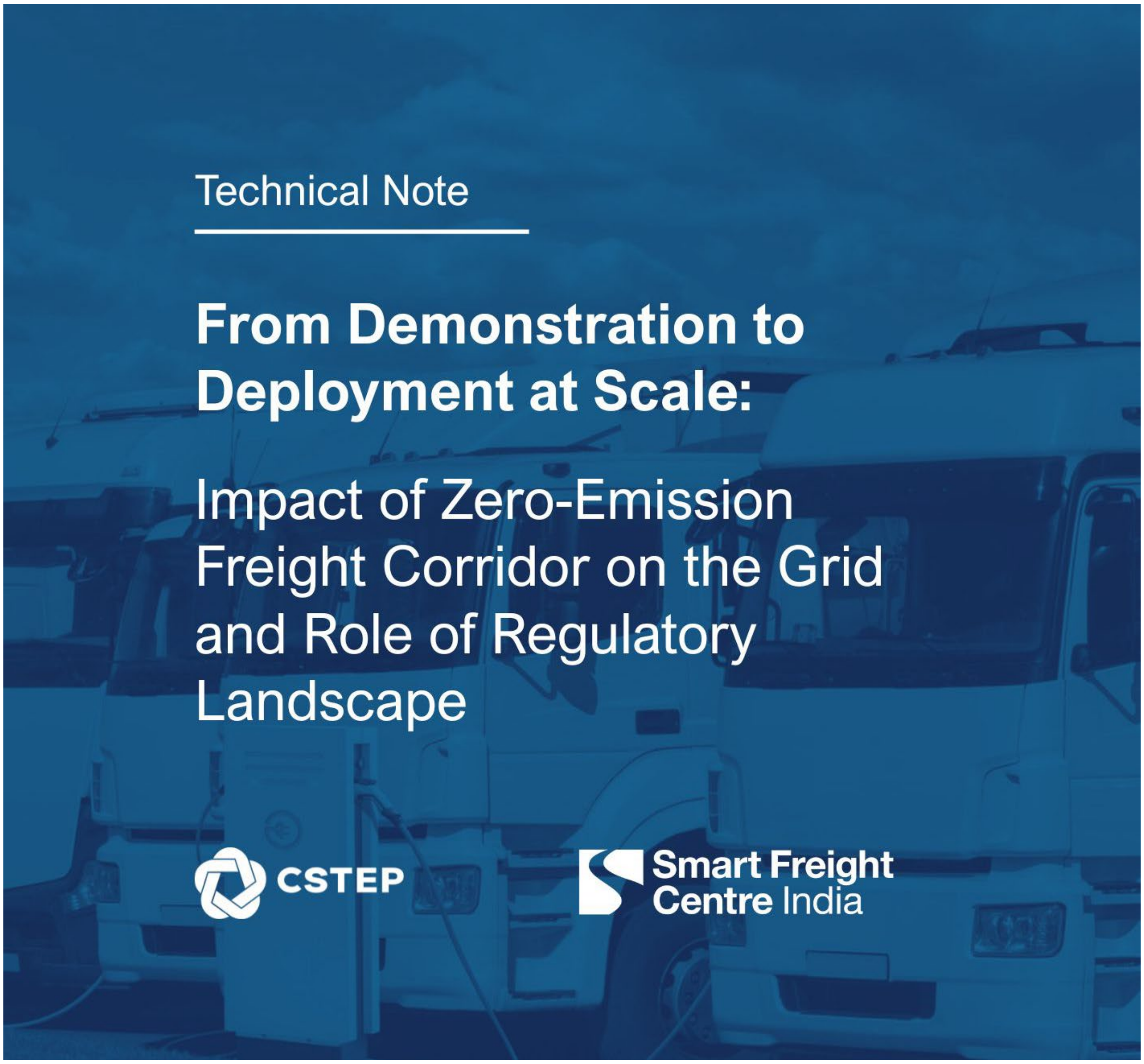
Smart Freight Centre India

CSTEP



From Demonstration to Deployment at Scale

Impact of Zero-Emission Freight Corridor on the Grid and Role of Regulatory Landscape

This technical note is the second in a series on scaling up zero-emission freight in India through corridor electrification. The previous note put forth a strategic framework for corridor-level deployment of electric trucks, using the Bengaluru–Mumbai corridor as a case study. This note focuses on the charging infrastructure, including the corresponding energy needs and grid readiness, and the challenges of scaling it up for the Bengaluru–Mumbai corridor.

Adopting electric trucks for highway deployment beyond pilots and demonstrations hinges primarily on operational reliability. Accessible, discoverable, technically compatible, and strategically located charging infrastructure can enable uninterrupted highway operations of electric trucks.

There are three technologically different alternatives for charging electric trucks: plug-in charging, battery swapping, and pantograph charging. Their technology readiness levels (TRLs) and suitability in the Indian context are presented in Table 1.

