_Report/TCI-IIM%20Report.pdf

There are many requirements to achieve the optimum performance of e-trucks that need to be addressed during product development. More demanding duty cycle, annual mileage than typical passenger cars. These include, higher power and associated cooling requirements; harsher environment (temperature, weather elements, shock/vibration, etc.); higher manufacturing variability due to up-fitters, various bodies, and in-use requirements and higher number of charge/ discharge cycles than light-duty vehicles. It is also evident that some of the OEMs are experimenting with the placing of the battery in the vehicle for distributed payload and improved safety. Several of these issues need to be informed based on data and evidence from the ground. This makes a case for a well thought out pilot to initiate the process and support decision making for implementation.

This requires strong participation of OEM in the transition phase.

SECTION 2
Logistic services and electric trucks: Perception survey

Response and participation of the logistic service providers – that is the key consumer group, is central to the successful implementation of the e-truck programme. This new technology will have to be adapted to the logistics ecosystem that is primarily driven by the diesel-powered internal combustion trucks.

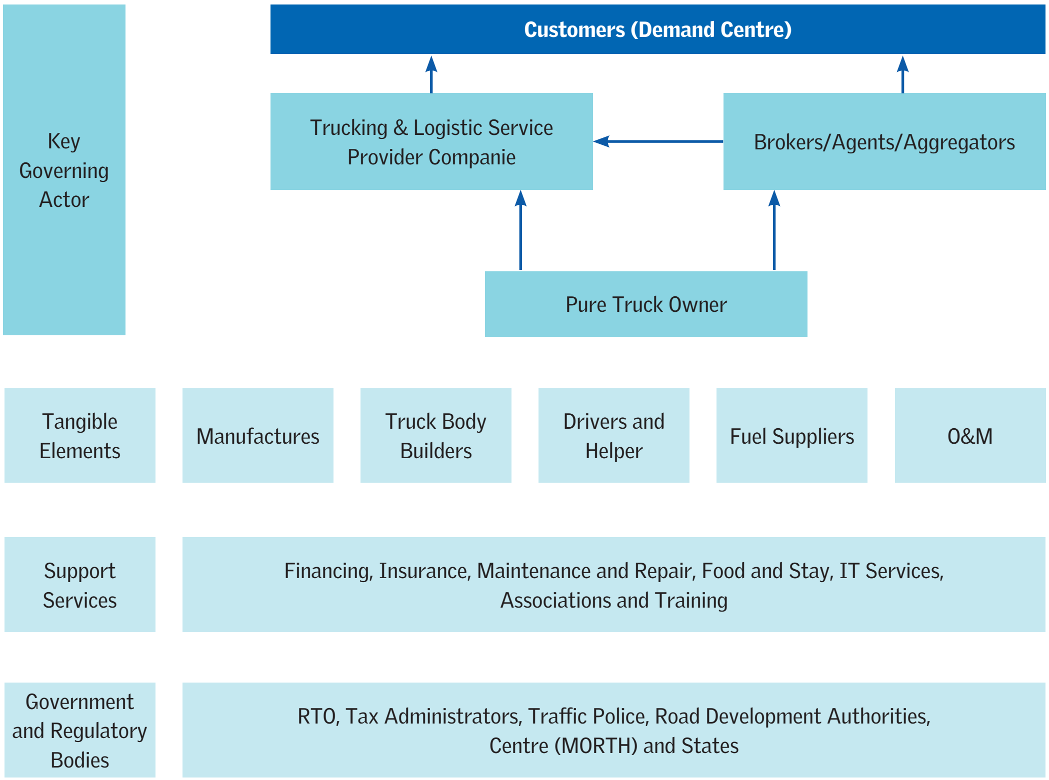
This requires a deeper understanding of the operational characteristics of the medium and heavy-duty trucks and the structure of the freight transport in India. The structure of the Indian trucking industry is linked with the classification of the truck segments and the maximum permissible tonnages allowed by these vehicles (see *Figure 7: Structure of the trucking industry (internal combustion engine powered vehicles*). As the trucking industry lacks a cohesive organization, obtaining reliable and comprehensive data regarding various aspects of these operations, including ownership patterns, are a daunting task.

Investigation and perspective: Highlights

For the purpose of this assessment, more than 16 logistic agencies were consulted. The objective of the logistic service providers survey was to obtain information on the operational characteristics of the medium/heavy duty truck fleet, their needs, plans, and prospective freight electrification. During the survey several questions were asked including, but not limited to, the following:

- Market structure of medium and long-haul freight systems in India and percentage of freight ownership in the sector.
- Current fleet operations and its characteristics (number of vehicles by type, size, and fuel type).
- Vehicle refuelling frequency, driving pattern of vehicles (miles per day, hour per day, type of terrain).
- Expectations of fleet size changes in the next 3 – 5 years.
- Any future plan to adopt e-trucks (if so, how many, by type and size).
- Perception regarding freight electrification and its domination in near future.
- Perception of barriers to e-truck infrastructure development, support needed, and plans for future scale of infrastructure.

Figure 7: Structure of the trucking industry (internal combustion engine powered vehicles)



Source: CSE, Author Compilation

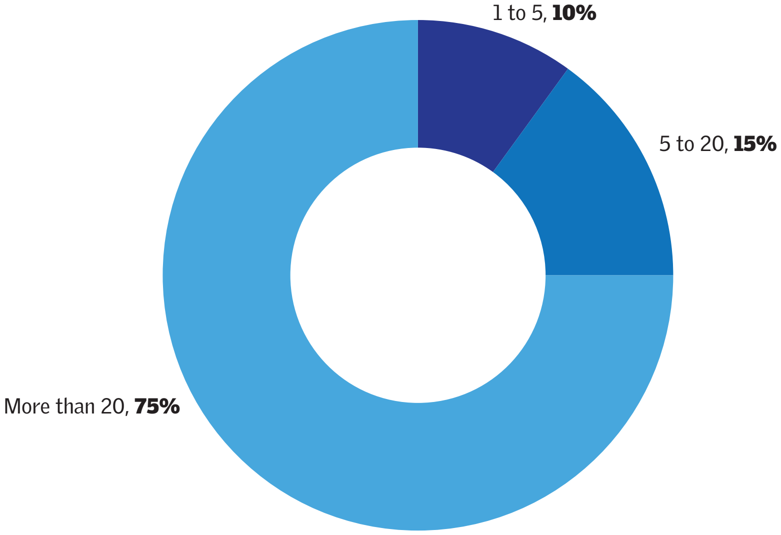
The main emphasis of the investigation cantered on interacting with third-party logistics and fourth-party logistics companies, particularly in the nearby locations within the identified geographies (DDU Varanasi and Delhi-NCR). These logistic companies offer a wide array of services that cover the entire supply chain, such as warehousing, inventory management, packaging, and comprehensive supply chain management.

During the discussions with these logistic service providers, truck association companies, and individual truck owners/entrepreneurs, it was evident that the trucking industry lacks proper organization.

Some well-known logistic companies are attempting to streamline their operations by owning and managing larger fleets. However, they are still heavily dependent on market conditions to optimize their logistic costs. Additionally, gathering reliable and detailed data on various aspects of this industry, including ownership patterns, operational patterns among others, poses a significant challenge.

The survey results indicate that 75 per cent of truck owners possess more than 20 trucks. The sector is predominantly dominated by small owners. It has been reported that many of these small operators are associated with transport companies or freight forwarding companies (see *Graph 8: Ownership of trucks in India*).

Graph 8: Ownership of trucks in India



Source: Field investigation for the study

With regard to the experience and years of operation, the data reveals that 56 per cent of the surveyed truck owners have been in the business for 1 to 10 years, while 30 per cent have been in the industry for 11 to 20 years.

Additionally, 15 per cent have been involved in this business for 20 years or more. Furthermore, over 50 per cent of the truck owners have entered this industry by switching over from being employed in the same field and deciding to purchase a truck due to the perceived profitability of the business.

Other reasons cited by the truck owners, especially by those interviewed in locations along the NH-19 and DDU (Varanasi, Mughal Sarai, Chandauli area) and those who cater to the Tier 2 & 3 markets, include inheritance of family business, ease of entry and exit, relatively low investment requirements, manageable time and attention needed, and the ability to supplement the entrepreneur's income.

As per the president of the wholesale market in Chandasi (near Mughal Sarai), there are over 800 traders actively conducting business in the mandi. On a daily

HIGHLIGHTS OF THE FREIGHT LOGISTIC COMPANIES AS EVIDENT FROM THE SURVEY

- Majority of goods transporters in India are small operators owning one or two trucks. In some cases, the small operators own between 5 to 10 trucks. The trucks are not registered under one individual person presumably to avoid income-tax, labour legislations, etc.
- The small operators are involved only in the physical movement of goods and depend on the booking agents and other fleet operators/ transporters for obtaining business.
- Some are attached to major transport companies, brokers and vehicle suppliers. They do not generally come in direct business contact with the users.
- The long-haul truck operates with average of 2 – 4 lit/km with full truck loads with speed of 50 – 60 km/hr along the long highway corridors.
- The small truck owners operating within the states, and or crossing multiple districts specially the construction material transporters, are mostly not obeying the restrictions on overloading.
- The organized logistic service providers viz. TCI, Darcl, Delivery etc. are following the standards and regulations issued by the relevant ministry. These operators have their own truck drivers and are paid as per Government of India norms. They also receive incentives if consignment is delivered to the customer on-time and or before the scheduled time.
- These operators have strict operational norms for truckers. Drivers aren't allowed to operate during the night hours if consignment includes non-perishable products.
- The small truck operators and individual truck owners have a geography-based lobby to provide demand services on priority to their truckers first.

basis, around 1,700 trucks are engaged in supplying coal to the market. Each truck carries approximately 30 to 40 tonnes of coal daily. The mandi witnesses coal trading worth Rs 60 crore (Rs 600 million) every month.

To handle the coal unloading process, laborers work tirelessly for about 10 hours each day. For unloading a single truck, the traders pay an amount ranging from Rs 1,200 to Rs 1,500, which is then distributed among the laborers.

Delhi-NCR has a significant concentration of manufacturing activities in its southern and north-eastern parts. The current clusters for manufacturing are located along NH-8 and NH-2 in the southern region, and NH-24, NH-91, and NH-58 in the north-eastern region. This has led to the establishment of numerous warehouses in these clusters, making them the preferred choice for many businesses.

The NH-8 area (Delhi-Jaipur Highway) has become the central focus for warehousing due to its advantageous location and the high concentration of manufacturing activities. Industries such as auto and auto ancillary, cement, chemicals, pharmaceuticals, and food processing are major contributors to the growing demand for warehousing in this region. Additionally, its excellent connectivity to various industrial towns has turned it into a hub of economic opportunities.

Considering these factors, the future plan for truck electrification in this area becomes even more significant. The electrification of trucks not only supports the e-truck transitioning, but it also instils confidence among logistic service providers to shift from internal combustion engine (ICE) vehicles to e-trucks. Given these favourable conditions, the NH-8 highway emerges as the most preferred choice to run the pilot project (See Table 6: *Industrial clusters in the Delhi-NCR region*).

Table 6: Industrial clusters in the Delhi-NCR region

Manufacturing Cluster	Industrial Areas
Delhi	Industrial areas within Delhi, such as Narela, Okhla, Bawana and Rohtak road, among others
NH-8 & NH-2	Manesar, Taoru Road, Dharuhera, Bhiwandi, Bawal, Neemrana, Pataudi, Luhari, Kulana, Jamalpur, Jhajjar, Bhora kalan, Badshapur, Farukh Nagar, Jamalpur, Kulana, Taj Nagar and Taru Road
NH-1 & NH-10	NH-1 & NH-10 Industrial areas accessible from NH-1 and NH-10, such as Sonipat, Panipat, Bahadurgarh and Rohtak, among others

Source: Field survey for the study

According to the responses gathered from a limited number of organized service providers, it is evident that they are actively involved in all segments of logistics, including tipper/trailer fleets, fast-moving consumer goods, and parcel delivery, with a primary focus on on-road freight transport.

Despite owning larger fleets, these providers exhibit a significant dependency on local unorganized logistic companies and individual truck owners and entrepreneurs. The primary reason stated by these operators for relying on the unorganized sector is that it facilitates their ability to mobilize and offer services in every corner of the cities they cater to. By collaborating with local logistic companies, individual truck owners and entrepreneurs can effectively penetrate the most remote areas to provide comprehensive coverage.

Additionally, collaborating with local unorganized logistic companies and individual truck owners provides a level of flexibility and agility that would otherwise be challenging to achieve solely with their fleets. They therefore gain access to a wider range of vehicles and transportation options. This enables them to accommodate varying customer demands, adapt to fluctuating market conditions, and efficiently handle diverse cargo. TCI, one of the leading logistic service providers, has a fleet of over 20,000 trucks. They also opt to avail services from the market, either through individual truck owners or localized small logistic service providers.

While these organized logistic service providers may possess substantial resources in the form of their own larger fleets, they recognize the value of partnering with local unorganized logistic companies and individual truck owners. This strategic collaboration allows them to extend their reach, optimize costs, and ensure comprehensive and efficient service coverage throughout the cities they operate in.

When asked about the length of route in km travelled daily by the medium and high duty vehicles, the responses varied depending on the fleet's vocation and the type of vehicles they operated. According to the logistics sector's representatives, the average distance covered by a truck nationally, has increased by up to 100 – 150 km/day compared to the pre-GST era. The average distance covered by a truck (long haul trucks) is between 400 – 450 km/day.

According to the logistic company's information, long-haul trucks, when fully loaded, generally consume an average of 2-4 liters of fuel per kilometre while traveling at a speed of 50-60 km/hr. on highway corridors. However, within urban areas or while transiting through cities, their speed reduces to a maximum of 20 km/hr. The implementation of fast-tag operated toll systems has been effective in addressing overloading problems, especially concerning long-haul trucks that operate within specific regions.

However, the compliance with the restrictions on overloading remains a concern among small truck owners, particularly those involved in transporting construction materials, who often disregard these regulations. Following the implementation of the GST by the Government of India, hefty penalties for overloading have been imposed on truckers and logistic service providers.

In contrast, organized logistic service providers such as TCI, Darcl, and Delivery adhere to the standards and regulations set by the relevant Ministries. These operators employ their own truck drivers, who are compensated according to Government of India norms. Additionally, they receive incentives for delivering consignments to customers on time or even ahead of schedule. These operators maintain strict operational norms, restricting truckers from operating during night time for non-perishable products. Truckers often prefer operating during the night to avoid traffic congestion, particularly when passing through tier 2 and tier 3 cities.

It is worth noting that small truck operators and individual truck owners have established geographically-based lobbies, prioritizing demand services for their own truckers. Mumbai, Chennai, Kolkata, and Gujarat have witnessed significant logistics demand due to their port facilities and export-import activities. When truckers receive a return load demand while heading back to their base, the operators have the opportunity to maximize their profit margins.

Perception of e-trucks: Most logistic providers are not aware of what e-trucks may entail. A small segment has picked up the information from the larger conversation happening in the country. Some small-scale operations like those purchased by the Adani Group for port operations are the only live examples. However, most of the responses are based on the general understanding of what is needed in terms of upfront capital cost, charging requirements etc.

