WORKING PAPER

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Charging infrastructure in India: Incentives under FAME II and considerations for PM E-DRIVE

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INTRODUCTION

India has pledged to achieve net-zero greenhouse gas emissions by 2070 (Ministry of Environment, Forest and Climate Change, 2023). The transport sector accounts for about 14% of India's energy-related carbon dioxide emissions and in recent years was found to be the fastest-growing source of carbon emissions in the country (NewClimate Institute & Climate Analytics, 2020). The decarbonization of the transport sector will play a key role in achieving India's climate commitments, including those under the Paris Agreement.

Electric vehicles (EVs) are the most important technology for decarbonizing road transport (ICCT, 2020; Sen et al., 2023). The Government of India has been actively promoting EVs, and these vehicles need infrastructure for recharging. Inadequate charging infrastructure is one of the key barriers to the accelerated uptake of EVs in India (Ministry of Power, 2022) and ICCT research has found that even when consumers are inclined to purchase EVs, a lack of infrastructure could potentially hinder progress (Slowik et al., 2019).

The Government of India's flagship EV demand promotion policy, the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme, offered incentives for the development of charging infrastructure, among other support. The second phase of the scheme, FAME II, concluded in March 2024. The third iteration, the Prime Minister Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) scheme, was announced in September 2024 (Ministry of Heavy Industries, 2024b). The scheme was launched on October 1, 2024 and will be in effect until March 31, 2026, with ₹2,000 crore in funding to be allocated for charging infrastructure development, though further details (e.g, on incentive amounts, cost components, and the planned location of charging infrastructure) have yet to be publicized (Ministry of Heavy Industries, 2024d).

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In light of these policy developments, the objectives of this study are to:

1. Examine the performance of the charging infrastructure component of FAME II and assess how charging infrastructure developed under the scheme;
2. Provide an overview of installed charging infrastructure in India, including the number of chargers; and
3. Develop policy considerations for charging infrastructure deployment under the PM E-DRIVE scheme.

After providing background on fund allocation, components, incentives, and fund utilization under the FAME II scheme, we detail the current status of installed charging infrastructure in India. The study next identifies strategies for the development of charging infrastructure for light- and heavy-duty vehicles, explores the potential of battery swapping as an alternative charging solution to wired charging, and considers potential designs of fiscal incentives. The study closes with policy considerations for charging infrastructure development for the PM E-DRIVE scheme.

CHARGING INFRASTRUCTURE INCENTIVES UNDER THE FAME SCHEME

The first phase of the FAME scheme, FAME I, was launched in April 2015 and concluded in March 2019. FAME I had a budget outlay of ₹895 crore, of which ₹43 crore was earmarked for the development of 520 charging stations (Ministry of Heavy Industries, 2023b).[1] FAME II was launched in April 2019 with an initial allocation of ₹10,000 crore for demand incentives, support for charging infrastructure, administrative expenditures, and committed expenditures of FAME I, as presented in Table 1 (Ministry of Heavy Industries, 2019).

Table 1

Components of FAME II and corresponding fund allocation

Component	Earmarked funds (₹ crore)	Share of total earmarked funds
Demand incentives	8,596	85.96%
Public charging infrastructure	1,000	10.00%
Administrative expenditures, including publicity, information, communication, and education activities	38	0.38%
Committed expenditures of FAME I	366	3.66%
Total	**10,000**	**100%**

While FAME II was originally approved to be implemented for 3 years, to conclude in March 2022, it was extended in June 2021 through March 2024 (Ministry of Heavy Industries, 2022b). In February 2024, the scheme's outlay was enhanced from ₹10,000 crore to ₹11,500 crore and the components were restructured (Ministry of Heavy Industries, 2024a). Table 2 presents the updated fund allocations. Notably, charging infrastructure was allocated ₹839 crore after the revision, lower than the initial earmarked amount of ₹1,000 crore, and its share of total funds allocated dropped from 10% to 7% under the updated structure.

1 In this paper, a charging station refers to electric vehicle supply equipment (EVSE). This is the electrical equipment external to the electric vehicle that provides a connection to a power source for charging and is equipped with advanced features like smart metering, cellular capability, and network connectivity. One EVSE can have multiple charger connectors attached to it.

Table 2
Components of FAME II and corresponding fund allocation after February 2024 updates

Component	Earmarked funds (in ₹ crore)	Share of total earmarked funds
Electric two-wheelers	5,311	46%
Electric three-wheelers	987	9%
Electric four-wheelers	750	7%
Total for subsidies	**7,048**	**61%**
Electric buses	3,209	28%
Public charging infrastructure	839	7%
Grants for creation of capital assets	**4,048**	**35%**
Others	404	4%
Total	**11,500**	**100%**

Unlike for electric vehicle purchase subsidies, there was no target for the number of charging stations deployed under FAME II. The scheme offered incentives for developing public and semi-public wired charging stations in cities and on highways and expressways. Proposals were invited through two expressions of interest (EOI). The first, in August 2019, solicited bids for the deployment of wired public charging stations within cities (Ministry of Heavy Industries, 2019b). Entities eligible to avail incentives included urban local bodies, municipal corporations, public sector undertakings, government electricity distribution companies, and similar public or private entities. Charging stations were classified into three categories; depending on the category, up to 50%–100% of the cost of the electric vehicle supply equipment (EVSE) was subsidized. Other costs, including those associated with upstream charging infrastructure, land lease rental, and civil works, were not covered.[2] Table 3 presents the descriptions of these charging station categories and the corresponding incentive available.