Table 1: TRLs of alternative technologies for charging electric trucks

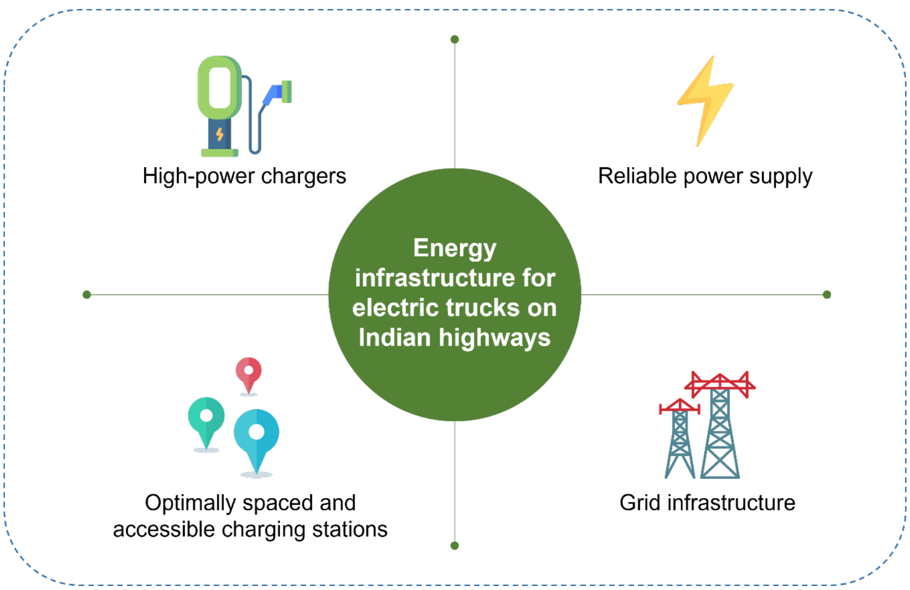
Charging mechanism	TRL	Suitability for Indian highways
Plug-in charging	TRL 8–9	• Since electric trucks require high-power (120 kW+) charging (which is an upgrade to the current electric-car-charging infrastructure), augmentation of grid infrastructure is needed. • Widespread demonstrations seen pan India.
Battery swapping	TRL 6–7	• Has a lower impact on the grid compared to plug-in charging. • Limited deployment in urban areas (mostly for captive users such as electric two-wheelers in quick commerce and electric three-wheelers in urban logistics and passenger mobility segments). • Pilots tailored for heavy-duty electric vehicle (EV) applications not yet widespread in India, mainly due to high CapEx and lack of battery standardisation.
Pantograph charging	TRL 6–8	• Draws power from dedicated overhead power lines along the route. • Allows electric trucks to have smaller on-board batteries, reducing vehicle weight. • Though pilots seen globally (like in Germany), near-zero demonstrations/pilots in India due to weaker techno-economics and lack of policy push.

Considering the market signals and policy developments, plug-in charging seems to be the most suitable technology for at-scale deployment, and hence, has been considered for this note.

Operational requisites for scaling up the deployment of plug-in charging

The efficient scale-up of a clean energy technology like electric trucks, from pilot stage to real-world operational deployment, requires policy certainty, technology readiness, financing ecosystem, capacity building, and infrastructure (energy, information and communications technology, and manufacturing). The energy infrastructure required to support electric truck operations on Indian highways is discussed here. The main components of this infrastructure are presented in Figure 1.

Figure 1: Components of energy infrastructure required for at-scale deployment



High-power chargers: To keep the charging downtime low and account for the large battery size of electric trucks, high-power chargers that provide fast charging are required on highways. The latest central government standards released by the Ministry of Heavy Industries (MHI) in 2025 mandate a minimum charger power of 120 kW.

Optimally spaced charging stations: Charging stations that are optimally spaced and adequate to meet the demand of electric trucks are crucial for operational feasibility. While the Ministry of Power (MoP) guidelines recommend charging stations at every 100 km on highways, a realistic charging network density can be determined on the basis of the actual demand on highways. Further, enabling the discoverability of charging stations through driver-friendly information channels and easy access, such as proper geometric design (e.g., turning radius), to ensure easy maneuvering of trucks, along with closer-to-corridor siting to avoid detours, can also enhance operational efficiency.

Reliable power supply: For ensuring uninterrupted operations of charging stations and minimum possible downtime, a reliable power supply is needed. It also helps build confidence among electric truck users and the ecosystem at large.

Upgradation of grid infrastructure: Since reliability of power supply is largely a function of grid infrastructure, upgrading the grid is essential for providing the required amount of power at the desired quality. The substations, cables, distribution transformers, and other components need to be augmented to meet the anticipated power demand from electric trucks.