The fleet surveys discussed so far provide similar qualitative findings regarding fleet operator interest, plans, and needs of EV trucks and charging infrastructure. These findings include:

- Insufficient charging infrastructure poses a significant obstacle to widespread adoption, much like the challenges faced in the electric-light-duty commercial vehicle market. Limited range, lengthy recharging times, and high upfront costs are also key concerns among the truck owners.
- There is greater inclination towards > 7.5 tonnes vehicles compared to other sizes. However, this preference might be influenced by a sample bias towards port drayage fleets.
- There is a strong desire for financial support, in the form of grants or other funding sources, to help address the high costs associated with vehicles and infrastructure.

The initial cost of acquiring e-trucks will be higher compared to conventional diesel trucks. High prices can be prohibitive for logistic providers and truck entrepreneurs. That can result from several factors, including high battery costs, start-up costs associated with the development of new EV models, and truck manufacturers' market power, which may be high because of the limited commercial product offerings in the industry. Battery technology, which forms a significant portion of the cost, is improving but remains relatively expensive. The higher upfront cost can act as a barrier for fleet operators and businesses looking to transition to e-trucks, especially for smaller companies or those operating on slim profit margins.

- Fleets struggle to make the business case for e-truck adoption because of the high cost of the vehicles and infrastructure.

- Despite the decreasing costs of battery cells, the high expense of battery packs remains a significant concern for e-truck adoption. There are apprehensions regarding replacement costs. The fleet operators also worry about the impact of climatic conditions on battery performance.
- Without incentives, financing is challenging. Limited leasing options are available for fleets that prefer leasing over purchase of e-trucks.
- In theory, maintenance costs for e-trucks are lower than for conventional trucks. But the requirement of technicians and the higher chances of a new technology facing technical issues during the early part of deployment can cut these savings. Only with some years of experience, the real-world maintenance savings will become clearer.
- This requires diverse approaches and involvement of the industry to develop cost-effective solutions for batteries such as battery leasing model, extension of battery warranties beyond 5 years, adoption of tougher durability requirements, and working with fleets to “right-size” the battery to each customer’s duty cycle.
- Encourage regulators to evaluate non-fiscal incentives to encourage e-truck adoption, such as high-occupancy vehicle lanes, green loading zones, and preferential access.
- The logistic providers have also raised issues with respect to the freight and fare rates as that impacts cost recovery and earnings. The authority to establish freight and fare rates is granted to state governments under Section 67(1) of the Motor Vehicle Act, 1988. This provision enables state governments to issue directives to State Transport Authorities (STAs) regarding the fixation of these rates. Additionally, according to Section 79(2)(iv) of the Act, the Regional Transport Authority (RTA) has the discretion to specify rates for the transportation of goods while granting a public carrier permit.

However, states currently do not have an objective foundation for determining freight rates and a dedicated agency to enforce these rates. In an industry primarily dominated by individual truck operators, the determination of freight rates heavily rely on the involvement of goods booking agents and brokers. These intermediaries play a pivotal role in facilitating the transportation of goods for truck owners.

The broker acts as a liaison between the truck owner and the booking agents, sourcing the goods for transport. Ultimately, it is the broker and booking agent who negotiate and establish the freight rate for the truck owners.

There are intermediaries for fare, and freight rate systems. The calculation of freight rates in this industry typically takes into account several factors. These factors include distance travelled, size and type of the truck utilized for transportation, nature of the cargo, and any additional services that may be required, such as loading and unloading.

Freight rates exhibit considerable variability, primarily due to the diversity of logistic companies operating in the market. Each company may have its own unique pricing structures and strategies, resulting in differing rates for similar routes and destinations. The specific route and destination play a crucial role in determining the freight rates, with factors such as road conditions, tolls, and transportation regulations affecting the overall cost.

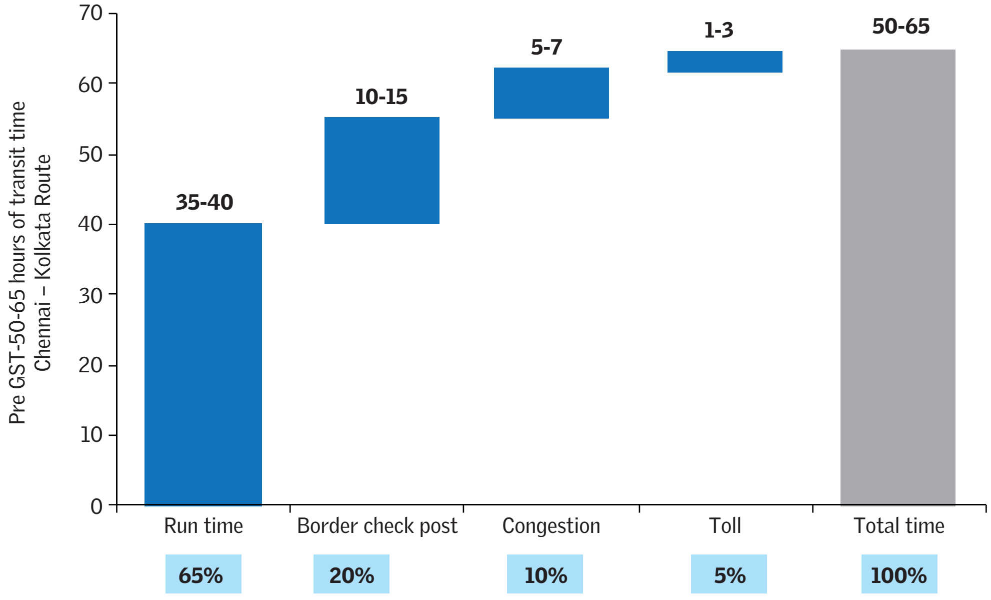
Consequently, lack of organized data and standardization in the trucking industry makes it challenging to establish consistent pricing benchmarks. This absence of reliable information hampers the ability of industry stakeholders to accurately assess market dynamics and make informed decisions. Transport rates in the logistic field in India are influenced by several factors that determine the overall cost of transportation. These include distance of the journey, delivery time, route and infrastructure, type and size of vehicle, fuel prices, insurance, liability, nature of cargo, and seasonal demand, and market competition.

The introduction of GST has had a notable influence on freight rates and enhanced the operational effectiveness of the trucking industry. Following the implementation of GST, freight operators have observed reduced transportation time. According to data compiled by MoRTH, the elimination of interstate check posts has resulted in a 20 per cent decrease in travel time for long-haul trucks and other cargo vehicles. Consequently, logistics costs have reduced by a significant margin, ranging from 30 per cent to 40 per cent.

A typical truck spends 20 per cent of it's run time at interstate check posts. It is evident that on an average, a truck in India runs an annual distance of 60,000 km as against 200,000 km in the western countries[42]. This had increased the freight cost substantially pre-GST. However, post GST the distance travelled by trucks per day has increased by at least 30 per cent and trucks are covering 300-325 km a day on an average against about 225km a day before GST era[43].

A lot of these issues will come under spotlight when truck electrification takes off and cost recovery on capital investment will become more compelling (see *Graph 9: Breakup of transit time (in hour) for logistic players*).

Graph 9: Breakup of transit time (in hour) for logistic players



Source: Based on MoRTH Data, analysed for the study

SECTION 3
Energy providers and electric trucks

Electric trucks have very specific charging requirements. These trucks are typically used for long-haul transportation and carry substantial payloads that increase power consumption. They have greater power needs due to their larger battery sizes and heavy payloads and require concentrated charging of multiple vehicles in the resting or depot spaces along the highways. Therefore, the charging infrastructure needs to be designed to meet their specific charging needs to avoid delays. This needs advanced planning for charging in logistic hubs and on-route charging.

Even though this is a critical intervention point there is little awareness and understanding among the stakeholders including OEMs and logistic providers about the charging solutions needed for operating heavy duty e-trucks.

Charging solution providers: perception survey

The perception survey encompassed Electric Vehicle Supply Equipment (EVSE) manufacturers, assemblers, aggregators, and charge point operators, to map out perspectives on the challenges and prospects associated with the future implementation of the charging solutions for e-trucks. The objective was to gather insights into the barriers to widespread adoption and identify the potential solutions and opportunities from their first hand experiences, observations, and opinions.

The survey targeting EVSE hardware and software suppliers to gather specific information and insights related to the following areas:

- Product availability (in terms of voltage and power capacity) and barriers to scaling the product voltage range
- Import dependency on hardware sub-components used in EVSE and its supply chain
- Charging standards: known charging standards and preferences
- software to enable demand management and load balancing
- Recommendations for policies and regulations supportive of e-truck charging infrastructure development

This sheds light on critical considerations such as infrastructure requirements, technical limitations, market demand, policy support, and potential collaborations, - all of which are crucial to the future development of electric charging infrastructure for the freight sector.

Interviews were carried out with charging point operators, Charger OEMs, and ancillary service providers. A majority of these stakeholders had their offices located in Delhi-NCR, Gurgaon region and Lucknow.

The primary objective of these interviews was to gather valuable insights and identify essential reforms. Their responses were diverse:

- Delays in completing infrastructure projects, obstructing rapid deployment.
- The combined deployment costs, along with the true costs of ongoing operations and maintenance, proved to be prohibitive.
- Limited aggregate demand anticipated for commercial heavy-duty e-truck charging sites for at least the next 5 years.
- Uncertainty surrounding the charging standards required for this specific vehicle segment, along with ambiguity in decisions regarding strategic locations along expressways.
- Inadequate understanding of the cost, technology, and grid services associated with large-scale deployment of heavy-duty-truck charging.

The stakeholders underscore the crucial necessity for reforms to enable a more seamless transition to e-trucks.

The on-site investigation along the Delhi-Jaipur Highways revealed that charging infrastructure has predominantly been established at hotels and nearby petrol pumps. Specific details of the surveyed charging stations along the Delhi-Jaipur Highway including their specifications have been observed (see *Table 7: DC Fast charging stations along Delhi-Jaipur highway*).

On recommendations for policies or regulations that might help to strategize for their charging product development for e-truck, the charging service providers recommend that demand-side stakeholders need to be obligated to follow government mandates, similar to the regulations applied to passenger segment vehicles.

Several of them are confident that e-truck adoption will extend across different weight classes, with the electric light commercial vehicles segment already gaining momentum. They expect deployment of electric medium and heavy-duty e-trucks

Table 7: DC Fast charging stations along Delhi-Jaipur highway

Service Provider	Manufacturers	Location	Power Rating (kW)	Production Date
Zivah Electriva	Zivah Electriva	Hotel Prince, Raghunathpura	60	Aug-22
Tata Power	ABB	Rajshree Hotel, Chandwaji	30 (7.5X2)	Oct-21
Tata Power	ABB	Neemrana	25	Oct-21
Tata Power	ABB	Syari	25	Oct-21
Statiq	Exicom Power Solutions	Hotel Highway Express, Behror	60	Apr-22
Statiq	Exicom Power Solutions	Hotel Highway King	60	Sep-21
Charge+Zone	Quench Chargers	Hotel Highway King, Behror	60	Jan-22
Yahhvi	Yahhvi	Hotel Ajay Residency, Kherki Daula	30	Nov-21
Start Solar Pvt. Ltd	Exicom, Delta	Hotel Highway King Shahpura	120	Apr-22
Start Solar Pvt. Ltd	Exicom, Delta	Hotel Highway King, Neelka	120	Apr-22
Start Solar Pvt. Ltd	Exicom, Delta	Hotel Highway King Bilaspur	120	Dec-22

Source: Compilation for the study

to occur in the near future, with a substantial penetration rate projected by 2030. The representatives expressed their thoughts on potential locations for charging solutions for these e-trucks.

With regard to the standards, the respondents were well-informed about the prevailing market trends regarding the choice of charging standards. The majority of them expressed a strong preference for the CCS2 (Combined Charging System 2) charging standards, highlighting its advantages and suitability for their specific needs. However, it is worth noting that a small number of respondents expressed a mixed opinion, indicating that they have different perspectives on the selection and preference for charging standards.

Each respondent has provided perspective on the barriers. Some of the highlights are as follow:

- Use case is not clear enough in the heavy-duty segment
- Total deployment costs, combined with the true costs of ongoing operations and maintenance, can be prohibitive.
- The completion timeframe for infrastructure projects can be yearlong, which presents a significant obstacle to rapid deployment.
- Large-scale deployment of heavy duty trucks charging is not yet well-understood from the perspective of cost, technology, and grid services.

- Supply chain for the sub-component for EVSE is a challenge. Most are dependent on international market for the critical components. Some of the observations in this regards are as follow.
    - o Rectifier manufacturing is not possible in India because of Infrastructure cost is very high and the limited scale of market does not make business case for it.
    - o Some have observed that their gun manufacturer is not interested to making the GUN in India due to Infra cost and limited testing setup in India
- Any development, including testing and field verification, typically requires a time frame of approximately two years.
    - o Even minor modifications in chargers necessitate a field verification process that typically takes around six months to complete.
- Its discrete timeline for grid connection with several administrative approvals and sourcing of electricity (brown and green electricity)
- High-capacity charger would require heavy upfront investment for acquisition of chargers. This presents financial challenges.

Observations of the respondents on their recommendations for policies or regulations to facilitate the progress of e-truck charging site development:

- Demand charges are cost-prohibitive and may be addressed via policy approaches.
- Incentives, schemes similar to FAME II to subsidize early adopters would be beneficial targeting high-capacity DC fast chargers (may be 120kW above)
- A global standard for common charging connectors and protocols would keep costs down and optimize maturation of technology
- During the initial years, operational cost support would be required to meet the operational start-up losses. This is needed till the time public e-truck charging market develops.
- Clean fuel goals incentivizing fleets to adopt EVs have been a productive approach so far.

Observations of the respondents on best practices regarding the deployment of medium and heavy-duty e-trucks charging infrastructure in the near future:

- Collaboration with freight operators and OEMs to understand their daily distance travel, vehicle battery design and power requirements.
- Collaborate with individual freight operators and truck owners to assess the optimal approach for their specific needs, whether it is implementing behind-the-fence depot charging or in-route charging.
- Prioritize convenient access to 3-phase power sources with either dedicated

transformer or enough capacity reserve, which are crucial for efficient charging operations.

- Demand management and load balancing needs attention. It is necessary to work with network management software companies. Consider this approach in sites with multiple chargers that require adherence to open standards (openADR), and energy storage.