Table 3
Categories of charging stations incentivized under FAME II's first expression of interest

Charging station category	Location	Example	Subsidy available
Category A	Public places	Municipal parking lots, fueling stations, streets, malls, market complexes, airports, railway stations, metro stations, bus stops	Up to 70% of the cost of EVSE
Category B	Premises of a state or central government office complex, government educational institution, or any other public office	Udyog Bhavan, Shram Shakti Bhawan, Public Sector Undertaking (PSU) office complexes	Up to 100% of the cost of EVSE
Category C	Semi-restricted premises	Cooperative housing societies or EV charging stations established for taxi aggregators for charging of taxis	Up to 50% of the cost of EVSE

In response to about 106 proposals from public and private entities, in January 2020, 2,636 charging stations were sanctioned to 62 cities (Ministry of Heavy Industries,

2 Upstream charging infrastructure costs are what charge point operators pay to the electricity distribution companies for the setup of distribution transformers, electricity cables, AC distribution boxes, circuit breakers and isolators, protection equipment, and other implements. Civil works refer to the preparation of land for the charging station, such as through trenching and leveling, and any construction work like constructing a platform where the EVSE will be installed.

2020).[3] Of these, 1,633 were fast charging stations and 1,003 were slow charging stations (Ministry of Heavy Industries, 2020). In September 2020, an additional 241 charging stations were approved, bringing the total to 2,877 stations in 68 cities across 25 states and union territories (PTI, 2020; Ministry of Heavy Industries, 2021). All of the subsidies for charging stations sanctioned under this EOI were awarded to 22 public entities (Ministry of Heavy Industries, 2021); no private sector entity was awarded subsidies.

In October 2020, the second EOI was released and invited proposals for the deployment of wired fast charging stations on highways and expressways (Department of Heavy Industry & Ministry of Heavy Industries and Public Enterprises, 2020). A total of 25 corridors were identified for the deployment, and proposals were solicited from government organizations, public sector undertakings, government electricity distribution companies, oil public sector undertakings, and similar public or private entities. A maximum 70% of the cost of the EVSE was subsidized under this EOI. Other costs, such as those pertaining to upstream charging infrastructure, land lease cost, and civil works, were not covered. In all, 1,576 charging stations across 16 highways and 9 nine expressways were approved for incentives under the EOI (Ministry of Heavy Industries, 2022a). All of the subsidies for the sanctioned charging stations were awarded to three public entities (Ministry of Heavy Industries, 2022a).

In March 2023, ₹800 crore in subsidies were sanctioned for three PSUs—Indian Oil, Bharat Petroleum, and Hindustan Petroleum, all oil marketing companies (OMCs)—to set up 7,432 wired public fast charging stations across the country (Ministry of Heavy Industries, 2023a). The sanctioned amount would subsidize 70% of the cost of the EVSE and up to 80% of the cost of upstream charging infrastructure. Of the 7,432 charging stations sanctioned, 5,662 chargers were of 50–60 kW capacity and the remaining 1,770 were of 100–120 kW capacity. Offering incentives to OMCs was aimed at overcoming the challenge of ensuring sufficient land for charging infrastructure, as these firms were expected to have adequate space on the premises of their retail outlets.

A summary of the three funding tranches under FAME II is presented in Table 4.

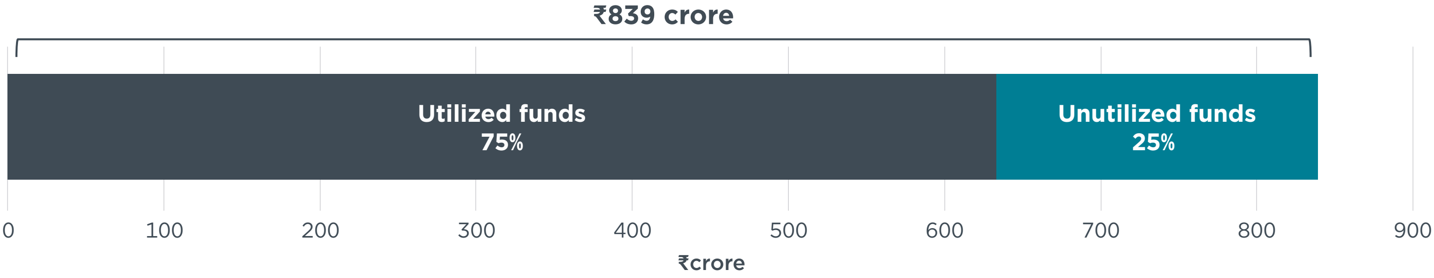
Table 4
Funding tranches for charging infrastructure development under FAME II

Tranche	Number of charging stations sanctioned	Number and type of awardees
1	2,877	22 public sector entities
2	1,576	3 public sector entities
3	7,432	3 public sector undertakings, all oil marketing companies

Figure 1 presents the fund utilization for charging infrastructure under FAME II. Of the ₹893 crore allocated for charging infrastructure, ₹633 crore (75%) were utilized by the end of the scheme (Ministry of Heavy Industries, 2024c). Entities that were awarded funds under FAME II explained that the underutilization was due to difficulties with approvals for electricity connections and related issues, lack of coordination with power distribution companies, rejection of applications seeking electricity connections, space constraints, and safety concerns regarding setting up charging infrastructure at fueling stations.