Bengaluru–Mumbai corridor: Demand for charging infrastructure and impact on grid

The Bengaluru–Mumbai corridor connects several industrial clusters, consumption centres, and ports. With an overall length of about 1,000 km, the corridor (along NH48) passes through Karnataka and Maharashtra, traversing the jurisdictions of three electricity distribution companies (DISCOMs): Bangalore Electricity Supply Company Limited (BESCOM), Hubli Electricity Supply Company Limited (HESCOM), and Maharashtra State Electricity Distribution Company Limited (MSEDCL).

This section details the assessment of the charging demand from electric trucks and its impact on the grid for the Bengaluru–Mumbai corridor. For the assessment, three adoption scenarios were considered, which are described ahead. Next, the electric truck traffic was assessed for these adoption scenarios for the years 2030 and 2035, followed by the estimation of the number of electric-truck–charging-station clusters and their locations. Finally, the impact on the grid was assessed in terms of the energy demand from electric truck charging, including peak loads, for these two years.

How many electric trucks would ply on the Bengaluru–Mumbai corridor by 2030 and 2035?

The following three scenarios were considered for the assessment:

1. **Scenario 1 (S1)** is based on the consultations held by Smart Freight Centre (SFC) India and Center for Study of Science, Technology and Policy (CSTEP) with shippers and transport operators along the corridor. It projects that 300 electric trucks would ply every day by 2030, which will increase to 1,600 by 2035.

2. **Scenario 2 (S2)** is based on the projections for all Indian electric truck corridors made by the Office of Principal Scientific Adviser (PSA) to the Prime Minster of India, which were proportioned for the Bengaluru–Mumbai corridor. It projects 650 electric trucks to be plying per day by 2030, with the number going up to 5,000 by 2035.
3. **Scenario 3 (S3)** is informed by the current electric truck sales trends across Karnataka and Maharashtra but considers an aggressive and widespread electric truck adoption along the corridor (100% by 2035). It projects the number of electric trucks plying per day to be 1,400 by 2030 and 12,600 by 2035.

Projections for 2030 (under the three scenarios) indicate that at least 300 electric trucks are likely to ply daily in each direction on the corridor. At the higher end, this would be about 1,400 electric trucks per day, which is about 15% of the projected total medium- and heavy-duty truck (MHDT) traffic[1] on the corridor. By 2035, 1,600 to 12,600 electric trucks may ply every day on the corridor, making up 13% to 100% of the total MHDT traffic.

Where should the charging infrastructure for electric trucks be set up?

Based on the insights from early electric truck trials and stakeholder consultations, electric trucks with a gross vehicle weight (GVW) of 18 tonnes, a battery capacity of 200 kWh, and an energy efficiency of 0.8 to 1.0 km/kWh have been considered for the assessment. A well-established infrastructure-siting algorithm (Flow Refueling Location Model [FRLM]) was employed to identify 14 cities/towns along the corridor to set up electric truck charging clusters (see Figures 2 and 3) at an average spacing of 120 km. It is to be noted that the clusters were identified keeping in mind that if an electric truck starts a trip at either end of the corridor, it should be able to traverse the entire corridor successfully.

[1] Projected using the current observed MHDT traffic as input, considering a conservative annual growth rate of 5%.