- When representatives from charging solution sector were asked about the major obstacles to implementing EV charging infrastructure for e-trucks, they had varied responses. These responses are categorized into common themes. The four most frequently mentioned barriers were:

» Current charging solution have longer wait times
» High cost of infrastructure
» Land acquisitions, and open-ended timeline

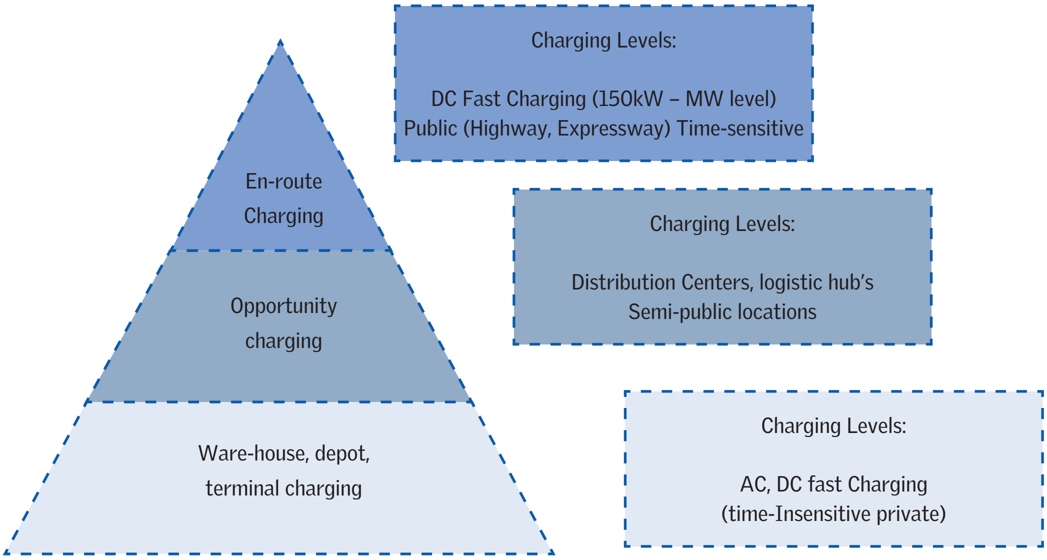
- Observations of the respondents on distinctive challenges associated with e-truck charging in comparison to light-duty EV charging:

» Time constraints and remote charging initiation: One respondent noted that DC fast charging ports designed for MHD vehicles have a limited time window for initiating charging. If the charging process does not commence within a few minutes, the charging ports may time out. Currently, there is also no capability to remotely initiate a charge session. This can present logistical challenges.
» Coordination with electric utility companies**:** Another respondent emphasized the importance of effective coordination with electric utility companies to address the added complexity associated with higher power demand and to ensure appropriate infrastructure is in place.
» Energy Storage and Backup Charging Plans**:** One respondent expressed that e-truck charging typically necessitates the inclusion of energy storage systems and the development of emergency backup charging plans for commercial vehicles. These measures are crucial to ensure reliable charging options, particularly in situations where power outages or disruptions may occur.

These insights highlight the unique challenges that are anticipated for heavy duty charging. This requires optimizing charging initiation protocols, collaboration with electric utility companies for infrastructure support, different charging paradigm and implementation measures like energy storage and backup charging plans to enhance the reliability of charging operations.

When the respondents were asked about the appropriate charging locations, the response was represented in the graphical form (see *Figure 8: E-truck Charging paradigm*).

Figure 8: E-truck Charging paradigm



Source: Analysis for the study

Power sector representatives: Perspective

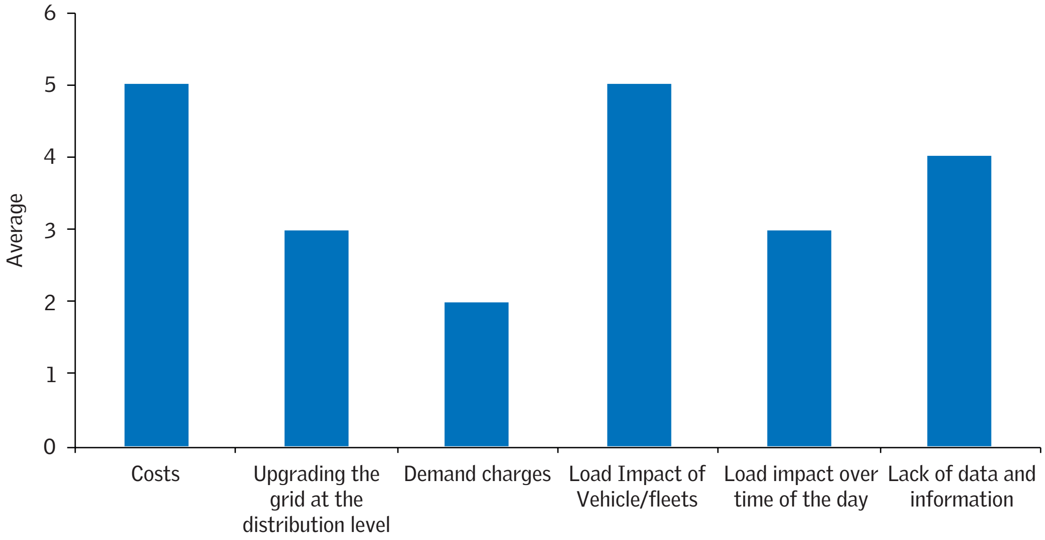
The consultation with the representatives of the electrical utility and technical institutions in power sector focussed on the following issues related to freight electrification:

- Distribution grid readiness to accommodate near future charging demand if electrification of freight segment takes off.
- Role and importance of data acquisition to project the short- and long-term demand for electricity by the EV segment.
- Electricity procurement - sourcing of green and brown power to energies charging infrastructure.
- The challenges associated with mega watt charger integration with distribution grid and its management

The surveys were conducted to assess the preparedness of the Indian market for the electrification of the freight sector and the significance of integrating the transport and power sectors.

Interviews and surveys were specifically conducted with distribution companies and central electricity authority (CEA). DISCOMs play a crucial role in the transportation sectors, and their input is essential for identifying the challenges.

Graph 10: Average ranking for barriers for upgrading distribution grid



Source: Analysis for the study

The purpose was to gain insights and comprehensively analyse the barriers that may impede the widespread adoption of e-trucks in the near future. The insights gathered from interviews and surveys shed light on factors such as infrastructure requirements, grid integration challenges, charging infrastructure availability, operational considerations, and regulatory or policy barriers. This can facilitate in formulating targeted strategies and solutions.

The three top barriers to the adoption of e-trucks as identified by the DISCOMs include costs, upgrading the grid at the distribution level, and data acquisition (see *Graph 10: Average ranking for barriers for upgrading distribution grid*).

Other Barriers mentioned by the electric utilities:

- Cost of infrastructure investment. The existing structure protects ratepayers from cost increases associated with infrastructure expansion projects for new loads that may not materialize.
- Concentrated new load at truck charging depots would require further distribution system upgrades. This will need to address:
  - ← Peak power increase/ charging demand patterns
  - ← Power quality related challenges
  - ← Megawatt charging integration with the distribution grid
  - ← Regulatory challenges with DISCOMs
- Lack of awareness, education, and importance of energy applications among fleets operators

- Irregular infrastructure usage requiring large investment to meet load peak, but no consistent utilization
- Lack of data and Information to precisely forecast the near future demand from e-trucks
- Concentrated new load in charging depots that could require further distribution system upgrades and or new feeder line expansion
- Technology readiness to optimize the charging need through smart charging or V2G applications
- Capital investments required for infrastructure upgrades and restriction to socialize the cost amongst the users.

Demand Drivers- Fleet Aggregators

- Due to the small ownership pattern of trucks in India, fleet aggregators play an important role.
- Fleet aggregators are likely to play a crucial role in the early electrification of trucks in India. Fleet aggregators may act as intermediaries that bring together truck owners and operators, technology providers, and customers to facilitate the adoption of e-trucks. Here are some specific roles that fleet aggregators may fulfill.
- **Encouraging adoption:** Fleet aggregators may actively promote the adoption of e-trucks among fleet owners and operators. They can provide information, education, and support to help these stakeholders understand the benefits of electric vehicles, such as reduced operating costs, lower maintenance requirements, and environmental advantages.
- **Infrastructure planning:** Fleet aggregators can contribute towards planning and developing the necessary charging infrastructure for e-trucks. They can identify optimal locations for charging stations, negotiate with charging infrastructure providers, and collaborate with utilities and government agencies to ensure a reliable and accessible charging network.
- **Economies of scale:** By aggregating the demand for e-trucks from multiple fleet owners and operators, fleet aggregators can negotiate better deals with vehicle manufacturers, charging infrastructure providers, and other stakeholders. This can help to reduce the upfront costs of e-trucks and improve economic viability for the fleet operators.
- **Operational optimization:** Fleet aggregators can leverage data and technology to optimize the operations of e-truck fleet. They can use advanced analytics and route optimization algorithms to improve efficiency, reduce downtime, and maximize the utilization of e-trucks. This can result in cost savings for fleet operators and encourage further adoption of e-trucks.

- **Battery swapping and energy management:** Fleet aggregators can explore innovative solutions like battery swapping to overcome the limitations of charging infrastructure and ensure uninterrupted operation of e-trucks. They can coordinate battery swapping stations and manage the logistics of swapping batteries, enabling quick turnaround time and extended vehicle uptime.
- **Maintenance and service:** Fleet aggregators can work closely with manufacturers and service providers to establish efficient maintenance and service networks for e-trucks. They coordinate routine maintenance, repairs, and servicing to ensure the smooth operation of the vehicles and minimize downtime.
- **Data analytics and reporting:** Fleet aggregators can gather and analyse data on the performance, efficiency, and energy consumption of e-truck fleets. This information helps fleet owners, operators, and manufacturers gain insights into the real-world performance of e-trucks, identify areas for improvement, and refine their strategies.
- **Ongoing projects:** Flipkart, Myntra, IKEA and Zomato have committed to 100 per cent EV transition by 2030. Gati Ltd — an express logistics and supply chain solutions provider — intends to convert its entire pickup and delivery fleet into alternative fuel vehicles by 2025. This is an opportunity.

SECTION 4
Charging infrastructure for e-trucks: Anticipated challenges

Perception survey of the charging providers and the power distribution agencies has revealed several issues related to the charging infrastructure that need to be addressed if a sizeable truck electrification programme is planned.

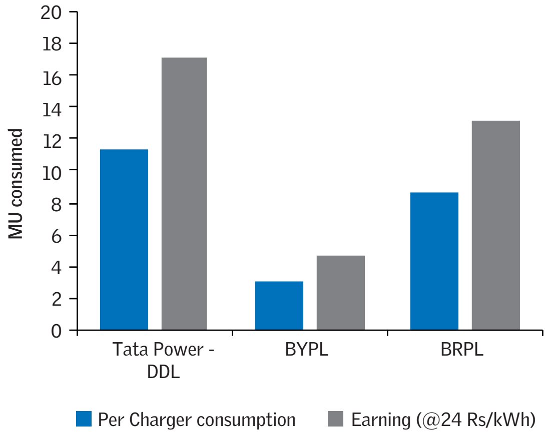
At this stage there is no evidence on ground to indicate what it might take to meet the charging requirements of heavy duty trucks. The only somewhat comparable experience that exists with respect to heavy power withdrawal for charging of vehicles is depot-based charging of heavy-duty electric buses. This is illustratively evident in the monthly energy consumption data provided by the Central Electricity Authority (CEA)[44] for electric buses. This data set indicates per charger electricity consumption and earnings for different electricity distribution companies. This indicates the need for careful planning and execution to address upcoming challenges related to freight logistics (see *Graphs 11 and 12: Consumption pattern for heavy duty electric buses*).

Ensuring uninterrupted and reliable energy supply to e-Trucks needs significant investments in new charging infrastructure capable of meeting high voltage and current flow from Electric Vehicle Supply Equipment (EVSE) to the vehicles. Faster charging time and reliable power are needed for timely deliveries and uninterrupted travel distances.

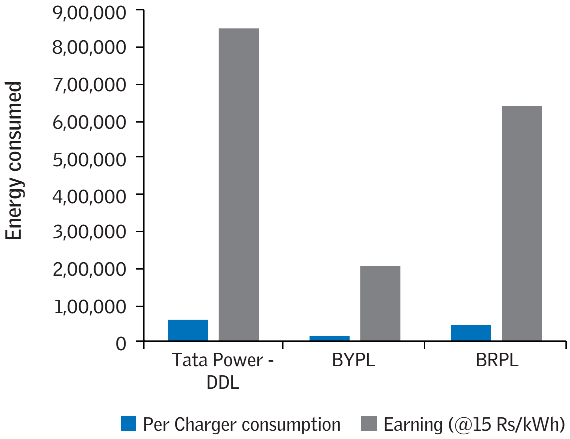
Given the voltage level of AC and DC charging options, lighter commercial vehicles and or smaller trucks in urban, peri-urban, and regional applications are likely to be able to use depot/fixed station charging with power ranging from approximately 22 kW level, 2 chargers up to 50 kW and DC fast chargers – depending on the energy needs of the truck.

However, medium and heavy-duty trucks will require much more powerful charging equipment, relying on a network of ubiquitous, high powered DC fast chargers ranging from 350 – 10,000 kW[45]

Graph 11: Consumption pattern for heavy duty electric buses



Graph 12: Consumption pattern for heavy duty electric buses



Source: Analysis based on CEA data

Illustratively, the total peak load required to meet the refuelling needs of 100 trucks (40-tonne trucks) equipped with a battery capacity of 105-185 kWh would need (with a combination of slow and fast chargers), approximately 13 MW. To meet this kind of requirement most DISCOMs need planning and investments in advance. Meeting these needs will often require changes in primary and secondary power distribution systems (feeders that deliver power to distribution transformers and to end customers) and substation upgrades. For large loads, a new substation may be needed.

The Government of India has progressed with the intent to strengthen the public charging network (adding both slow and fast) to ease the transition. This needs further strengthening keeping the requirements of this segment. Currently, there are four prominent charging technologies that are adopted by various EVs. These are based on connector type and digital communication protocols used viz. Bharat EV charger, CCS, GB/T, and CHAdeMO.

There are differences among the major charging methodologies. For instance, Bharat Charger uses GB/T methodology and power rating limits that are lower compared to other methodologies (see *Table 8: Charging Methodologies adopted by India and other countries*). However, unlike smaller EVs such as car or motorcycles, e-trucks have larger batteries and higher energy requirements to support their heavy-duty operations. Thus, the e-truck industry requires MW (megawatt) chargers to cater to the high energy demands.