3 The sanctioned amount refers to funds earmarked for the development of charging stations. This is different from the actual funds utilized, which is the spending ultimately undertaken or funds used from this sanctioned amount.

Figure 1
FAME II charging infrastructure fund utilization



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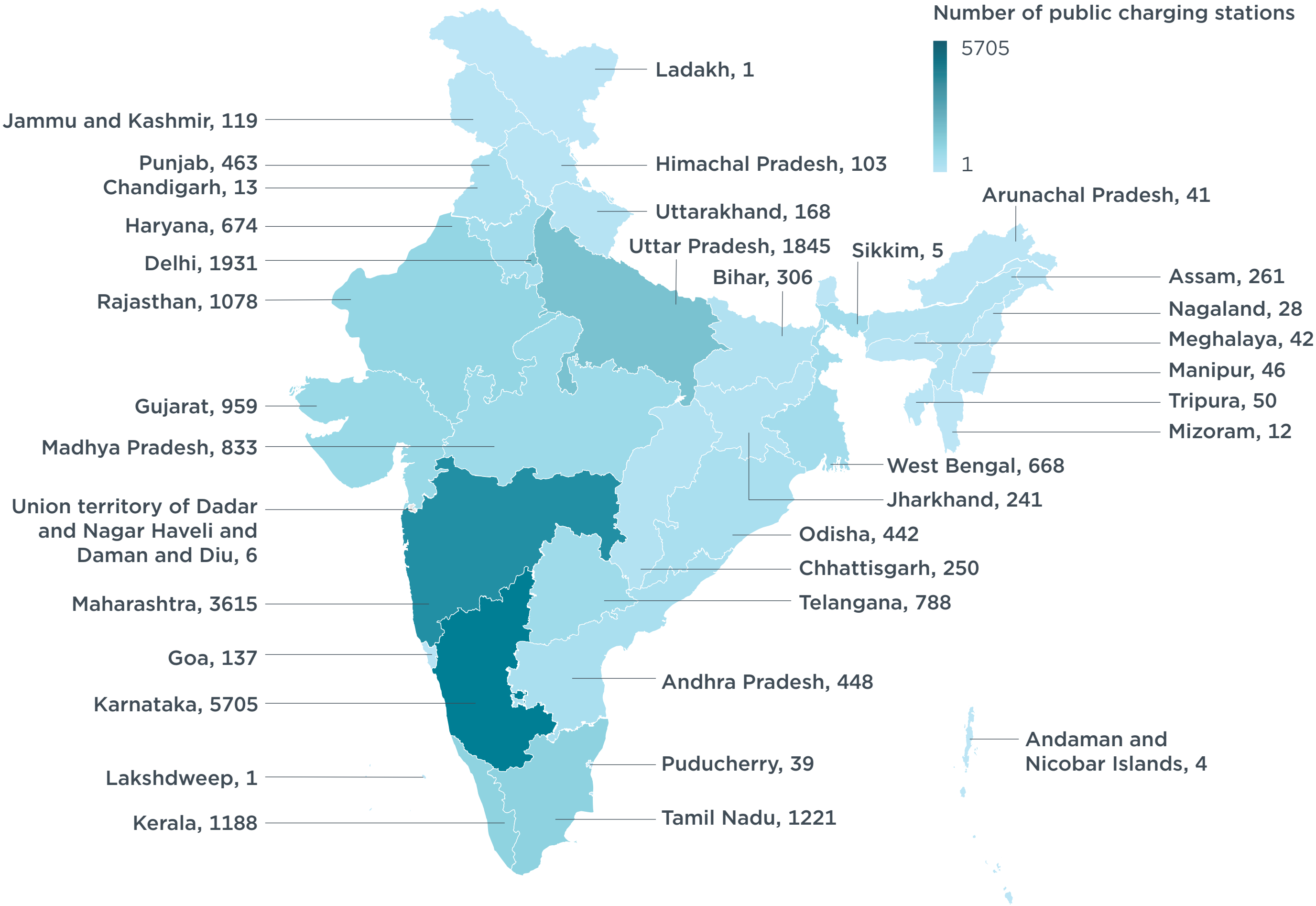
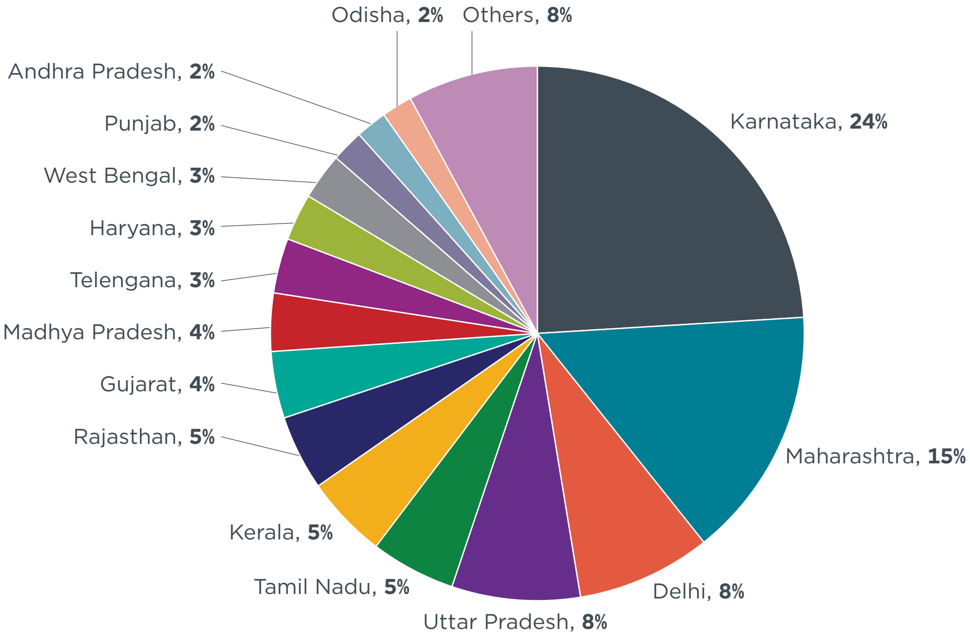
CURRENT STATE OF PUBLIC CHARGING INFRASTRUCTURE IN INDIA