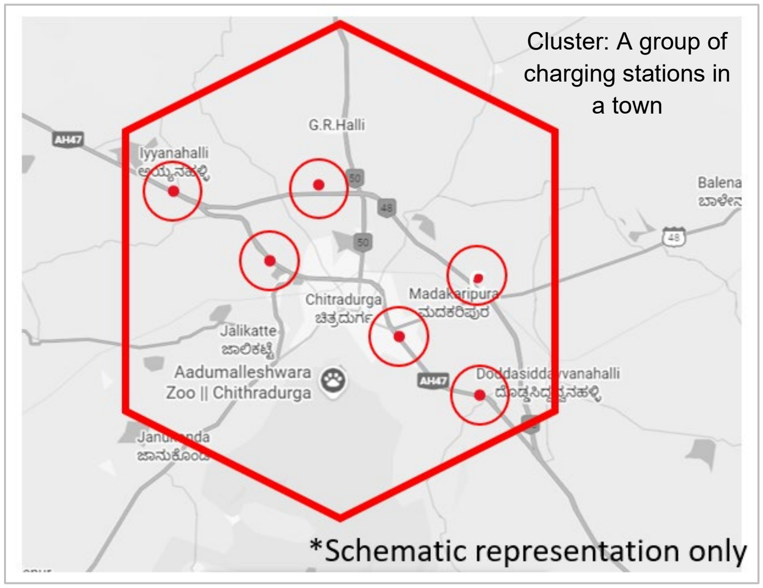


Figure 2: Electric truck charging cluster

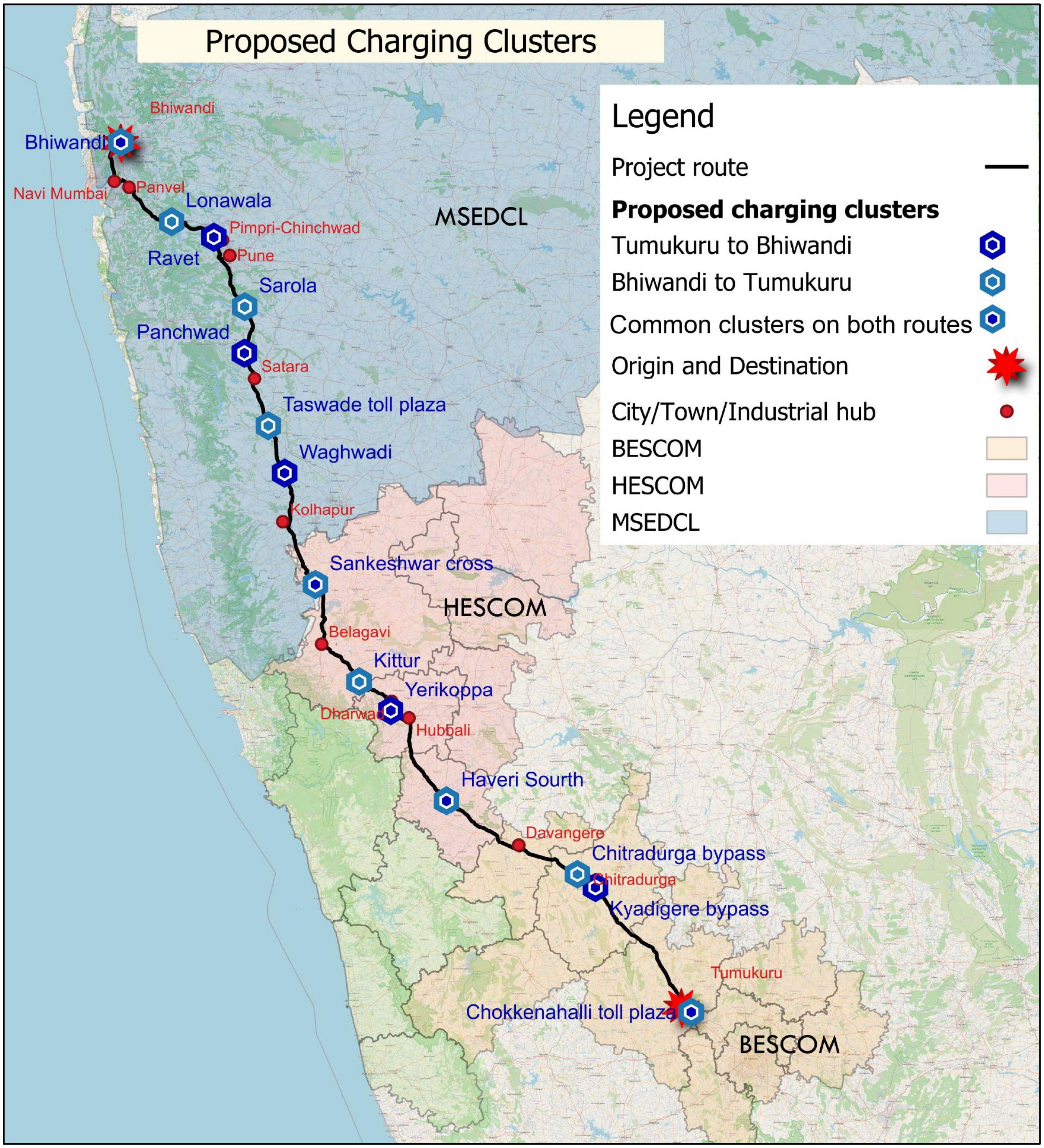


Figure 3: Identified electric truck clusters on Bengaluru–Mumbai corridor

How many high-power chargers will be required?

The number of high-power charger guns required for electric trucks were estimated for the identified clusters, and subsequently for the corridor (see Figure 4). Based on stakeholder consultations and market trends, 120 kW chargers were considered as the commonly used chargers for heavy-duty charging till 2030, and for 2035, 360 kW chargers were considered. Temporal variations in hourly electric truck traffic, as well as travel time, were also considered.