Table 8: Charging methodologies adopted in India and other countries

Particular	CCS	CHAdeMO	GB/T	Bharat Charger
Country	Worldwide adopted	Worldwide adopted	China	India
Charging methodology	SAE J1772	IEC 62196-4	GB/T-20234	GB/T-20234
Physical layer for EVSE and EV communication	PLCC	CAN	CAN	CAN
Digital communication protocol between EVSE and EV	CCS	CHAdeMO	GB/T	AC-001, DC-001
Type of charging	AC and DC	Only DC	AC and DC	AC and DC
Charging limits	1000 V, 350 A, and 350 kW 1000V, 350A and 350 kW	500 V, 125 A, and 400 kW	750 V, 200A, and 187.5 kW	72 V, 200A, and 15kW 1000V, 300A, 150kW

Source: Compilation for the study

Table 9: Wired stationary charging types

Charger Type	Nominal Power Output	Charging Standard	Location	Estimated charging times
Overnight	50–150 kW DC	Combined Charging System (CCS) or CHAdeMO	Depot, public parking space	8 hours
Opportunity fast	150–350 kW DC		Public charging station, depot, destination location	0.5 hours
Opportunity ultra-fast	750 kW–3 MW DC	Megawatt Charging System (MCS) or ChaoJ	Public charging station, depot, destination location	0.5 hours

Source: Compilation for the study

Indicative information is available for the common charging types, their typical locations, and estimated charging time (Table *9: Wired stationary charging types).*

The currently available guidelines - "Charging Infrastructure for Electric Vehicles – Guidelines and Standards" issued by the Ministry of Power (MoP) has revised the consolidated guidelines and standards on January, 14, 2022. In fact, the standards and technical specifications for EV vary across Level 1, Level 2, and Level 3 charging stations across different countries. Mapping of different charger specifications in India (MoP, 2022) and other countries helps to understand the difference (see *Table 8: Charging methodologies adopted in India and other countries*). The Megawatt Charging System (MCS), (Charging Forward with

Electric Trucks June 6, 2023 22 to be deployed by 2024), is designed to deliver power up to 3.75 MW (3750kW).

The MW chargers play a critical role in the charging infrastructure for medium and heavy-duty e-trucks, as they offer significantly higher charging power compared to standard-level chargers. This high charging power is particularly beneficial for fleet operators who aim to minimize downtime and ensure fast turnaround time for their trucks. It is evident from the literature that with MW chargers multiple e-trucks can be charged simultaneously, reducing waiting time and maximizing operational efficiency. Moreover, MW chargers are essential for meeting the energy demand of large-scale e-truck fleets[46].

The MW chargers are capable of handling the higher power demand of the truck fleet effectively, efficiently and adequately. Global information shows that standardization of both hardware and software becomes crucial in this context to achieve economies of scale and reduce development costs for manufacturers of trucks and chargers. By establishing standardization, compatibility between different charging systems can be ensured, enabling interoperability.

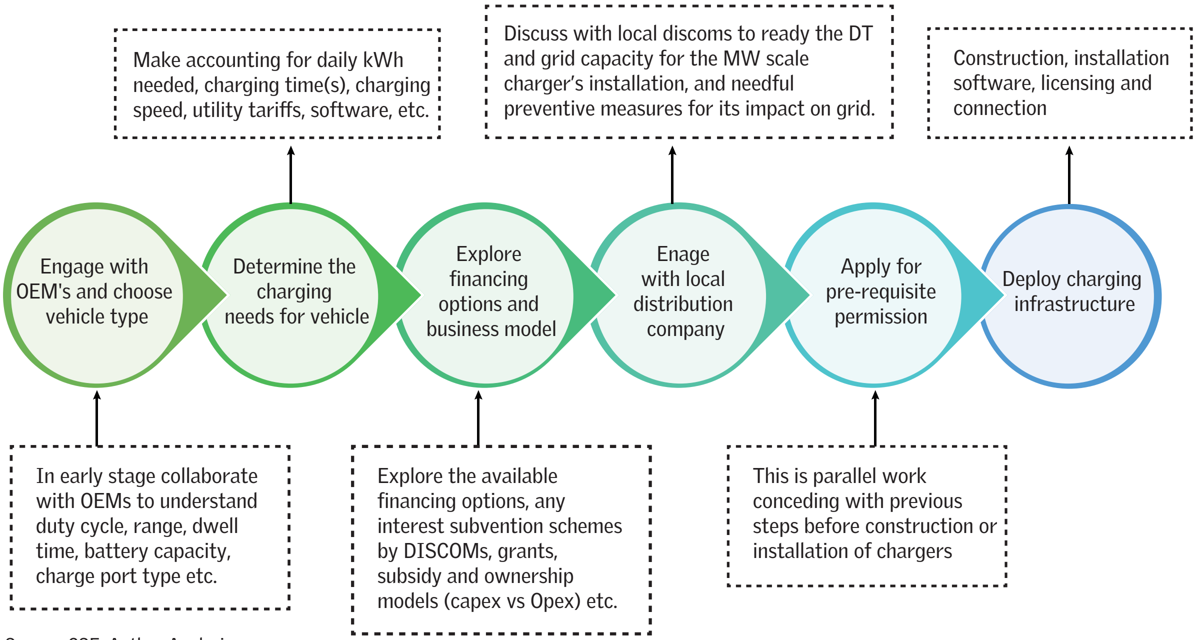
Globally, more innovations are underway. It is evident from the international experience that organizations like the National Renewable Energy Laboratory (NREL) are working on a high-power charging standard called the Megawatt Charging System specifically designed for this segment of vehicles. While existing charging standards typically accommodate slower charging over a few hours, faster en-route charging requires multiple megawatts of power. The MCS can enable charging capacities of up to 3.75 megawatts, which is seven times higher than the current light-duty fast charging technology that peaks at 500 kilowatts. With those considerations, MCS should use a minimum voltage of 500 VDC and a maximum voltage of 1250 VDC.

'In-Road Dynamic Wireless Charging' or 'Wireless power transfer' presents a viable alternative to the conventional method of charging devices through wired connections and plugs. Wireless power transfer relies on the principle of near-field electromagnetic coupling, which enables power transmission without the need for physical contact or radiation. This technology offers two primary types of wireless power transfer: inductive and capacitive. Inductive wireless power transfer involves utilization of conducting coils to establish an electromagnetic field for power transmission. These coils, typically present in both the transmitting and receiving devices, form a magnetic link that allows energy to be transferred between them. By inducing an alternating current in the transmitting coil, an oscillating magnetic field is generated, which, in turn, induces a current in the receiving coil. This current can be converted back into usable electrical power to charge the device wirelessly.

On the other hand, capacitive wireless power transfer employs electric fields to establish the power transmission link. It utilizes conducting plates, typically present in the transmitting and receiving devices, to create an electric field between them. By applying a high-frequency alternating current to the transmitting plate, an electric field is generated, which induces a current in the receiving plate. Similar to inductive wireless power transfer, this current can be converted into usable electrical power to charge the device without the need for physical connections[47]. Swedish Transport Administration is conducting tests with electric power for heavy transports on public roads.

Planning and implementations criteria for e-truck charging Infra: Although every project may require unique engineering solutions to adapt to the variability of sites and specific requirements, there are certain common elements that should be taken into account (see *Figure 9: Electric Vehicle Supply Equipment (EVSE) charging procurement roadmap* and *Figure 10: Possible method of charging e-trucks*).

Figure 9: Electric Vehicle Supply Equipment (EVSE) charging procurement roadmap



Source: CSE, Author Analysis

Figure 10: Possible method of charging e-trucks

CENTRALIZED HUBS

Establishing centralized hubs strategically located along major transportation routes or within urban centers. Serve as dedicated charging points for eTrucks, allowing them to park and recharge during their downtime. This centralized model facilitates better planning and management of charging infrastructure and ensures that eTrucks can easily access charging facilities when needed.

WAREHOUSE CHARGING

Another strategy suggests integrating charging facilities into warehouses and distribution hubs where eTrucks frequently load and unload goods. By incorporating charging infrastructure at these locations, eTrucks can recharge their batteries during their operational breaks, optimizing their time and minimizing downtime.

PUBLIC CHARGING STATIONS

Public charging stations, akin to those available for electric cars, are also considered as viable options for eTruck charging. These stations can be strategically placed at various points across cities and highways, providing eTruck drivers with additional charging options and promoting the widespread adoption of eTrucks.

EN ROUTE CHARGERS AT REST STOPS

To facilitate long-haul transportation, en route chargers can be installed at designated rest stops along major highways and transport corridors. These charging points enable eTrucks to recharge their batteries while making scheduled stops during their journeys, ensuring they have enough power to reach their destinations without unnecessary delays.

BATTERY SWAPPING STATIONS

Some proposals explore the concept of battery swapping stations, where depleted eTruck batteries are exchanged for fully charged ones. This approach can significantly reduce charging times and increase eTruck availability, making it particularly suitable for time-sensitive logistics operations.

DYNAMIC CHARGING

Dynamic charging technologies are also under consideration, enabling eTrucks to charge while in motion. This involves embedding charging infrastructure within the road surface, allowing continuous charging during transit. Dynamic charging can extend the operational range of eTrucks and decrease the need for frequent charging stops.

SMART GRID INTEGRATION

Implementing smart grid technologies is another aspect of eTruck charging strategies. By leveraging smart grids, charging infrastructure can be optimized to match the power demand of eTrucks, reducing strain on the grid during peak periods and allowing for more efficient charging processes.

Source: Analysis for the study

There are five potential methods of charging e-trucks, each with its own unique characteristics related to where they can be found, their cost, feasibility, and flexibility (see *Box: Indicative process for MHD e-trucks charging implementation*).

For example, certain approaches propose charging e-trucks at centralized hubs where vehicles can park, while others suggest utilizing charging facilities at warehouses where loading and unloading take place. Public charging stations and rest stops equipped with en-route chargers are also considered as potential options for e-truck charging. Various strategies have been put forth to address the charging needs of e-truck, each offering unique solutions for different operational scenarios. These strategies aim to ensure that e-truck have access to reliable and efficient charging options, allowing them to cover long distances and fulfil their transportation duties effectively.

INDICATIVE PROCESS FOR CHARGING IMPLEMENTATION

Developing and implementing a successful strategy for transitioning a fleet requires careful consideration of numerous factors. Although each project requires customized engineering due to the uniqueness of each site and undertaking, there are several common elements that should be taken into account.

- Develop team with trained professional who's work with all key stakeholders mostly responsible for making change.
- Asses current fleet (fleet composition, including vehicle types, usage patterns, and energy requirements) and understand current service capacity, additional capacity needs, timeline and costs associated.
- Clearly define the objectives and targets for fleet electrification while setting specific and measurable target will help guide the electrification plan.
- Select vehicle type and its compatible charger: connect with vehicle and EVSE OEM's to understand the operational data (load, distance traveled, fleets usage etc.,) together with its charging guns and kW capacity.
- Conduct a comprehensive financial assessment to determine the costs and benefits associated with fleet electrification. Consider factors such as vehicle acquisition costs, charging infrastructure expenses, maintenance and operating costs, and potential incentives or grants available.
- Procure EVSE components and civil contractors: Site visit understand the infra needs, select civil contractors, canopy suppliers, software providers to meet the charging requirement.
- Draft the infra and parking layout together with Liaoning of needful certification and permits before and or parallel to the prior steps.
- Construction charging Infra: define the timeline for civil, electrical work followed by the DISCOM'S to energies the systems with defined safety procedures.
- Commission charging hardware and define the standard operating procedures to swiftly operate the system.

Source: Compilation for the study

Adopting appropriate charging strategy

Literature survey indicates that the practicality of transitioning to electric trucks becomes more viable when adequate charging infrastructure is in place supporting higher charging rates[48].

Due to the disorganized and fragmented nature of the logistics fleet market, the demand creation and distribution of commercial trucks will depend considerably on a "return-to-base" approach. This strategy entails installing high-power charging infrastructure at the commercial facilities, including depots, yards, and hubs[49]. The purpose is to enable e-trucks to undergo complete charging outside of working hours, such as overnight or between shifts. The larger battery sizes that require high power charging infrastructure can significantly increase the peak demand and stretch the distribution grid[50].

The operational schedules of e-trucks can play a role in influencing the peak demand for charging[51]. The rise in peak demand poses a potential strain on electrical distribution systems, necessitating the upgrade of networks to handle the increased load. However, these upgrades present additional challenges due to the high investment required and the longer time needed for completion[52]. Thus, providing charging services at the host commercial premises to meet the operational schedule of the fleet and to minimize the peak demand at the same time, is a significant challenge[53].

It is necessary to explore various charging strategies that can cater to the specific needs of e-trucks while overcoming these challenges. Numerous studies and research papers have proposed different charging strategies and smart charging frameworks to tackle issues related to uncontrolled charging of a large number of electric vehicles that imbalance the residential and distribution systems[54]. To achieve the widespread adoption and successful deployment of e-trucks across various transportation sectors, a comprehensive charging infrastructure can be established through the integration of centralized hubs, warehouse charging, public stations, en-route chargers, smart grid integration, battery swapping, and dynamic charging technologies. Several market research studies have been conducted to gain insights into the most effective charging infrastructure.

Broadly, five potential e-truck charging strategies have emerged, which can be experimentally implemented to optimize costs and operations[55] (see *Table 10: Charging strategies for e-trucks*).

Table 10: Charging strategies for e-trucks

	Overnight Only	Overnight and mid-route	Mid-route only	Battery Swapping	Overhead catenary
Location	Operator's hub	Operator's hub and private or public mid-route charging station	Private or public mid-route charging station	Operator's hub or public swapping station	While driving, using catenary
Cost	Low capex if only level 2; opex can be lower if charging when electricity cost is lowest at night	Potentially lower capex for chargers and smaller battery; higher opex if using public mid-route charging	Potentially lower capex for chargers and smaller battery; higher opex if using public mid-route charging	High capex for swapping infrastructure and battery storage; high opex for swapping labor	Considerable cost for building catenary infrastructure
Feasibility	Viable today	Limited availability of mid-route charging infrastructure	Limited availability of mid-route charging infrastructure	No pilots for commercial sector	Some pilot projects announced
Flexibility	No flexibility for externalities or total route length	Option to extend stops if needed	Needs predictable routes	Possible only where swapping station available	Possible only where catenary available

Source: McKinsey & Company: *Why most electric trucks will choose overnight charging* | McKinsey

Managed charging technology

Significant investments and strategic dialogues are required for megawatt chargers. Investors need innovative service business models to optimize costs for both consumers and themselves. This is essential due to the substantial financial commitment required. Looking ahead, distribution grids will soon experience a significant strain as they cater to the charging demand of fleets consisting of medium-heavy duty e-trucks. This situation poses a challenge for operators and distribution companies, as they must effectively manage the increased demand while ensuring power quality remains intact.

The charging requirements at the megawatt level will need to adapt to meet the energy and fuel needs of e-truck fleets. However, managing this substantial increase in demand while maintaining the stability and reliability of power supply is no easy task for operators and distribution companies.

It is crucial for stakeholders to devise effective strategies and implement robust systems. Conversations with DISCOMs convey that this may involve exploring alternative energy sources, improving grid infrastructure, and adopting advanced load management techniques. By doing so, operators and distribution companies can ensure a smooth transition to megawatt-level charging, while safeguarding the power quality and reliability that consumers expect.

In managed charging, follow the process of controlling the charging in a way that optimizes grid stability, electricity demand, and charging costs. It involves using smart charging technologies and strategies to efficiently manage the charging process. The main goal of managed charging is to ensure that the charging of EVs is coordinated and controlled to avoid overloading of the power grid during periods of high electricity demand. By implementing managed charging, utilities and grid operators can mitigate the impact of simultaneous charging of large numbers of EVs to avoid straining of the grid infrastructure. Its ultimate goal is to influence (uncontrolled) charging behaviour of users. Managed charging can take one of two forms: passive or active[56].