As of June 2024, there were 23,731 wired public charging stations in India (Bureau of Energy Efficiency, n.d.). The top chart in Figure 2 presents the number of wired public charging stations by state and the bottom chart presents the share of charging stations by state. Karnataka had the most public charging stations, at 5,705, including 624 from the FAME II scheme; the state is home to 24% of all public charging stations in the country. Maharashtra had the second highest number of public charging stations (3,615, including 978 from FAME II) and was home to 15% of the country-wide total. This was followed by Delhi with 1,931 charging stations (8% of the national total), of which 184 were established under FAME II; Uttar Pradesh with 1,845 charging stations (8% of the national total), with 737 established under FAME II; and Tamil Nadu with 1,221 charging stations (5% of the national total), 944 under FAME II. Together, these five states represented 60% of the public charging stations in the country as of June 2024. These states also accounted for approximately half of all EV registrations across all segments in the country in FY 2023–24 (Ministry of Road Transport & Highways [MoRTH], 2024).

Figure 2

Number of wired public charging stations (top) and share of wired public charging stations (bottom) by state and union territory





Note: This map is presented without prejudice to the status of or sovereignty over any territory, the delimitation of international frontiers and boundaries, and the name of any territory, city, or area.

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India had approximately 45 lakh cumulative EV registrations by the end of June 2024 (MoRTH, 2024). There was one public charging station per 191 EVs, less than one charging station per square kilometer, and about two charging stations per 1 lakh people (Government of India, 2024).

CHARGING INFRASTRUCTURE FOR LIGHT-DUTY VEHICLES

In this paper, light-duty vehicles (LDVs) encompass two-wheelers and passenger cars.[4] We focus on personal-use two-wheelers, which accounted for approximately 100% of new two-wheeler sales in the country in FY 2023–24, and personal-use passenger cars, which accounted for 93% of new passenger car sales the same year (MoRTH, 2024).

Previous ICCT research projected that the majority of India's charging needs for LDVs will be met by residential chargers (Rajon Bernard et al., 2022a).[5] Residential charging offers the convenience of charging without leaving home and is often cheaper than public charging (Gupta, 2023; Rokadiya, 2021). In India, major urban hubs have been leading the transition to electric mobility (Firstpost, 2024; Reddy, 2022). We focus our LDV analysis on the development of residential charging infrastructure within cities and not on other charging solutions such as workplace and highway charging.