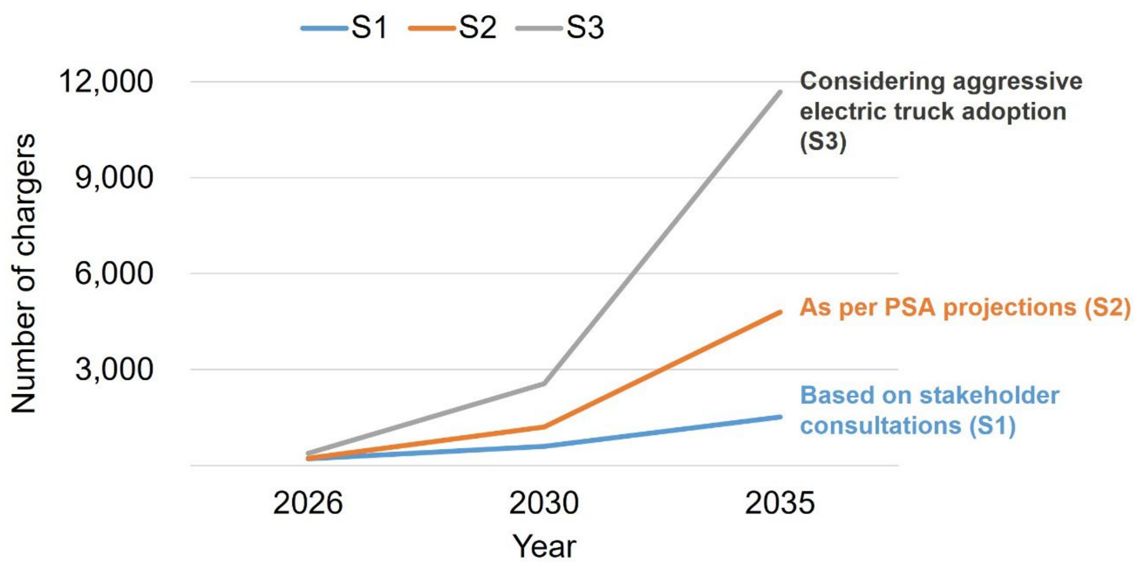


Figure 4: Demand for high-power chargers on Bengaluru–Mumbai corridor

It is estimated that at least 600 chargers will be required by 2030 to cater to the charging needs of electric trucks along the corridor. By 2035, this requirement is likely to increase by 2.5 times, to 1,500 chargers under Scenario 1, where electric trucks account for only about 15% of MHDT traffic. However, under an aggressive electric truck adoption scenario (Scenario 3), the requirement can become twenty times more.

What will be the impact of electric truck charging on the grid?

The impact on the grid due to the estimated electric truck traffic and the number of chargers required was assessed in terms of peak load and annual energy demand. It is presented in Figures 5 and 6.

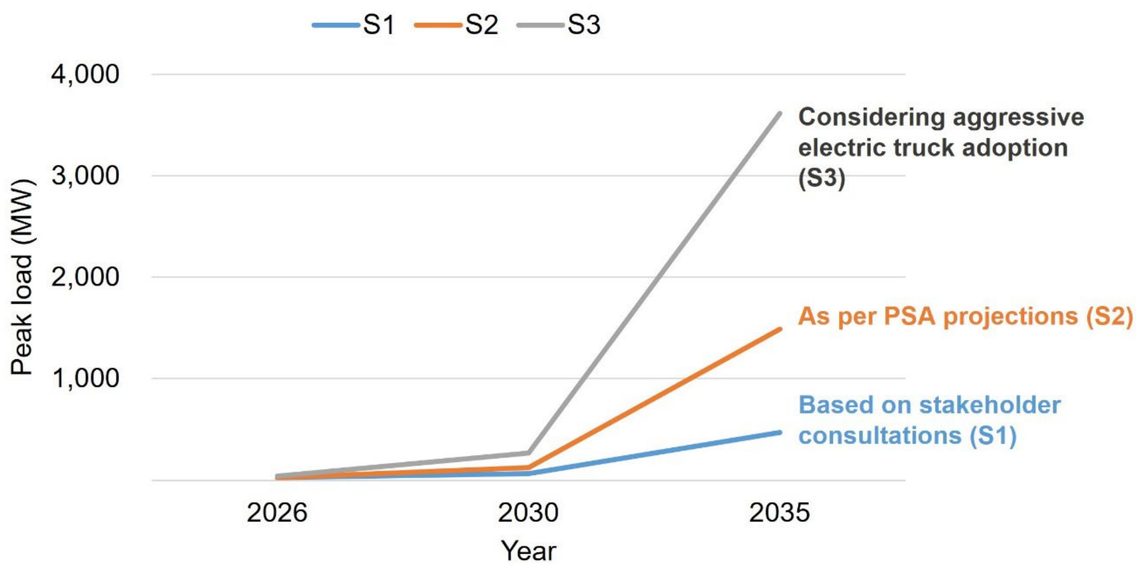


Figure 5: Peak load from electric truck charging on Bengaluru–Mumbai corridor

By 2030, the peak load from electric truck charging across the corridor is estimated to be 50 MW under Scenario 1, 120 MW under Scenario 2, and 250 MW under Scenario 3. By the same year, peak loads from the charging stations within BESCOM, HESCOM, and MSEDCL jurisdictions are estimated to be 80 MW, 70 MW, and 100 MW, respectively. These constitute 1%, 1.6%, and 0.4% of the projected peak demand of each of the three DISCOMs (BESCOM, HESCOM and MSEDCL), which is 8,670 MW, 4,495 MW, and 38,781 MW, respectively.