- **Passive managed charging**, also referred to as behavioural load control, leverages customer behaviour to impact charging patterns. One instance of this is through EV time-of-use rates, where predetermined pricing signals are provided to customers to influence their decisions on when to charge their vehicles. Another example involves notifying users and requesting specific behaviours without offering any incentives.
- **Active managed charging**, also referred to as direct load control, functions by employing communication signals that are usually sent by a utility or aggregator. These signals are utilized to control the charging of a vehicle or charger in a predetermined manner, enabling regulation and management of the charging process. The communications signals used in managed charging can adjust the time and/or rate of charge (both load curtailment and load increase), relative to a baseline. In this way, active managed charging is a form of demand response.

Thus, managed charging or smart charging is augmented with more sophisticated management or artificial intelligence. An advanced charging management system has the capability to offer suggestions or dynamically modify the charging behaviour of individual vehicles within a fleet. This is achieved by taking into account various factors such as facility loads, real-time grid costs, and the planned deployment of each vehicle. If strategically implemented then managed charging will have enough potential and allow fleet operators and or EVs owners to save operational and electrical infrastructure costs.

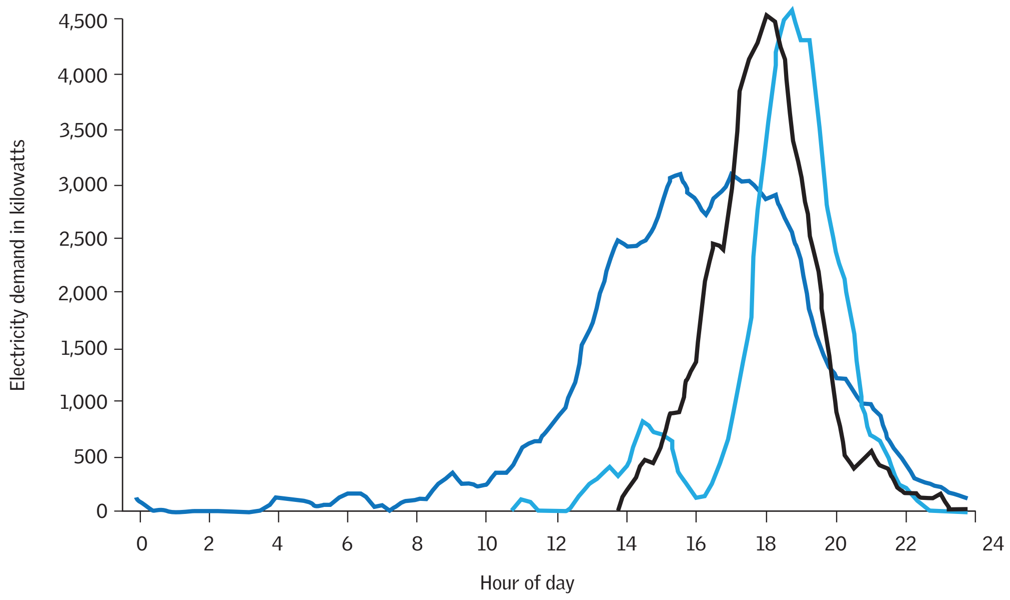
Issues related to megawatt charging: The energy demand for charging e-trucks will be substantial. But it will be more challenging to meet the need for extremely high instant power demand at specific locations in the power grid.

Typically, truck depots are situated in areas that cannot support high power flows. The electric utility companies will face the challenge of meeting the large energy requirements within limited charging time. Fleet depots can have a varying number of vehicles, ranging from dozens to hundreds, and each semi-truck has a charging capacity of 100 to 1,000 kW. Implementing fast charging technology for electric trucks can reduce downtime and parking demand, which are both significant factors for fleet operators and may necessitate additional upgrades to the power grid[57] (see *Graph 13: Average daily depot loads — 100 fleet vehicles*).

Electric freight with vehicles that spend more time at depots could be more flexible with their charging schemes. Some people may choose to recharge traditionally at the end of the workday, which might increase load during evening peaks when the rest of the grid is using the most electricity. Fleets engaged in overnight deliveries may be charged during the morning rush. Beyond depots, on-route charging may present even greater load challenges.

In the analysis carried out by the US based NREL, the power consumption of three fleets, each consisting of 100 vehicles, was examined (see *Graph 13: Average daily depot load — 100 fleet vehicles*). The data reveals that peak loads can reach up to 4.5 MW when utilizing a 100-kW charger at the conclusion of the workday[58]. This study looked at chargers with lower power capacity than the standards for heavy-duty trucks, indicating that even higher loads could be attained with fewer trucks in certain depots.

Graph 13: Average daily depot load — 100 fleet vehicles



Source: NREL

Another recent NREL study, looking at drayage fleets located near the port of New York and New Jersey, found that fleet facilities that currently have a peak electricity demand of less than 0.1 MW could see peak loads in excess of 10 MW if approximately 100 trucks were to be entirely electrified and charged with 350 kW chargers[59].

Beyond depots, on-route charging may present even greater load challenges. A National Grid analysis of vehicle telematic data at highway stops found that to meet peak demand charging requirements at the large truck stops could require capacities of 10 MW by 2030, and upward of 30 MW by 2050. This capacity is greater than that of many small towns[60].

The integration of e-mobility infrastructure with the electricity network of the utilities exposes the perils of nuisance components of electronics involved, viz., harmonics, reactive compensation and flickering which endangers the electricity distribution network.

DISCOMs across various states foresee this as the dominant reason behind the reluctance to encourage EV charging infrastructure within their network with weak ends. The DISCOMs in spite of their pledge to provide 24x7 power supply are subject to load shedding due to commercial to technical reasons. As the distribution utilities are required to follow a competitive bidding process and specific guidelines issued by state electricity regulatory commission, they are constrained to respond in shorter duration.

The distribution utilities are also expected to ensure continuous electricity supply to EV charging stations. The significantly varying electricity demand by the EV charging stations within their sanctioned or contracted load may increase vulnerability towards the Deviation Settlement Mechanism (DSM) at state level. DSM prices are linked at respective market rates prevailing at power exchanges, which at times may impose significant financial liabilities, which will remain unrecoverable. In addition to this, such demand variation may lead to affecting the technical limits of voltage, current, reactive compensation, and harmonics at the distribution network. Since many of such parameters viz., Harmonics, reactive compensation, and flickering are difficult to be monitored. Its impact on the entire distribution network is evident. The DISCOMs discourage such connectivity at their own costs and direct the applicant to ensure such compliance as part of their connectivity agreement with DISCOMs.

Modifications and investments in grid infrastructure

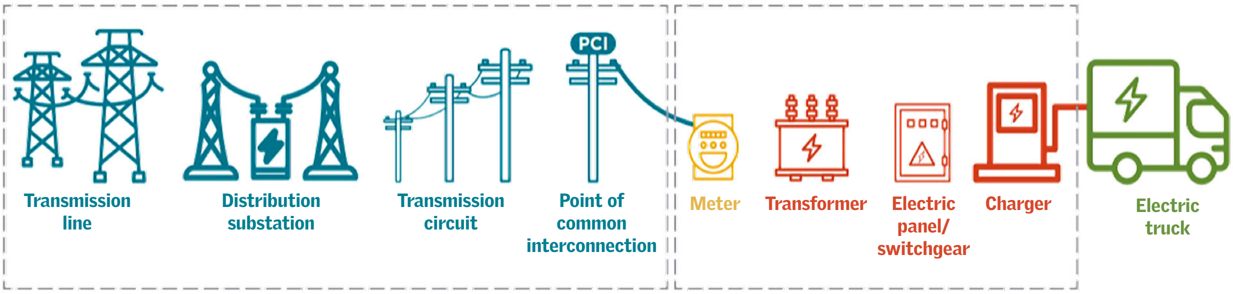
Any electrical update that goes beyond the neighbourhood transformer can be very cost intensive and take years to plan and construct. When a line's rated capacity is exceeded by the amount of power demanded, transformers and feeders must be upgraded. Operating this infrastructure within its rated limitation is essential for maintaining public safety. Exceeding the rated line carrying capacity can cause thermal overload, which may result in outages. Beyond specific load increases, upgrades may be required at the feeder's substation to ensure that the machinery is capable of handling the increased demand for electricity (see *Figure 11: Cost borne by electric utility and charge point operators*).

Upgradation of distribution grid and timeline

While certain distribution lines may transport up to 10 MW of rare peak power, the majority of distribution lines are only rated for 2-4 MW, which is easily exceeded by a single truck plant having more than 20 fleets. These improvements are in part a result of grid rules that supply what is necessary. Utilities are required by law to react to service requests in order to save consumers money and prevent infrastructure waste. Although shared infrastructure can be created as load projections grow, laws normally demand that utilities respond to consumers' demand for electric services rather than foresee them. Nowadays, practically all DISCOMs in every state demand that consumers pay for system expansion.

Viewed this way, the lack of extra capacity trucks is not only cost cumbersome for shifting towards e-mobility for e-truck segments but also involves a significant lead time for making the grid ready. A truck can be delivered in a few months and it uses the same amount of energy as a building that takes at least a year to build. As customers value convenience, DC fast chargers— that may be to

Figure 11: Cost borne by electric utility and charge point operators



Source: ICCT, Delhi EV Policy 2.0

Table 11: Average grid infrastructure cost and timelines

Infrastructure	Cause	Average Cost* (Rs Lakh)	Average timelines
New Transformer	>250 or 400 kW load	5 - 8	3-8 months
Upgrade feeder circuit and breaker	> 2 MW load	45 – 70	4-12 months
Substation upgrade	> 5-10 MW load	150 – 250	12-18 months
New substation installation	> 5-10 MW load	335 – 500	24-48 months

Source: Analysed for the study

recharge an electric vehicle's battery to 80 per cent under 20 minutes—are needed to accomplish that.

These upgrades are partially a function of grid regulations to encourage providing only what is needed. To save customers money and avoid wasteful infrastructure, electric utilities are regulated to respond to service requests. While shared infrastructure can be built as load forecasts increase, the regulations generally require that utilities respond to customers' electric service requests rather than anticipate them. The electrical infrastructure to be upgraded by electric utilities can include distribution lines, local stations, breakers, transformers, and switchgears. Electricity grid upgrades are necessary where on-site power availability is not sufficient. Grid upgrades can range from minor, such as only upgrading the breaker and distribution transformer, to major upgrades of the distribution lines and substation. It is necessary to illustrate the tentative cost for new infrastructure upgrades and average timelines for each set-up (see *Table 11: Average grid infrastructure cost and timelines*).

Remedial solutions to prevent the stress

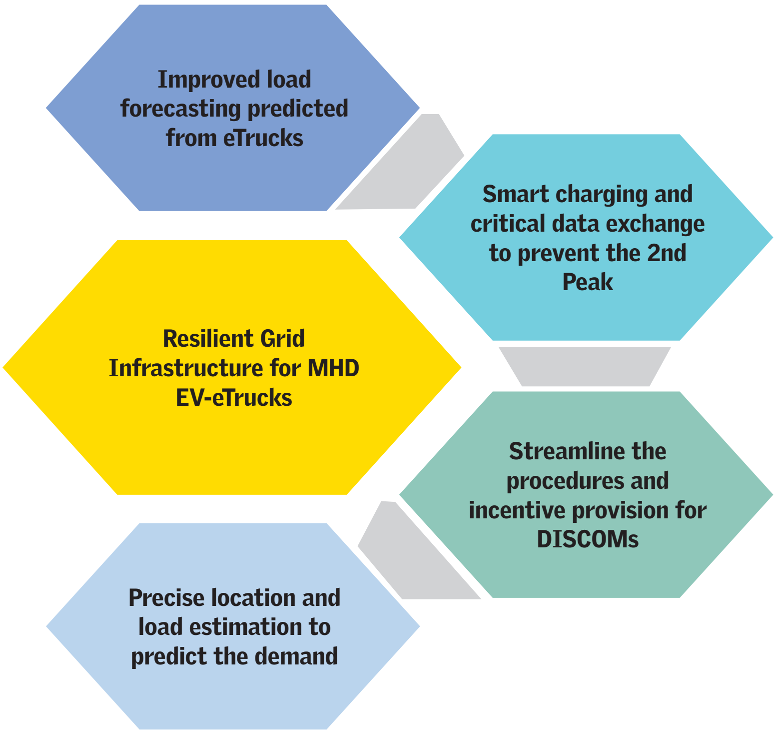
The grid challenges posed by e-trucks require multiple solutions rather than a single fix. The power demand from a large e-truck depot is substantial and exceeds the current capabilities of Discoms. While Discoms face the challenge of providing power in new locations, it still aligns with their core business. However, electrifying a depot presents additional unfamiliar requirements alongside understanding the unique operation of e-trucks. Fleet operators, logistics service providers, and charging service providers must acquire new skills related to power procurement, charger installation, and management of charging power and time.

The Discoms, regulators, and fleets need to adapt their business practices to embrace electric trucking.

The distribution companies and regulators face structural challenges:

- Meeting the substantial increase in power demand necessitates an unprecedented level of mobilization, unlike anything witnessed in the past several decades.

Figure 12: Possible solution to prevent overloading issues



- Discoms must ensure they have sufficient manpower and engineering resources to rapidly construct the required infrastructure.
- The power requirements for electrification are uncertain regarding geographic locations and adoption pace.
- The concentration of new loads at depots, rather than being distributed across a region, adds to the challenge.
- Regulations aimed at cost savings for customers are inadequate in both financial and functional terms to meet the rapid and essential growth in load demand.
- DISCOM's need more information about the specific areas where new electric loads will be concentrated.
- Draw a roadmap for EV charging infrastructure. Need for formal process for reviewing technical aspects and specifying standards/regulations for charging infrastructure.
- Need a formal process to roll out policy, planning and regulatory/tariff related issues with focus on regulatory aspects and policy interventions, tariff challenges, subsidies/incentives.

- There is a committee on technical standards that has specified the regulations related to connectivity with grid that include power factor, load factor, harmonics, and voltage deviations.

Technical standards for any entity and connectivity with the grid are under exclusive control of the Central Electricity Authority. These include harmonics, Flicker, DC Injection, etc. for Grid under control, as well as to prevent voltage imbalance. The same standards are extended to electric mobility charging stations. The CEA is further to incorporate safety of supply and has accordingly modified the CEA (Measures relating to safety and electric supply) Regulations, 2010. The charging stations need to comply with the safety requirements of the IEC 61851 standards.

Leveraging policy support for charging of e-trucks

The government has implemented favourable policies and regulations to incentivize DISCOMs to support establishment of charging infrastructure and zero emission vehicles, and renewable energy-based power generation. These incentives take the form of tax benefits, subsidies, or grants.