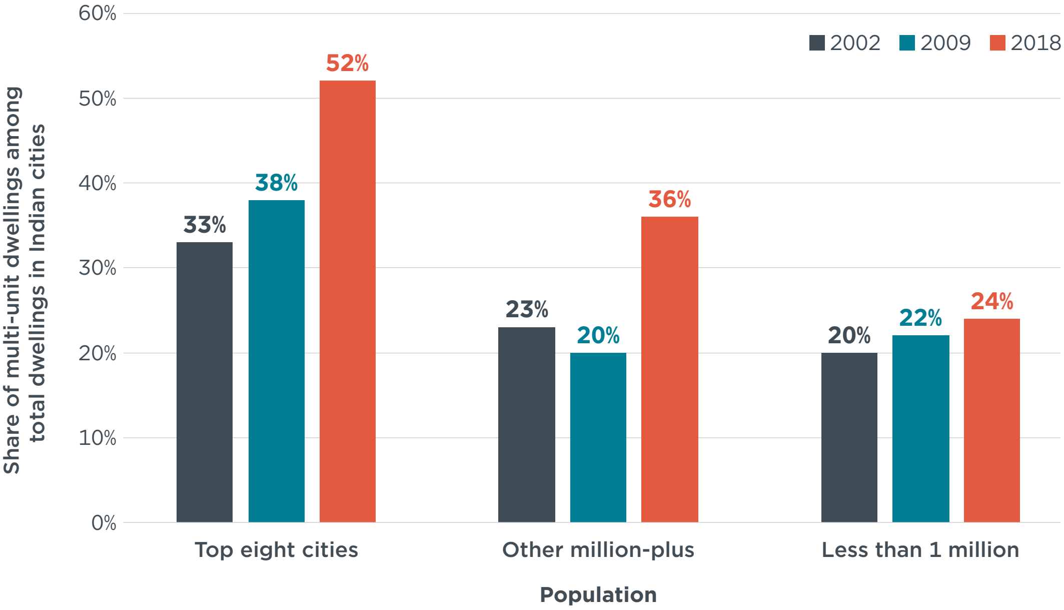
Housing trends in Indian cities indicate that the share of multi-unit dwellings (MUDs) as a proportion of total dwelling units has been rising (Sai, 2020). MUDs are residential structures that contain multiple housing units within one building or within multiple buildings located in a shared complex. Flats (apartments) are a common type of MUD in India. Figure 3 presents the share of MUDs to total dwellings in Indian cities in 2002, 2009, and 2018. In India's eight most populous cities—Delhi, Greater Mumbai, Kolkata, Chennai, Bengaluru, Greater Hyderabad, Ahmedabad, and Pune—the share of MUDs increased from 33% in 2002 to 38% in 2009 and 52% in 2018. In other cities with populations over 1 million, the share was 23% in 2002 and dropped slightly to 20% in 2009 before rising to 36% in 2018. A similar trend was observed in cities with populations of less than 1 million, where MUDs comprised 20% of total dwellings in 2002, 22% in 2009, and 24% in 2018 (Sai, 2020). Thus while the share of MUDs has been increasing across Indian cities generally, the trend has been pronounced in the eight most populous cities.

4 In FY 2023–24, two-wheelers and passenger cars accounted for 74% and 19% of new vehicle sales in India, respectively; three-wheelers accounted for just 3% of new vehicle sales that year and thus are not a focus of this paper (Society of Indian Automobile Manufacturers [SIAM], 2024b).

5 For this paper, residential chargers include both home chargers installed in independent single-family houses and home chargers installed in apartment complexes and multi-unit dwellings.

Figure 3

Share of multi-unit dwellings among total dwellings in Indian cities in 2002, 2009, and 2018



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Given these trends, prioritizing the deployment of chargers in MUDs in cities can help enhance access to charging infrastructure for a significant share of the urban population. Moreover, unlike chargers in single-family homes—which are generally used by only one household—chargers in MUDs can potentially be shared by multiple households, which can lead to higher utilization and higher returns for the charge point operator.

Previous ICCT research found that costs to install chargers at MUDs in the United States are 3 to 5 times higher than at single-family homes (Pierce & Bui, 2024). One reason is that MUD parking lots might require trenching through asphalt and concrete, which are common in MUDs. The study also found that costs are even higher when chargers are installed incrementally, rather than all at once. To lower costs, therefore, government incentives could be structured in a way that facilitates simultaneous electrification of all MUD parking spots.

The next section presents examples from other countries of policies to enhance charging access in MUDs. All of these policies are designed to facilitate the simultaneous (rather than incremental) installation of chargers in MUD parking lots.

EXAMPLES FROM OUTSIDE INDIA OF INCENTIVE PROGRAMS FOR CHARGING IN MULTI-UNIT DWELLINGS

Leading EV markets across the globe have offered incentives for the development of charging infrastructure in MUDs. In the United States, for instance, the state of Massachusetts' MassEVIP Multi-Unit Dwelling and Educational Campus Charging program offers incentives to MUD property owners and managers, rather than to individual residents, to purchase and install chargers in MUDs with five or more residential units (Commonwealth of Massachusetts, 2024). In France, public-private partnerships have been leveraged: Logivolt, a start-up specializing in charging infrastructure deployment in MUDs, pre-equips 100% of parking spaces in a MUD with cable trays, ducts, and other electrical equipment, and residents who wish to use a charging station pay a connection fee. This arrangement is facilitated through a loan to Logivolt from Caisse des Dépôts, a French public financial institution. Over time, the loan is reimbursed to Logivolt by the residents through billing and subscription fees. Logivolt remains the owner of the electrical installation until the end of the contract or until it is purchased by the building owner (Logivolt, n.d.). Logivolt also seeks out and applies for available incentives, which helps lower costs for participating residents.