By 2035, this peak load is expected to increase to 3.5 GW in the case of aggressive electric truck adoption (Scenario 3). To deal with this peak demand of 3.5 GW, DISCOMs need to ensure adequacy and readiness of the electrical grid infrastructure upstream of the charging stations. The existing substations, cables, and distribution transformers should be evaluated to ensure the availability of sufficient capacity margin to accommodate the impending rise in power demand due to electric truck charging over time, otherwise new installations will become necessary. Large loads (such as these electric truck charging stations) might have a detrimental impact on the voltage profile of the power system as well. This possibility should be considered at the grid planning stage.

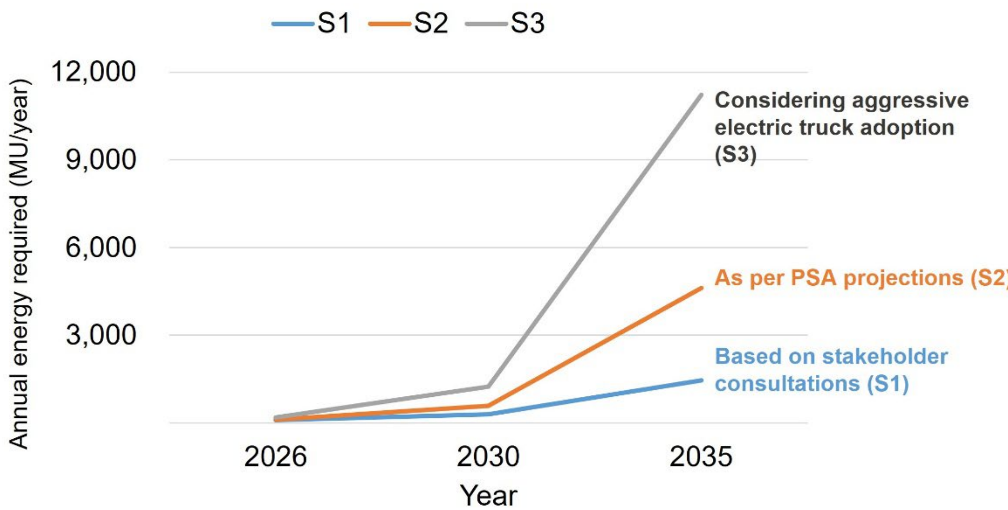


Figure 6: Energy demand from electric trucks on Bengaluru–Mumbai corridor

In terms of annual energy demand, the electric trucks on the corridor will require at least 300 MU/year by 2030 in Scenario 1. In case of aggressive electric truck adoption (Scenario 3), 1 BU/year will be needed by 2030, which will increase to 11 BU/year by 2035.

The energy demand from electric truck charging in 2030 makes up less than 1% of the projected combined energy demand of BESCOM, HESCOM, and MSEDCL. So, meeting this energy demand would not pose a major challenge for DISCOMs. However, it should be noted that additional energy demand will arise from other EVs, such as electric buses and electric cars, on the highway corridor. Therefore, the net demand from the overall EV traffic on the corridor is likely to be much more.

Role of regulatory framework in scaling up deployment

While the establishment of high-power charging infrastructure on highways is largely driven by private and government investments, it is bound by energy (electricity) supply and the associated regulatory landscape.

At the central-policy level, the Guidelines for Installation and Operation of Electric Vehicle Charging Infrastructure published by MoP in 2024 and the Operational Guidelines for Deployment of EV Public Charging Stations under the PM E-DRIVE Scheme published by MHI in 2025 are well-positioned to support the development of heavy-duty chargers for electric trucks along highways. They specify the criteria for location of charging stations, power rating of chargers, and guidelines for tariff design, and explicitly permit open access.

The real bottlenecks for heavy-duty charging corridors on highways mostly stem from state-level regulations and implementation issues (in terms of consideration of high-load connections, tariff design, etc.). For the Bengaluru–Mumbai corridor, the regulations governing the states of Karnataka and Maharashtra are the relevant ones to consider, besides the national-level regulations.

This section dives into the regulatory aspects of scaling up deployment, discussing the supportive elements, as well as the challenges posed by some of the regulations.

Regulatory support

1. Liberalisation of Charge Point Operator (CPO) entry

Under the Electricity Act, 2003, an entity procuring and distributing electricity has to obtain a distribution license for distributing electricity within its premises. The guidelines put forth by MoP classify EV charging as a service that does not require a CPO to obtain a distribution license for providing electricity for charging EVs.