Ministry of Power has issued guidelines and standards for public EV charging infrastructure on 14^{th} January 2022:

- To enable faster adoption of EV in the country, ensuring safe, reliable, accessible and affordable charging infrastructure and ecosystem
- To provide affordable tariff for charging station operators and EV owners.
- To proactively support creation of EV charging infrastructure
- To encourage preparedness of electrical distribution network
- To promote energy security and emission reduction by promoting EV ecosystem

The aforementioned guidelines have outlined the public charging infrastructure specifications for long range EVs and/or medium and heavy-duty trucks. Such fast-charging stations meant for 100 per cent in-house/captive charging should have the following specifications:

- At least two chargers of minimum 100 kW (200-750 Volt or higher) each of different specifications (CCS/CHAdeMO chargers for above capacity or BIS Standard for e-bus charging station (Level 4: 250 to 500 kW) with single connector gun each.
- Liquid cooled cables for high-speed charging facility and for onboard charging of EVs, and fluid cooled batteries required.
- Such public charging stations shall be at a maximum distance of every 100 km, one on each side of the highways/roads

VEHICLE TO GRID FRAMEWORK

Vehicle to Grid (V2G) technology enables EVs to not only consume electricity but also feed excess power back into the grid when connected to a charging station. A vehicle-to-grid (V2G) tariff framework is a pricing structure that governs the exchange of electricity between electric vehicles (EVs) and the electric grid. A Vehicle to Grid tariff framework establishes the rules and rates for this bidirectional flow of electricity.

Here are key considerations in developing a V2G tariff framework:

Time-of-Day (ToD) Pricing: ToD pricing is a common approach in V2G tariff frameworks. It involves dividing the day into different time periods with varying electricity rates. By incentivizing EV owners to charge during off-peak hours and discharge power during peak demand periods, ToD pricing can help balance the grid and reduce strain on the electricity system. The recently issued amendment of Electricity (Rights of Consumers) Rules 2023 dated 24th March 2023, has introduced a Time of Day framework for Commercial & Industrial (C&I) consumers can find this in sync with the objective of the Rules. The proposed rules may have a bearing on the tariff imposition on EV Charging stations of the charging point operators in case the peak hour slots of the TOD matches with the charging time of the EV charging stations. Accordingly, the charging point operators need to invest into strategies to defer the charging time to off-peak hours to ensure cost viability for the EV charging stations as well as keeping EV tariff low to EV consumers.

Net Metering and or Net Billing: Net metering allows EV owners to offset their electricity consumption by exporting excess power to the grid. Under this framework, the energy supplied to the grid is subtracted from the energy consumed from the grid, and the EV owner is billed or credited accordingly. Net metering tariffs can encourage EV owners to participate in V2G programs and maximize the utilization of renewable energy. Recently introduced Ministry of Power Electricity (Rights of Consumers) Rules 2023 has introduced Net Billing as alternative to Net Metering.

Feed-in Tariffs (FiTs): FiTs provide a fixed payment rate for the electricity supplied to the grid by EVs participating in V2G programs. This approach guarantees a specific revenue stream for EV owners, which can incentivize their active participation in V2G services. FiTs are typically set based on factors like the prevailing wholesale electricity prices, renewable energy generation, and grid requirements.

Capacity-based Tariffs: Capacity-based tariffs focus on the power capacity of EVs participating in V2G programs. EV owners may receive payments based on the maximum power they can provide to the grid during peak demand periods. This approach encourages EV owners to maintain higher charge levels to support the grid when needed the most.

Aforesaid guidelines also mandate provisions of land at promotional rates for public charging systems, to address the concern of high cost of rent for land and chargers. As part of incentive to reduce the upfront cost, the land available with government/public entities shall be provided to government/public entities at a fixed rate of Rs 1/kWh to be paid to the land-owning agency for 10 years subject to revenue sharing.

Under phase-II of FAME-India Scheme, Rs. 1000 Cr. has been allocated for the

Ancillary Services Compensation: In some V2G tariff frameworks, EV owners may receive compensation for providing ancillary services to the grid. Ancillary services refer to services beyond standard energy supply, such as frequency regulation, voltage control, or grid stabilization. By utilizing the flexibility of EV batteries, these services can help optimize grid stability and reliability.

Demand Response Programs: V2G tariff frameworks can incorporate demand response programs, where EV owners respond to grid signals to increase or decrease their electricity consumption or discharge. These programs may include dynamic pricing or incentives for EV owners to adjust their charging and discharging patterns based on grid conditions and requirements.

Regulatory Considerations: Developing a V2G tariff framework requires regulatory support and clear guidelines from government authorities. These regulations should address issues such as metering and billing standards, grid connection requirements, interoperability, data privacy, and consumer protection. The V2G connectivity was deliberated as part of the discussions of CEA led committee constituted for technical and regulatory aspect of EV charging stations. The committee deliberated that V2G network wouldn't be possible for AC chargers and is technically viable for bidirectional connections like DC. With an AC charger, converter converts the AC from supply to DC for the battery pack but it doesn't house any inverter to covert DC from battery back to AC.

It was deliberated that since there will be losses involved in AC chargers, meaning thereby the supply discharged by the EV charges will be less than the power it takes to charge the battery, it doesn't make a business case to be further investigated for specifying technical standards for the same as part of the CEA's Technical Standards for connectivity of Distributed Generation Resources to the Grid. However, the V2G framework can be explored for acting as part of the ancillary services or act as embedded spinning reserves at disposal of the distribution licensee. The V2G framework enables EV consumers to allow the grid to discharge from the battery if required. EV users could be incentivized to charge their vehicle during the day and off-peak hours, when solar energy is abundant. Such EV chargers can pool either at parking slots at working place to offset the peak energy procurement of the DISCOM using Demand Response Program.

It's Important to note that V2G tariff frameworks can vary between regions and countries based on their specific grid infrastructure, energy policies, and market conditions. The design of an effective V2G tariff framework should consider the goals of grid stability, renewable energy integration, economic incentives for EV owners, and the overall transition to a more sustainable and resilient energy system.

charging infrastructure development. The Ministry of Power has sanctioned 2,877 electric vehicle charging stations in 68 cities across 25 states/uTs. Further, 1576 charging stations across 9 expressways and 16 highways under phase-II of FAME India Scheme has also been sanctioned.

The Ministry of Housing & Urban Affairs (MoHUA) has amended the Model Building Byelaws 2016 to establish charging stations and infrastructure in private and commercial buildings.

The Ministry of Power has emphasized on standards/regulations for charging set up as well as infrastructure associated with it, through a technical committee. This committee has laid recommendations and action as per following:

- Regulations regarding connectivity with grid: For supply of quality power, it is essential that power factor, load factor, harmonics, voltage deviations etc. are kept within the prescribed limit as defined by Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations. The CEA has already amended the regulation to incorporate necessary changes with respect to safety condition requirements of EV charging stations. CEA has further amended the regulations to include Vehicle to Grid (V2G) in aforementioned regulations.
- Communication protocols are required for communication and control between electric vehicles and charging stations (also known as Electric Vehicle Supply Equipment EVSE), and a Central Management System). In this regard, standards have been specified as below:
    - *Standard protocol for communication between EVSE and* central management system *required to comply with Open Charge Point Protocol (OCPP). Communication using OCPP is carried on the Internet, using wired media or wireless (Wi Fi or GPRS or 3G/4G wireless). OCPP is encrypted and therefore reasonably safe from hacking.*
    - *Standard for Communication between Electric Vehicle and EVSE has been specified for low, medium and high voltage categories.*
    - *Testing and verification of all the components of Electric Vehicle and Charging Stations, like battery, motor, power electronics should be done at centres spread across the country. Testing and verification of equipment w.r.t standards are already being done by ARAI. They should also be done by other accredited laboratories, for example, ICAT Manesar, CPRI, GARC Chennai, VRDE Ahmednagar, etc.*
    - *Assessment and strengthening of capacity of sub transmission/distribution network to supply the load of electric vehicles has to be done by state DISCOM in coordination with state transport department/urban development department. Study of the stability and adequacy of the charging network to be ensured by the licensee while granting connectivity.*
    - *Energy performance standards for chargers shall be assessed by BEE. However, at present there are no IEC standards for reference.*
    - *Classification of charging points could be done between public charging, restricted public charging and inhouse/captive charging station. The permission required for each of these types could be different. However,*

permission from DISCOM would be required for all. For public charging points, these would be identified by the DISCOM, State Road Transport Department and Urban Development Department of the State.

- The ministry has duly acknowledged the technical impact of EV charging stations on DISCOM network and therefore allowed DISCOMs to leverage the funding from the Revamped Distribution Sector Scheme (RDSS) under 'Part A – Distribution Infrastructure' for the general upstream network augmentation in various areas. The cost of such works carried out by the DISCOMs with the financial assistance from Government of India under Revamped Scheme shall not be charged from the consumers for public charging Stations for EVs.
- DISCOMs need to collaborate to develop grid integration plans that facilitate the seamless integration of zero-emission trucks and renewable energy sources. This involves assessing the capacity of the existing grid infrastructure, identifying potential areas for grid upgrades, and developing strategies to accommodate increased renewable energy generation and charging demands.
- Facilitating knowledge sharing and technical collaboration between zero-emission trucks stakeholders and DISCOMs. This may include providing DISCOMs with information on zero-emission truck technologies, their charging characteristics, and any grid integration requirements. Conversely, DISCOMs can offer expertise on grid infrastructure, electrical codes, and safety considerations relevant to the zero-emission trucks integration.

Leveraging renewable energy for e-truck powering

Net-metering and Green Open Access

EV charging stations have been classified as 'Prosumer' and allowing charging has been classified as a 'service'. The Ministry of Power has also directed DISCOMs to provide electricity connection to public charging stations in accordance with the timeline specified in the "Electricity (Rights of Consumers) Rules 2020". The connection for a public charging station shall be provided within 7 days in metro cities, 15 days in other municipal areas and 30 days in rural areas. The appropriate Commission may specify a lesser time limit than the aforementioned limit.

Any public charging station /chain of charging stations may also obtain electricity from any power generation company through open access. Open access shall be provided within 15 days for this purpose. Only cross subsidy charges (not more than 20 per cent as per Tariff Policy Guidelines), transmission charges and wheeling charges shall be applicable.

The Ministry of Power Electricity (Rights of Consumers) Rules 2020 have classified prosumers as consumers and the relevant provision are highlighted as indicated below, substantiating the rights of EV charging station owners as part of net metering/gross metering or net billing benefits as part of regulatory interventions:

- *Consumer as prosumer. -(1) While the prosumers will maintain consumer status and have the same rights as the general consumer, they will also have the right to set up Renewable Energy (RE) generation unit including roof top solar photovoltaic (PV) systems – either on their own or through a service provider.*
- *Renewable Energy (RE) generation unit may also be set up on other parts of the premises of the prosumers, apart from the roof, however the total generation capacity of the RE unit shall not exceed the limit as specified by the Commission.*
- *The Commission shall lay down regulations on Grid Interactive Roof top Solar PV system and its related matters with timelines of not exceeding six months from the date of notification of these rules, in case the same has not been notified.*
- *The regulations on Grid Interactive Roof top Solar PV system and its related matters shall provide for net metering for loads up to ten kW and for gross metering for loads above ten kW.*

The aforementioned regulations nullified the varying interpretations allowing the EV charging stations to avail renewable energy and enabling provision of green electricity for charging. However, the Rules have limited such capacities to up to 10kW maximum for net metering and gross metering for loads above 10 kW. With such restrictions, even the public charging stations were not entitled to avail open access as most of the states have eligibility for open access as minimum 1 MW. Irrespective of such regulatory benefits, the public charging stations with load above 10 kW remain deprived not only of net metering/net billing benefit but also of green open access.

This has been duly acknowledged by the Ministry of Power and has brought in another amendment to Electricity Rights of Consumers Amendment Rules 2021 that was issued in June 2021. This has enhanced the limit of such regulatory interventions as 500 kW, the same is reproduced as herein below.

As per the aforementioned, the EV charging stations with solar rooftop with load above 10kW, become eligible for availing the regulatory benefits in terms of net-metering or net-billing or net feed-in (gross metering). However, since most of the state electricity regulatory commissions identify the eligibility for net metering by consumer category, this creates a regulatory ambiguity over eligibility of EV charging stations to avail net metering benefits. For instance, UPERC RSVP Regulations 2019 highlights as herein below:

- *(k) "Eligible consumer" for Net Metering Scheme means the consumers of a Licensee under agriculture (LMV-5) or domestic consumers under LMV-1 category. While under Gross Metering Scheme means a consumer of electricity in the area of supply of the Distribution Licensee, who intends to set up a grid connected rooftop Solar PV system in the consumer's premises which can be self-owned or third party owned, with an intent to sell the entire electricity to the distribution licensee at the rate prescribed by the Commission.*

Such interpretations deny the regulatory benefit to EV charging stations, which are categorized as separate consumer categories. This not only discourages such public charging stations to install solar rooftop but also denies them the policy/ regulatory incentives guaranteed by GOI as part of MoP (Electricity Rights of Consumers) Amendment Rules 2021.

An illustrative computation can demonstrate the substantial saving potential of the regulatory interventions of net metering or net billing that may help improve the financial viability of public charging stations (see *Table 12: Saving Potential in net metering or net billing mechanism*).

Table 12: Saving potential in net metering or net billing mechanism

Particulars	UoM	Values
Solar/Wind rooftop generation	kWh	100
Load consumption	kWh	120
Import from Grid	kWh	80
Solar power exported to grid	kWh	20
Applicable EV Tariff	Rs/kWh	6.5
Solar/Wind tariff	Rs/kWh	4.25
Total bill amount if there was no solar/micro wind installed by public charging station	**Rs**	**780**
Net Metering		
Billing will be done on net drawl from grid under Net metering	kWh	20
Bill amount paid to DISCOM	Rs	130
Saving to public charging stations under Net Metering	**Rs**	**650**
NET BILLING		
Billing will be done on account of total drawl from grid (minus) amount of solar power injected into grid under Net Billing tariff	Rs/kWh	3
Bill amount paid to DISCOM	Rs	460
Savings to public charging stations under Net Billing	**Rs**	**320**

Source: Analysis for the study

What is needed?

It is necessary to extend the RE policy benefits to EV charging infrastructure. The prevailing regulations in various states restrict such incentive mechanisms either to residential or commercial consumers and fail to recognize EV charging infrastructure consumers (which are a separate consumer category), as eligible for regulatory benefits under the net-metering and/or net billing regulations of the respective states.

The EV charging infrastructure providers may be allowed to install solar/micro wind with regulatory incentives of net-metering and net-billing. This will not only help to promote green energy for EV charging infrastructure, but also reduce the cost of running the electricity infrastructure. A clarification is needed from the Ministry of Power to classify the EV Charging stations as eligible consumers for the net metering/net billing incentives.

Since the load profile of public charging stations is usually erratic, the surplus generation may be used by the respective DISCOMs to offset their RPO mandate. If allowed, the public charging stations up to 500 kW may benefit.