Power utilities can also bear the upfront cost of developing charging infrastructure in MUDs. In France, a national decree authorizes the utility company Enedis to pre-finance EV-ready electrical infrastructure in MUDs. Enedis then recovers the investment by levying a fee, which is subsidized by the utility, to EV owners who wish to install a charger at their parking spot. Fees are the same for all residents of the same building, and minimum and maximum fees are set to keep the program affordable (French Energy Regulatory Commission, 2023).

For MUDs that lack dedicated parking, residents must park their cars on nearby streets or in public parking spaces. Additionally, even if dedicated parking is available, the MUD might not have the necessary electrical infrastructure available to set up charging infrastructure. Significant upgrades of the building's electrical infrastructure might be required, which could considerably escalate the cost of setting up charging infrastructure.

For residents who lack access to residential charging, the development of overnight curbside charging stations, also known as on-street charging, near MUDs is one policy option. Many governments have used public land to provide access to shared overnight charging infrastructure to those who do not have access to residential charging. Certain cities in Europe, for instance, have facilitated the deployment of overnight on-street charging infrastructure and community charging hubs through the provision of fiscal incentives.

The UK government's On-Street Residential Chargepoint Scheme (ORCS) provides grants to local government authorities for the installation of on-street residential chargers. Under the most recent terms of the program, funding of up to 50% of the capital cost was offered, with total funding not exceeding £7,500 per charge point and the total grant capped at £200,000 (Office for Zero Emission Vehicles, 2023b). To avail the grants, the charge points should be located in residential areas that lack private parking spaces. More than 6,000 charge points had been delivered under the scheme by September 2023 (Tankou et al., 2023).

Additionally, the UK government has earmarked £381 million under the Local Electric Vehicle Infrastructure (LEVI) Fund to support local authorities in England to plan and deliver charging infrastructure for residents without access to private residential parking (Department of Transport et al., 2024). The funds are for two components: capital for primarily low-power on-street charging infrastructure and staff capacity building to plan and deliver charging infrastructure (Office for Zero Emission Vehicles, 2023a). As of February 2024, over £185 million in funding had been approved for local authorities (Department of Transport et al., 2024).

Canada's Zero Emission Vehicle Infrastructure Program offers funding of up to C$5,000,000 per project for the deployment of charging infrastructure. The development of community public EV charging infrastructure and private EV charging infrastructure in existing multi-unit residential building is also funded under the scheme (Government of Canada, n.d.). Meanwhile, the government of New South Wales in Australia is investing $10 million to install curbside EV chargers in areas with the least access to private, off-street parking, with funding of up to A$800,000 per applicant (NSW Climate and Energy Action, 2024).

In Baden-Württemberg, Germany, funding has been made available for the development of E-Quartierhubs: off-street shared parking spaces equipped with charging infrastructure for electric vehicles available for long- and short-term parking by residents of nearby residential units, taxis, and rental cars (Ministerium für Verkehr Baden-Württemberg, 2023). Only projects that would reduce on-street parking and free up streets for public transport, cycling, pedestrians, and recreational activities are eligible for support. Funding under the program is offered to entities involved in the construction and operation of the E-Quartierhubs, and the application for funding must be submitted in cooperation with a municipality to ensure the recalibration of parking spaces and freeing up of public streets. Funding under the initiative can cover up to 75% of eligible costs (Ministerium für Verkehr Baden-Württemberg, 2023). If E-Quartierhubs are established near MUDs, this initiative can also be part of a solution to enable charging for MUD residents who lack residential charging access.

CHARGING INFRASTRUCTURE FOR MEDIUM- AND HEAVY-DUTY VEHICLES

In this paper, medium- and heavy-duty vehicles (MHDVs) includes all buses and medium- and heavy-duty trucks (MHDTs). For the truck segment, we focus our analysis on MHDTs because these account for 97% of road freight movement (light-duty trucks make up the balance; NITI Aayog & RMI, 2022). The deployment of electric MHDTs is at a nascent stage in India. In the bus segment, EVs accounted for 4% of new vehicle sales in FY 2023–24 (MoRTH, 2024), while in the truck segment, EV sales were less than 1% the same year.

Despite low uptake to date, MHDV adoption in India is expected to ramp up in the coming years. For India to fulfill its commitment to reducing its emissions in line with limiting global warming to below 2 °C, it will have to achieve 100% zero-emission bus sales by 2040 and 100% zero-emission truck sales by 2045 (Sen & Miller, 2023). Furthermore, for India to meet its target of net-zero emissions by 2070, 100% zero-emission truck sales will have to be achieved by no later than 2050 (Singh & Yadav, 2024).

The charging needs of HDVs can be met with different types of charging infrastructure depending on the daily vehicle kilometers traveled, type of operations, and idle time between operations. Specifically, three types of direct current (DC) chargers are used for HDVs: overnight chargers, opportunity fast chargers, and opportunity ultrafast chargers. Overnight chargers have a power output ranging from 50–150 kW; Combined Charging System (CCS) and CHAdeMO are the typical charging standards used for this type of charging. The chargers are usually located at truck and bus depots, truck logistic hubs, and captive parking spaces of operators, and can also be located at highway rest areas.