2. Charging network density guidelines

According to the MoP guidelines, at least one fast charging station is to be set up at every 100 km on each side of a highway with a minimum of two chargers, each having a power rating of 240 kW or more. Further, the PM E-DRIVE operational guidelines recommend Combined Charging System Type 2 (CCS2) as the charging standard for guns. This helps to predict future demand and instill confidence among private CPOs to invest in charging infrastructure development.

3. Tariff ceilings and differentials

The MoP guidelines specify that the distribution licensee (or DISCOMs) shall supply electricity to the stations with a single-part tariff not exceeding the average cost of supply (ACoS), with a time-of-day (ToD) differentiation (0.7x ACoS during solar hours and 1.3x ACoS during other times). This provision ensures that the charging tariffs are cost-effective for electric truck operators.

4. Open-access option

The MoP guidelines also allow CPOs to procure electricity through open access, paying only for wheeling and transmission, and a capped surcharge. This enables CPOs to directly procure clean and reliable energy.

5. Fiscal support via viability gap funding under PM E-DRIVE

Under the scheme, charging stations along highways are eligible for an 80% subsidy on upstream infrastructure costs. A 70% subsidy on charging equipment cost is also available for charging stations that are owned, operated, and managed by central/state/public sector undertakings. Additionally, Karnataka and Maharashtra provide capital subsidies to the tune of 25% and 15% of the equipment cost, respectively, capped at INR 10 lakh per station for developing up to 500 fast-charging stations in each state.

The state-level regulations, though supportive, are not specifically designed for the profile and scale of heavy-duty highway charging, which presents certain challenges, as elaborated below.

Regulatory challenges

The regulatory landscape is largely aligned for the deployment of heavy-duty charging along highways. However, it is insufficient to enable a planned and coordinated deployment of charging infrastructure along highways, unlike the National Electric Vehicle Infrastructure (NEVI) programme in the United States of America and the Alternative Fuels Infrastructure Regulation (AFIR) mandate in the European Union, which facilitate a strategically spaced, high-power, heavy-duty highway charging infrastructure and attract private investments through performance standards.

The following are the main challenges in the case of the Bengaluru–Mumbai corridor, which are informed by stakeholder consultations and a review of the related policies and regulations:

1. Grid connection complexity and bottlenecks

- The MoP guidelines require that DISCOMs provide a new connection for setting up EV charging stations within 30 days (depending on the location of the site) and within 90 days if grid infrastructure upgrades are required due to large loads from the proposed charging station.

  This requirement is not adequately supported by the state-level standards for heavy-duty charging. For Maharashtra, the Electricity Supply Code and Standards of Performance of Distribution Licensees in Maharashtra specifies a maximum of 30 days for new connections of up to 200 kVA. However, for connections with a sanctioned load of above 200 kVA, this period extends up to 1 year. Similarly, for Karnataka, the Conditions of Supply of Electricity of Distribution Licensees in the State of Karnataka specifies that new EV connections shall be provided within 15 days, but this applies only to connections with a sanctioned load of less than or equal to 150 kVA (i.e., low-tension [LT] connections).Thus, in these two states, the heavy-duty charging stations with prescribed loads of at least 480 kW, which need high-tension (HT) connections, cannot benefit from the fast-tracked application process. Consequently, their establishment and operationalisation is likely to be delayed.

- The MoP guidelines and planning norms (specifying a 100-km spacing between charging stations along highways) call for creating dense node networks, without taking into account the need for a corresponding distribution system strengthening and load forecasting. In some cases, the locations may not have spare capacity (MW) available and may require expensive grid upgrades.

2. Unfavorable tariff structure

The MoP guidelines recommend that DISCOMs supply electricity to CPOs with a single-tariff regime that does not exceed the ACoS (with ToD differentiation, as explained above under 'Regulatory support'). This guideline allows CPOs to pay only for the energy (kWh) consumed by them (depending on the quantum of energy dispersed to the EVs at the station), thereby ensuring minimal energy cost for the CPO (and thus for EV users).

While Maharashtra complies with the single-part tariff for both LT and HT EV-charging-station connections at a tariff of INR 7.82/kWh (energy charges of INR 6.68/kWh + wheeling charges of INR 1.14/kWh), DISCOMs in Karnataka continue to offer a two-part tariff (applicable for LT loads of <150 kW) to recover the costs towards network capacity expansion. Karnataka DISCOMs maintain that this two-part tariff is favorable for large energy users. It may be favorable for CPOs at a later stage (say by 2030), when EV traffic on highways (including electric trucks) increases sufficiently enough to ensure a high utilisation rate (of 40% or more) for charging stations, at which level, demand charges would constitute only a small share (less than 15%) of the total charges. However, in the current initial phase, where utilisation rates of highway charging stations are around 10%, a two-part tariff increases the total charging costs for electric trucks, with demand charges accounting for 40%–60% of the total charges, adding to the challenge of decarbonising road freight.