MoP (Electricity Rights of Consumers) Rules 2020 and its subsequent amendment attempted to address the regulatory interventions of net metering/net billing. In this regard, the Ministry of Power in June 2022 introduced Electricity (Promoting Renewable Energy Through Green Energy Open Access) Rules, 2022 (hereinafter referred as 'MoP Green OA Rules'). This has eased installation of solar rooftop by any public charging stations and states as herein below:

- *(2) Any entity, whether obligated or not may elect to generate, purchase and consume renewable energy as per their requirements by one or more of the following methods: -*
- *(A) Own Generation from renewable energy sources. –There shall not be any capacity limit for installation of power plants from renewable energy sources, by entities for their own consumption and such plants may be set up at any location in India and power shall be transmitted by using open access:*
- *Provided that the generating plant may be set up by the entity itself or by a developer with which the entity enters into a power purchase agreement.*

The aforementioned not only allowed public charging stations to install without any capacity limit but also allowed to avail green open access for off site renewable plants. In order to counter the open access eligibility under respective state regulations, the MoP Green OA Rules specifies as herein below:

Green Energy Open Access. – (1) To provide Green Energy Open Access to consumers of green energy, the appropriate Commission may, if necessary, amend the relevant regulations made by it and such regulations shall be consistent with these rules. All applications for open access of green energy in this regard shall be allowed by the nodal agency within a period of fifteen days:

Provided that only consumers who have contracted demand or sanctioned load of hundred kW and above shall be eligible to take power through Green Energy Open Access and there shall be no limit of supply of power for the captive consumers taking power under Green Energy Open Access:

Provided further that reasonable conditions such as the minimum number of time blocks, which shall not be more than twelve-time blocks, for which the consumer shall not change the quantum of power consumed through open access may be imposed so as to avoid high variation in demand to be met by the distribution licensee.

Banking. – (1) Banking shall be permitted at least on a monthly basis on payment of charges to compensate additional costs, if any, to the distribution licensee by the Banking and the Appropriate Commission shall fix the applicable charges.

(2) The permitted quantum of banked energy by the Green Energy Open Access consumers shall be at least thirty percent of the total monthly consumption of electricity from the distribution licensee by the consumers.

***Explanation:** For the purposes of this rule, the expression—Banking— means the surplus green energy injected in the grid and credited with the distribution licensee energy by the Green Energy Open Access consumers and that shall be drawn along with charges to compensate additional costs if any:*

Provided that the credit for banked energy shall not be permitted to be carried forward to subsequent months and the credit of energy banked during the month shall be adjusted during the same month.

As per aforementioned, the public charging stations installing their own captive RE generation shall not be subject to any load limitations. The aforementioned duly addresses the variable traffic and intermittent load requirement of public charging stations and has allowed RE Banking with incumbent distribution licensees.

Since the open access requires firm load requirement as part of the scheduling and dispatch requirement mandated under the CERC IEGC Regulations 2023 (hereinafter referred as 'Grid Code'), this has caused limitations for the public charging stations to avail Green Open Access. This necessitated the ministry to amend the rules to allow public charging stations to avail green electricity from their incumbent distribution licensee under the green tariff framework.

> *"(a) Any consumer may elect to purchase green energy either upto a certain percentage of the consumption or its entire consumption and they may place a requisition for this with their distribution licensee, which shall procure such quantity of green energy and supply it and the consumer shall have the flexibility to give separate requisition for solar and non-solar;"*
>
> *"Provided that the credit for banked energy shall not be permitted to be carried forward to subsequent banking cycles and shall be adjusted during the same banking cycle:*
>
> *Provided further that the un-utilised surplus banked energy shall be considered as lapsed at the end of each banking cycle and the Renewable Energy generating station shall be entitled to get Renewable Energy Certificates to the extent of the lapsed banked energy."*

Even with firm load required public charging stations, though the MoP Green Open Access Rules 2022 has resolved the regulatory conflict for fast charging stations, slow charging stations (with load less than 100 kW) remain deprived to avail of green electricity.

The Ministry has taken cognizance of the same and has issued amendment to MoP Green Open Access Rules 2023 and issued a transformational incentive for public charging stations with cumulative load above 100 kW but single point drawl load less than 100 kW within a distribution licensee jurisdiction.

> *(b) "entity" means any consumer who has contracted demand or sanctioned load of Hundred kW or more either through single connection or through multiple connections aggregating Hundred kW or more located in same electricity division of a distribution licensee, except for captive consumers:*
>
> *Provided that in case of captive consumers, there shall not be any load limitation;*
>
> *"Provided that only consumers who have contracted demand or sanctioned load of Hundred kW or more, either through single connection or through multiple connections aggregating Hundred kW or more located in same electricity division of a distribution licensee, shall be eligible to take power through Green Energy Open Access and there shall be no limit of supply of power for the captive consumers taking power under Green Energy Open Access:"*

The aforementioned amendment to MoP Green OA Rules has not only eliminated the regulatory ambiguity with respect to green open access but also has allowed the green open access for public charging stations with load less than 100 kW. Thereby, multiple public charging stations of load lesser than 100 kW can be aggregated to load 100 kW or above within a distribution licensee to avail of green open access.

Irrespective of the available framework for green open access, there is a need for adoption of the green open access rules by respective states. Further infrastructural requirements need to be thoroughly investigated for availing of open access as part of technical requirement. This needs to be assessed and duly amended to allow green open access.

There is a need to amend existing supply code regulations to ensure time bound issuance of connectivity as well as required technical specifications. This needs to be ensured by the public charging stations within distribution licensee jurisdiction. Various states apply either Parallel Operation Charges or Self Generation Tax on entities who own and operate their renewable energy plants. This has a cost disadvantage for the public charging stations as this increases the landed cost under open access and eventually discourages public charging stations from opting for Green Open Access.

DISCOMs often highlight the capex requirement to augment their distribution network. The state electricity regulators need to encourage capex support for system augmentation - specifically for EV charging stations led network optimization.

Within the recommended measures of RE banking provisions with the distribution utilities, the modalities of settlement and adjustment of RE plays a big role in maximizing the RE usage by the EV charging infrastructure provided within the scope of MoP's Green Open Access Rules. Very recently, Maharashtra Electricity Regulatory Commission has issued draft guidelines to enable green open access, and they have relaxed the metering specification from ABT to TOD meters. This has a significant cost advantage for entities eager to avail green open access. The same needs to be uniformly adopted across states.

This study has simulated the solar capacity requirements under two RE banking adjustment scenarios of -- 1) TOD wise settlement allowing settlement of peak and off-peak energy and 2) Lump Sum RE energy settlement on a monthly basis (see *Table 13: Scenario 1, 2,3: Time of day pricing (TOD) wise renewable energy banking adjustment*).

Assumptions:

1. EV charging infrastructure connected at 415 kV of 11 kV network with enabled Availability Based Tariff (ABT) meter for allowing green OA.
2. Assumed energy consumption profile and solar generation corresponding to TOD slots

Table 13: Scenario 1: Time of Day pricing (TOD) wise renewable energy banking adjustment

(1)

Particular		Location 1					Location 2				
		6am-10am (Peak)	10am-6pm (Off-peak)	6pm-10pm (Peak)	10pm-6am (Off-peak)	Total	6am-10am (Peak)	10am-6pm (Off-peak)	6pm-10pm (Peak)	10pm-6am (Off-peak)	1380
Day 1	Injection	100	300	180	350	**930**	300	400	300	380	**1300**
	Drawal	120	200	180	350	**850**	280	300	300	420	**80**
	Banking	-20	100	0	0	**80**	20	100	0	-40	**1587**
Day 2	Injection	115	345	207	403	**1070**	345	460	345	437	**1495**
	Drawal	150	250	225	438	**1063**	322	345	345	483	**92**
	Banking	-35	95	-18	-35	**7**	23	115	0	-46	**1508**
Day 3	Injection	109	328	197	382	**1016**	328	437	328	415	**1510**
	Drawal	143	238	214	416	**1009**	330	380	350	450	**-2**
	Banking	-33	90	-17	-33	**7**	-2	57	-22	-35	**4475**
Day 4	**Injection**	**324**	**973**	**584**	**1135**	**3016**	**973**	**1297**	**973**	**1232**	**4305**
	Drawal	**413**	**688**	**619**	**1203**	**2922**	**932**	**1025**	**995**	**1353**	**170**
	Banking	**-88**	**285**	**-35**	**-68**	**94**	**41**	**272**	**-22**	**-121**	**4475**

(2)

Particular	Total Banking during peak	Total Banking during Off-peak	Total Charges: Off-peak to off-peak or peak to Off-peak (in kind)	Total Charges to be paid (in kind)
Day 1	-20	100	6.40	6.40
Day 2	-53	60	0.56	0.60
Day 3	-50	57	0.53	0.50
Total	**-123**	**217**	**7.49**	**7.50**

(3)

Particular	UoM	Value
Banking Adjustment from Peak to Off-peak	kWh	368.15
Banking Charges @2%	kWh	7.36
Total Banking Charges	kWh	**14.86**
Total Solar Energy Requirement for three days	kWh	7,241.74
Total Solar Energy Requirement for 3 days	MU	0.01
Total Solar Energy Requirement	MU/Year	21.15
Solar Specific Yield	MU/MWp/Year	1.61
Estimated Solar Capacity at Generation Bus Bar	MWp/Year	13.17
Estimated Solar Capacity at Consumption End	**MWp/Year**	**15.73**

Source: Computed for the study

Table 14: Monthly lumpsum RE banking adjustment

(1)

Particular		Multiple location within DISCOM network				
		6am-10am (Peak)	10am-6pm (Off-peak)	6pm-10pm (Peak)	10pm-6am (Off-peak)	Total
Day 1	Injection	355	190	355	650	1550
	Drawal	325	160	325	620	1430
	Banking	30	30	30	30	120
Day 2	Injection	408	219	408	748	1783
	Drawal	406	200	406	775	1788
	Banking	2	18.5	2	-27.5	-5
Day 3	Injection	388	208	388	710	1693
	Drawal	386	190	386	736	1698
	Banking	2	18	2	-26	-5
Total	**Injection**	**1151**	**616**	**1151**	**2108**	**5026**
	Drawal	**1117**	**550**	**1117**	**2131**	**4916**
	Banking	**34**	**66**	**34**	**-24**	**110**

(2)

Particular	Total Banking during peak	Total Banking during Off-peak	Total Charges: Off-peak to off-peak or peak to Off-peak (in kind)	Total Charges to be paid (in kind)
Day 1	60	60	9.60	9.60
Day 2	4	-9	-0.40	-0.40
Day 3	4	-9	-0.38	-0.40
Total	**68**	**42**	**8.82**	**8.80**

(3)

Particular	UoM	Value
Banking Adjustment from Peak to Off-peak	kWh	42.45
Banking Charges @2%	kWh	0.85
Total Banking Charges	kWh	**9.65**
Total Solar Energy Requirement for three days	kWh	9,850.55
Total Solar Energy Requirement for 3 days	MU	0.01
Total Solar Energy Requirement	MU/Year	28.76
Solar Specific Yield	MU/MWp/Year	1.61
Estimated Solar Capacity at Generation Bus Bar	MWp/Year	17.91
Estimated Solar Capacity at Consumption End	**MWp/Year**	**21.40**

Source: Computed for the study

In the aforementioned scenario, the outcome impact of solar capacity has been captured in varying consumption patterns of two different EV charging infrastructure and another assumed with the same consumption pattern located at multiple places. The solar capacity required later would be 15.72 MWp while in others it would be 21.40 MWp.

It is now understood that present electricity infrastructure at 11 kV does not allow electricity flow at more than 5 MW. This will scuttle the Green Open Access due to technical challenges. Even though the charging point operators will be eligible to avail of higher quantum of electricity, the restriction of technical equipment in connectivity and interpretation challenges to allow green open access above their sanctioned load will put hindrances for green electricity access to charging point operators.

From the DISCOM perspective, if green open access is allowed over and above their sanctioned or contracted load, energy fed into the system at peak will pose an operational challenge from grid safety and security perspective.

Therefore, the pious intent to decarbonize the EV segment will not reach fruition in case the same is not adopted by the respective state electricity regulators.

Cost comparison of power: Local DISCOM Vs Open Access

The EV Charging stations with cumulative load above 100 kW can avail green open access under third party open access transactions or may consider setting up their respective captive generating stations. In this regard it may be assumed that the charging point operators with combination of fast and slow charging stations within a distribution licensee area viz., UPPCL (Uttar Pradesh Power Corporation Ltd), and with cumulative load of 1 MW with solar generating stations connected at 33 kV transmission substation, can avail of green open access not only for green charging but also to save the operating costs. This is because of the differential in landed cost of DISCOM and Green Open Access (see *Table 15: Landed cost model under green open access for electric vehicle charging stations*).

Table 15: Landed cost model under green open access for electric vehicle charging stations

Particulars	UoM	Captive	3rd party OA
Contract Demand	kVA	1000	1000
Specific Generation	MWh/MWp/Year	1544	1544
Capacity	MW	1.00	1.00
Gross Generation PLF	%	18%	18%
Units Delivered to Injection Point	Mn kWh	1.54	1.54
Less: Transmission Losses	%	3.27	3.27
Less: Wheeling Losses	%	0.46	0.46
Banking Charges	%	6.00	6.00
Units Delivered to Withdrawal Point	Mn kWh	1.49	1.49
Impact Of Losses	Rs/kWh	0.15	0.17
Tariff at Generation Bus Bar	**Rs/kWh**	**4.00**	**4.50**
Transmission Charges @ 50%	0.2465/kWh	0.12	0.12
Wheeling Charges @ 50%	0.920/Kwh	0.46	0.46
SLDC Charges	Rs/kW/Month	0.05	0.05
Cross Subsidy Charges (HV 1 Consumers)	Rs/kWh	0.00	2.12
Additional Charges	Rs/kWh	-	-
Total Open Access Charges + Losses	Rs/kWh	0.79	2.93
Tariff to consumer at Delivery Point	**Rs/kWh**	**4.79**	**7.43**
UPPCL EV Tariff (A)	**Rs/kWh**	**7.00**	**7.00**
Electricity Duty @7.50%	Rs/kWh	0.53	0.53
UPPCL Replaceable Tariff (A+B)	**Rs/kWh**	**7.53**	**7.53**
Discount Offered to Consumers	**Rs/kWh**	**2.74**	**0.10**

Note: FAC not included in the landed cost computation

Source: Compiled for the study

As per this analysis, it is quite explicitly clear that the commercial viability to opt for green open access is feasible only in case of captive transactions. The EV charging point operators set up the RE capacity to serve the requirement of the EV charging infrastructure.

The perusal of open access regulations and orders issued by the respective regulatory commissions point out another regulatory deviation where the cross subsidy surcharge and additional surcharge, considering EV as consumer category have not been defined. This regulatory deviation creates a puzzling framework for public charging stations to avail Green Open Access using third party open access transactions wherein the equity participation to set up renewable source is not mandated.

The information about open access provided by the Electricity Act 2003 implies that consumers have the option to obtain electricity supply from sources other than the current distribution licensee, using the distribution and transmission network, while paying the applicable open access charges and ensuring technical feasibility.

Within the open access framework, there are two types of transactions: bilateral and collective. Collective transactions involve transactions on a power exchange platform, while bilateral transactions involve transactions between an open access consumer and a generating source. Bilateral transactions can be carried out in two ways: captive and third party. Captive transactions refer to consumers obtaining electricity from a generating plant set up for their own use, which requires meeting the Captive Eligibility condition outlined in the Electricity Rules 2005.