Opportunity fast chargers have a power output ranging from 150–350 kW; CCS and CHAdeMO are the charging standards used. These chargers are typically located at public parking spaces, along highways, and at depots, freight facilities, and goods hubs where loading and unloading of trucks takes place. Opportunity ultrafast chargers, for their part, have a power output of 750 kW and higher. Estimated charging time can range from a few minutes to 30 minutes. Similar to opportunity fast chargers, these chargers can be located at public parking spaces, along highways, and in some cases at depots. Higher power standards are currently being developed and tested across the globe. In 2023, China approved the ChaoJi-1 charging standard, which supports a charging power of up to 1.2 MW (Storch, 2023). The new Megawatt Charging System for the European and North American markets could deliver a power output of up to 3.75 MW (Rajon Bernard et al., 2022b). A summary of these chargers and their characteristics is presented in Table 5.

Table 5

Types of chargers for heavy-duty vehicles

Charger type	Power output	Charging standard	Location
Overnight charger	50–150 kW	CCS and CHAdeMO	Truck and bus depots, logistic hubs, and captive parking spaces
Opportunity fast charger	150–350 kW	CCS and CHAdeMO	Public parking spaces, along highways, at bus and truck depots
Opportunity ultrafast charger	750 kW and higher	ChaoJi-1 and Megawatt Charging System	Public parking spaces, highways and expressways, and bus and truck depots

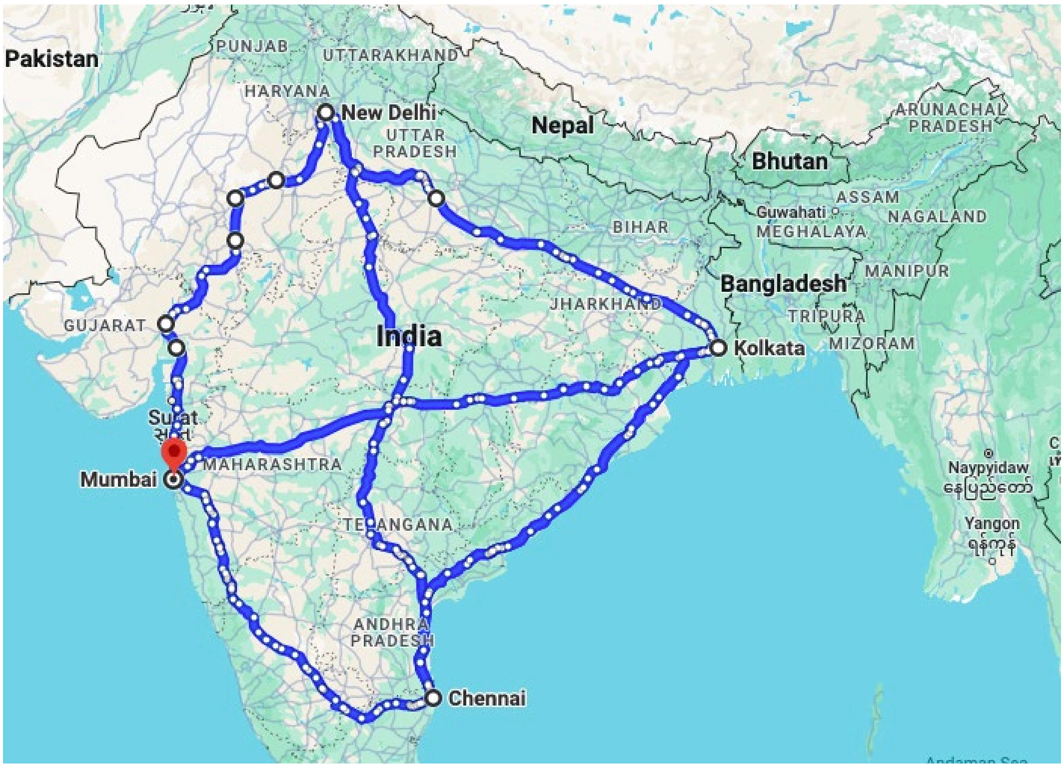
A previous ICCT analysis projected that India will have 700,000 electric HDVs by 2030, and that these would require 510,000 chargers (Rajon Bernard et al., 2022a). The same study projected that while the majority of charging needs of HDVs will be met by overnight charging, a combination of chargers will be needed. Overnight chargers are cost-effective due to their lower hardware cost and the lower cost of electricity due to charging during off-peak hours. Trucks and buses that return to base after their daily run, such as those deployed in urban and regional operations, will most likely rely on overnight charging. These vehicles are also expected to have uniform daily travel distances, predictable passenger or goods payloads, adequate duty cycles, and significant idle time between operations, making them well suited for early electrification among vehicles in the HDV segment. Overnight chargers could be deployed at logistic hubs, bus transit hubs, and truck and bus depots located in urban nodes of high traffic logistic and bus corridors.

Opportunity fast chargers and ultrafast chargers will also be needed to meet the top-up charging needs of HDVs traveling long distances that are not able to complete their daily operational run on a single full charge. These chargers will also be needed to address range anxiety and instill confidence in the operation of electric HDVs. Opportunity fast chargers and ultrafast chargers could be deployed along expressways and highways.