3. Lack of dedicated tariff categories, billing, and data infrastructure

- Dedicated EV tariff categories enable quick, single-window application processes, which result in faster deployment of charging infrastructure. While Maharashtra has dedicated tariff categories for both LT and HT EV connections (LT VIII and HT IX), Karnataka has a dedicated EV tariff category only for LT connections, i.e., LT-6(c), applicable to connections that are equal to or less than 150 kW. Hence, the advantages of the fast-tracked, single-window application process and tariff reduction are enjoyed only by the LT EV connections, and do not benefit the heavy-duty charging stations for electric trucks along highways (which have HT EV connections), increasing the timelines for establishing a charging infrastructure for CPOs.
- While the MoP guidelines and state-level demand flexibility regulations recommend an infrastructure for smart charging, unified energy interface, and open and automated demand response systems, there are no explicit regulatory incentives for EVs to participate in demand response or ancillary services (vehicle-to-grid [V2G]) to support the grid while maximising the use of renewable energy (RE) in Karnataka. The case is no different in Maharashtra. Though the Central Electricity Authority (CEA) had rolled out guidelines regarding V2G earlier, Karnataka and Maharashtra currently lack explicit regulations, incentives, and systems that can enable EV users to give back to the grid through the V2G technology.

4. Open-access complexity

While the open-access regulations allow charging stations to directly procure energy from generators, these regulations were designed for steady and predictable industrial loads. For the discontinuous and variable EV charging loads on highways, the cross-subsidy surcharge (CSS), in addition to wheeling and transmission charges, makes the power costs prohibitively high. For example, Karnataka levies a CSS of INR 2.44/kWh, while Maharashtra levies a CSS of INR 0.94/kWh. These charges increase the cost of procuring clean energy through open access, thus discouraging clean freight movement.

5. Administrative and procedural bottlenecks

While the central and state regulations call for fast-tracked, single-window applications for new EV meter connections, the timelines of multi-agency clearances that are additionally required are not aligned. Timelines of land-use and bye-laws compliance by the local municipal authorities and safety approvals from fire departments and the Petroleum and Explosives Safety Organisation (PESO), specifically for the charging/swapping stations set up at fuel retail outlets (petroleum service stations), are often misaligned. For instance, a new EV connection is provided to an LT EV-charging station within 15 days, but it takes nearly 120 days for land conversion and 60 days to obtain an NOC from the fire department in Karnataka.

Conclusion

The charging network for the Bengaluru–Mumbai corridor will span the states of Karnataka and Maharashtra. The two states have different grid conditions, tariff structures, and DISCOM reliability and response levels. Further, the variation in charges (demand, energy, CSS) make planning and investment difficult at the corridor level. Unlike in a single, integrated financial model for the entire corridor, in this case, CPOs cannot apply a uniform energy procurement cost or charging tariff. Moreover, the variation in tariffs may lead to disparity in utilisation of charging stations: fleet operators are likely to maximise charging at stations with lower tariffs, resulting in asymmetric utilisation and commercial unviability of charging stations with higher tariffs.

CSTEP and SFC are actively engaging with energy regulators, DISCOMs, and CPOs to address these regulatory barriers, enable inter-agency coordination across states, and drive public and private investment towards electric truck charging infrastructure.

The overall EV demand and adoption (including that of electric trucks) is poised to surge in the coming years as battery prices decline globally. The combined electricity demand for charging all the EVs will thus grow substantially, which will require ramping up the supply-side ecosystem. This, together with the concentrated demand along the highway corridor, presents an opportunity for integrating RE sources to facilitate the at-scale deployment of electric truck charging infrastructure.

Moreover, the significant decarbonisation potential of electric trucks can be constrained if the electricity used for charging them is predominantly fossil-fuel-based. Coal power plants generate most of India's grid electricity, resulting in a high carbon footprint of 0.71 kg CO_2/kWh. Studies show that a 12 tonne (GVW) electric truck with an annual run of 75,000 km can help abate 44 to 53 tonnes of carbon dioxide annually when charged using RE-dominant electricity (with a low carbon footprint of 0.3 kg CO_2/kWh), while also generating a potential carbon credit revenue of INR 19,000 to INR 24,000. Thus, RE integration for electric truck charging can help realise the maximum climate mitigation potential of electric trucks.

In light of this, the next and final technical note in this series will delve into the opportunities for powering electric trucks through RE sources and the associated regulatory landscape for operationalising a clean-energy-powered Bengaluru–Mumbai zero-emission freight corridor.

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