In this case, the captive user must hold a minimum of 26 per cent equity in the generating project and consume at least 51 per cent of the total net generation from the project within each financial year.

The MoP Green Open Access Rules combined with MoP guidelines on EV Charging stations make the case of greening the EV charging stations. However, the open access is subject to the payment of open access charges as determined by the state electricity regulator from time to time. The present case of subsidized EV tariff may not make a positive case for captive intrastate open access for the EV Charging stations in various state (see *Table 15: Comparative saving analysis of landed DISCOM tariff vis-à-vis open access tariff*).

Table 16: Comparative saving analysis of landed DISCOM tariff vis-à-vis open access tariff

Particulars	Delhi	Rajasthan	Haryana	Maharashtra	Gujarat
Technology	Solar	Solar	Solar	Solar	Solar
Project Size AC (MW)	7.41	7.41	7.41	7.41	7.41
Project Size DC (MWp)	10.00	10.00	10.00	10.00	10.00
Specific Generation(kWh/kWp)	1600	1800	1580	1600	1750
Annual Generation (kWh)	1,60,00,000	1,80,00,000	1,58,00,000	1,60,00,000	1,75,00,000
Tariff at Solar Plant Busbar	4.00	4.00	4.00	4.00	4.00
Transmission Losses	0.90%	4.28%	7.00%	3.18%	3.60%
Transmission Losses in units	1,44,000	7,70,400	11,06,000	5,08,800	6,30,000
Energy Injected into STU	1,58,56,000	1,72,29,600	1,46,94,000	1,54,91,200	1,68,70,000
Wheeling Losses (withdrawal at 11kV)	7.02%	12.60%	9.67%	12.00%	9.50%
Wheeling Losses in units	11,13,091	21,70,930	14,20,910	18,58,944	16,02,650
Energy Available after Wheeling Losses	1,47,42,909	1,50,58,670	1,32,73,090	1,36,32,256	1,52,67,350
Banking Facility 8% in Kind	11,79,433	12,04,694	10,61,847	10,90,580	12,21,388
Energy Available for withdrawal	1,35,63,476	1,38,53,977	1,22,11,243	1,25,41,676	1,40,45,962
Annual Generation Cost (After adjusting Losses)	4.72	5.20	5.18	5.10	4.98
Losses in INR per kWh	0.72	1.20	1.18	1.10	0.98
Wheeling Charges (INR/kWh)	1.06	0.79	0.86	1.43	0.83
Wheeling Charges as per actual withdrawal	1.24	0.98	1.03	1.77	1.00
Transmission Charges (INR/kWh)	0.38	0.62	0.36	0.77	0.38
Transmission Charges as per actual withdrawal (INR/kWh)	0.45	0.81	0.47	0.98	0.47
Scheduling Charges (INR/Day)	1,000.00	2,000.00	2,000.00	2,250.00	2,000.00
Scheduling Charges as per actual withdrawal (INR/kWh)	0.03	0.05	0.06	0.07	0.05
System Operation Charge (INR/MW/Day)	-	-	-	12,360.00	-
System Operation Charge as per actual withdrawal (INR/kWh)	-	-	-	2.66	-
Self-Generation Tax (INR/kWh)	0.20	0.20	0.20	0.20	0.20
Self-Generation Tax as per actual withdrawal (ED)	0.20	0.20	0.20	0.20	0.20
Net Landed Cost (INR/kWh)	6.64	7.24	6.94	10.78	6.71
Open Access Charges (INR/kWh)	2.64	3.24	2.94	6.78	2.71
DISCOM Landed Tariff (INR/kWh)	7.20	7.02	6.67	6.91	6.39
Savings in Green Open Access (INR/kWh)	0.56	-0.22	-0.26	-3.88	-0.32

Source: Analysis for the study

A specific illustrative analysis has been carried out in the specific state boundaries that intersect with the Delhi-Mumbai expressway. This ascertains and demonstrates whether any charging point operators have any effective incentive to provide charging services along this expressway in the upcoming period. This analysis shows that the savings in Green Open Access is either too minimal to negative across the states of Delhi, Rajasthan, Haryana, Maharashtra and Gujarat along this corridor.

The regulatory commissions are keeping the EV tariff lesser in a bid to promote electric vehicles. It appears that the loading of open access charges makes commercial case for open access difficult or non-feasible in most of these states. DISCOMs are apprehensive of providing further incentive mechanisms to such installations. They are concerned that any further incentive will lead to under-recovery and increase cross-subsidizing burden on other consumer categories. At present there is only a possibility of green open access that exists for charging point operators installing their own captive installations in their locations.

SECTION 5
Way forward

Need a detailed roadmap for e-truck roll out: The Office of the Principal Scientific Adviser, (PSA) Government of India, has already provided a guidance on the roadmap for deployment of zero emissions trucks integrating the scope of field research, standard and regulations, technology assessment and development and pilot project preparation for implementation. A wide range of tasks, methodology and deliverables along with budget have been identified. This needs to be taken forward with appropriate directions to the concerned ministries and departments. The implementation of the pilot projects along with the stakeholders to support deployment strategy for e-trucks needs to be prioritized.

Drive product development with appropriate standards: While OEMs are in the process of developing products, more evolved and comprehensive regulations and technical standards are needed for safe and durable operations of e-trucks. The PSA roadmap has identified standardisation of battery communication protocol, appropriate drive cycle for range/energy assessment, interoperability among others as some of the critical areas of interventions. Battery standards as well as standardised format for recycling and repurposing format for batteries are also needed.

Strengthen fuel economy standards for ICE trucks for quicker electrification: Provide the timeline for successive improvement in fuel economy improvement targets and advancement in testing protocol to give a longer-term policy visibility of the pathway. This may be supported by a suitable timeline for zero emissions mandate while modifying the EV super-credit multiplier and disclosure of test data.

Implement carbon credit trading system to mobilise resources and investment: There is already a regulatory provision of carbon trading system under the Energy Conservation Act and Bureau of Energy Efficiency is developing this mechanism for the vehicles. Bring e-trucks within the scope and enable companies operating e-trucks to earn credits based on their reduced carbon emissions and meeting of the emissions reduction obligation.

The national policy needs to unify highway planning with obligatory EV infrastructure: This can be placed every 80 km on both sides of the highway.

Additionally, locating RE projects in proximity to charging infrastructure is essential to enhance the renewable energy share in the energy mix, a critical factor for optimizing GHG reduction advantages.

Need standardized protocol for managed charging strategy and demand response: The utilities are required to invest in upgrading and designing the network to cater to peak system demand, which is capital-intensive. The regulator ought to create a mechanism for demand response products in the ancillary market, allowing charging service providers to participate in it. Several new technologies related to managed charging of EVs have initially been introduced through pilot platforms. These require large-scale technology deployment. While standards and guidelines in India include provisions for communication protocols between EVSE and other stakeholders, there has been a lack of pilot initiatives on large-scale managed charging projects. To promote the adoption of managed charging of EVs, it is crucial for DISCOMs and regulators to undertake pilot initiatives to demonstrate the potential advantages and challenges.

The Central Electricity Authority (CEA), in conjunction with DISCOMs, also need to generate short and long-term demand projections for EV penetration based on available charging data. There is currently no regulatory mandate for DISCOMs to incorporate the CEA forecasts into their planning processes.

Design a suitable tariff that increases feasibility of operation of charging infrastructure facilities even at low asset utilization level: Electricity demand charges i.e., “Fixed Demand Charges in EV tariff” pertain to fixed fees imposed on charging station operators, determined by the connected load, regardless of the actual usage of the charging station facility. For chargers located along highways and expressways, initial phases might witness low asset utilization, and the application of electricity demand charges can present challenges for high-capacity chargers to achieve break-even points.

Allow recovery of network investment cost through regulatory provisions and tariff determination. Adapt energy utility rate structure to accelerate the cost-effective electrification of e-trucks. The cost of supply is higher than the approved EV tariff (accrual of EV tariff subsidy committed by government). Even if this allows recovery of utility capital costs it may discourage the electrification of the e-trucks. Innovative EV tariff should be adopted to be an enabler. The state EV policies can make changes specifically concerning road freight vehicles and define specific tariff rates for the megawatt chargers for e-trucks.

Smart charging techniques: This may also enable new services to optimize the cost of charging, mitigate the secondary peak, encourage to utilize clean source of energy, and delay the infrastructure augmentation, if compensated appropriately. Assess the resilience and requirements of infrastructure along highways and key locations. Ensure connectivity and safety measures.

Leveraging policy support for charging of e-trucks: The government has implemented favourable policies and regulations to incentivize DISCOMs to create a supportive environment by offering various incentives for supporting zero emission vehicles and their engagement in renewable energy-based power generation and the establishment of charging infrastructure. These incentives can take the form of tax benefits, subsidies, or grants. The Ministry of Power has issued guidelines and standards for public EV charging infrastructure on 14^{th} January 2022. Under phase-II of FAME-India Scheme, Rs. 1000 Cr. has been allocated for the charging infrastructure development. The Ministry of Power has sanctioned 2,877 electric vehicle charging stations in 68 cities across 25 states/UTs. Further, 1576 charging stations across 9 Expressways and 16 Highways under phase-II of FAME India Scheme has also been sanctioned.

Introduce point-of-sale incentive for e-trucks: Incentive and subsidy, and policy support schemes for e-trucks need to be integrated in the upcoming FAME III (Faster Adoption and Manufacturing of Electric Vehicles) program.

Financing e-trucks: Need a combination of financing instruments and insurance policy including viability gap funding of e-trucks. Coordinate with the financial institutions to design appropriate financial products and specially address risk mitigation.

It is very clear that the State Electricity Regulatory Commissions (SERCs) ought to permit the spreading of capital expenditures (capex) to enhance e-truck Infrastructure. The central and state governments need to include the exemptions of cross subsidy surcharge and additional surcharge and this exemption should be mandated by the State Government through Section 108, directing State Electricity Regulatory Commissions (SERCs) to formulate regulations that encompass the project's entire useful lifespan.

Tax measures to reduce operational costs: During the initial phase, incentives, road tax credits, and rationalisation of GST etc can help to lower the operational and charging expenses of e-trucks.

Enable stakeholder collaboration for establishing charging network: The vehicle OEMs, start-ups involved in e-truck development, financial institutions, logistic service providers, charging equipment providers, and infrastructure companies need to align and coordinate to plan charging locations, upgradation of grid along highways, expressways, logistic hubs, and economic corridors. This also requires empirical estimation of investment required for both charging infra and procurement of electricity.

Also, logistic service providers, fleet operators, and OEM's have the opportunity to engage with private sector stakeholders and financial institutions to create innovative business models, partnerships, and institutional mechanisms. By doing so, they can effectively leverage financing resources required to achieve their transportation electrification objectives.

Charging Infrastructure and data analytics: The vehicle electrification programme brings with it a significant increase in data related to vehicle and energy usage. This is an opportunity to design effective policy measures based on data to improve vehicle performance, charging patterns, and overall energy consumption. This information can be utilized to develop targeted incentive programs and financial incentives. This needs seamless communication and data sharing standards, use of data analytics for performance optimization, enhanced fleet management etc. This can also enable environmental and safety reporting.

Capacity building and knowledge dissemination: Design and launch awareness campaigns around the benefits of electrification of trucking. Establish collaborative partnerships with market leaders to gain insights into effective deployment strategies for e-trucks. Promote skill development and training programs to equip the workforce with the necessary expertise to operate and maintain e-trucks. This will ensure a smooth integration of electric vehicles into the existing logistics ecosystem.

Advanced planning and roadmap for setting charging infrastructure for powering e-trucks: The conversation with the charging providers, and electricity distribution companies (DISCOMs) has brought out the need for advanced planning for charging infrastructure for e-trucks. Heavy power withdrawal for heavy duty e-trucks with large batteries require special attention to ensure uninterrupted and reliable energy supply and significant investments in new charging infrastructure capable of meeting high voltage and current flow from Electric Vehicle Supply Equipment (EVSE) to the vehicles. Charging time and reliable power will matter for timely deliveries and uninterrupted travel. These will require much more powerful charging equipment, relying on a network of ubiquitous, high powered DC fast chargers ranging from 350 – 10000 kW.

The e-truck industry requires megawatt chargers and the Megawatt Charging Standard are being designed to deliver power up to 3.75 MW (3750kW) by 2024. These are capable of handling the higher power demand effectively and efficiently. Standardization of both hardware and software becomes crucial. By establishing standardization, compatibility between different charging systems can be ensured, enabling interoperability. Although every project may require unique engineering solutions due to variations in sites and specific requirements, there are certain common elements that should be taken into account. This requires installing high-power charging infrastructure at the commercial facilities, including depots, yards, and hubs

Leveraging renewable energy for e-truck powering: Currently, the EV charging stations with solar rooftop with load above 10kW, become eligible for availing the regulatory benefits in terms of net-metering or net-billing or net feed-in (gross metering). However, since most of the state electricity regulatory commissions identify the eligibility for net metering by consumers category, this creates a regulatory ambiguity over eligibility of EV charging stations to avail net metering benefits. The EV charging infrastructure providers may be allowed to install solar/ micro wind with regulatory incentives of net-metering and net-billing. This can also reduce the cost of running the electricity infrastructure. A clarification is needed to be issued from the Ministry of Power (MoP) to consider EV Charging stations to be classified as eligible consumers as part of the net metering/net billing incentives.

The infrastructure for EV Charging should be categorized as an eligible consumer, enabling it to access the benefits of net metering or net billing mechanisms. This classification would not only facilitate a more dynamic and efficient use of energy resources but also incentivize the adoption of renewable energy sources for EV charging stations.

Allowance for yearly Renewable Energy (RE) banking should include the flexibility for adjustments within both peak and off-peak time of day (TOD) periods.

Upgradation of distribution grid and timeline: Although shared infrastructure can be created as load projections grow, laws normally demand that utilities respond to consumers' demands for electric service rather than foresee them. Nowadays, practically all DISCOMs in every state demand that consumers pay for system expansion. To save customers money and avoid wasteful infrastructure, electric utilities are regulated to respond to service requests. While shared infrastructure can be built as load forecasts increase, generally regulations require that utilities respond to customers' electric service requests rather than anticipate them. The electrical infrastructure to be upgraded by electric utilities can include distribution lines, local stations, breakers, transformers, and switchgears. Electricity grid upgrades are necessary where on-site power availability is not sufficient. Grid upgrades can range from minor, such as only upgrading the breaker and distribution transformer, to major upgrades of the distribution lines and substation. It is necessary to illustrate the tentative cost for new infrastructure upgrades and average timelines for each set-up (see *Table 11: Average grid infrastructure cost and timelines*).

Enable third-party aggregators to engage in the aggregation of distributed energy resources, encompassing EVs, through regulatory measures. This participation aims to facilitate grid services, which in turn promote the effective deployment of Vehicle to Grid (VG) projects, optimizing a wide array of resources for enhanced efficiency.

Remedial solutions to prevent the stress: Addressing the grid challenges posed by e-trucks requires multiple solutions rather than a single fix. Fleet operators, logistics service providers, and charging service providers must acquire new skills related to power procurement, charger installation, and managing charging power and time.

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