In the early stages of HDV electrification, charging infrastructure could be developed along high-volume highway corridors and major urban nodes along these corridors. Development of charging infrastructure in such areas could lead to high charger utilization, enhancing cost effectiveness. To cater to the varying charging needs of HDVs, overnight chargers could be deployed at bus or truck depots within the urban nodes and opportunity fast and ultrafast chargers could be deployed along the highways connecting them.

The Golden Quadrilateral highway corridor of India connects the four major metropolitan cities of New Delhi, Kolkata, Chennai, and Mumbai (Figure 4). The corridor comprises four primary sections (New Delhi—Kolkata, Kolkata—Chennai, Chennai—Mumbai, and Mumbai—Delhi), while two diagonal highways, known as the Golden Diagonals, connect New Delhi to Chennai and Mumbai to Kolkata. Several economic, industrial, agricultural, and cultural hubs fall along this corridor. These highways comprise 0.5% of India's road network, but carry approximately 40% of the country's road freight (Dedicated Freight Corridor Corporation of India Limited, 2022). Further, most of the high-demand routes for intercity bus travel correspond to these highway networks: A recent study found that 10 of the 17 cities in India with the highest demand for intercity bus services were within the Golden Quadrilateral, and that these 10 accounted for 79% of trips originating from the surveyed cities (Gadepalli et al., 2024). Furthermore, of the top destinations for intercity bus travel among the 17 cities identified, 51% of the bus services terminated in cities falling along the Golden Quadrilateral.

Figure 4
Golden Quadrilateral and Golden Diagonal highway corridor



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Governments of countries leading in the EV transition are prioritizing the development of charging infrastructure for MHDVs along major freight routes. In March 2024, for instance, the United States released the *National Zero-Emission Freight Corridor Strategy*, which seeks to encourage investment, planning, and deployment of fueling infrastructure to accelerate the adoption of zero-emission freight vehicles and offers related guidance to federal grant programs. The initiative prioritizes the development of zero-emission truck fueling infrastructure, including charging stations in major freight hubs and along heavily used freight corridors by volume (Joint Office of Energy and Transportation, 2024).

In 2023, Enova SF, a Norwegian state enterprise that promotes the decarbonization of the energy sector, launched a funding program to support the establishment of charging infrastructure for electric heavy-duty commercial vehicles. Under this program, Enova identified four corridors with high volumes of heavy goods vehicle movement. The program offers financial support of up to 80% of the approved costs of the charging hub, limited to NOK 10 million (Manthey, 2023; Randall, 2023). Meanwhile, under the Regional Electrification Pilots for Heavy Transport framework, the Swedish Energy Agency has collaborated with Circle K, a private sector entity, to finance the development of HDV chargers positioned along key transit routes across the country (Hughes, 2023).

ZEVWISE, a global coalition of governments, international governmental organizations, development finance institutions, and nonprofit organizations, aims to deploy zero-emission MHDVs and develop publicly available charging infrastructure for these vehicles along key corridors by 2026. The initiative spans different countries and prioritizes road corridors with high traffic volumes that link vital global industrial hubs, ports, and cities. In all, 10 corridors are to be developed under this initiative (Drive to Zero, 2024).

BATTERY SWAPPING

Battery swapping is a solution to the recharging needs of EVs with a detachable battery. When a detachable battery runs out of charge, the user can visit a battery-swapping station and replace their discharged battery with a fully charged one within minutes. The batteries are owned, maintained, and charged by the battery-swapping operator and the vehicle user pays a fee to the operator for these services. Battery swapping has the potential to offer key advantages (Gode et al., 2022):

- **Reduced upfront cost of the battery electric vehicle (BEV).** The battery accounts for about 40% of the cost of a BEV (Rao, 2024). Under a battery-as-a-service (BaaS) business model, swap-capable BEVs are sold without the battery, and this brings their upfront cost down substantially.
- **Reduced charging downtime.** Swapping a depleted battery with a fully charged one typically takes about 2 minutes for an electric two- or three-wheeler (ETEnergyWorld, 2024). For BEV buses, the time is about 3–4 minutes (India Energy Storage Alliance, 2019). Based on the experience of China, battery swapping takes about 3 minutes for BEV cars and 3–6 minutes for BEV trucks (Cheng, 2024; Cui et al., 2023).
- **Small real estate footprint.** A battery-swap station can cater to the recharging needs of multiple BEVs at a time within a relatively small geographic area. These stations can also serve as a potential solution in locations with dense vehicular traffic and limited availability of land for setting up adequate charging stations.
- **Grid load management.** Battery-swapping operators can charge during off-peak hours; this allows them to leverage lower electricity prices and avoids stressing the grid. Furthermore, when operating under conditions of bidirectional power supply, battery-swapping stations can send electricity stored in the batteries back to the grid during the time of day when demand for battery swapping is low, further easing the load on the grid.
- **Battery health management.** In battery-swapping kiosks, batteries are charged in temperature-controlled environments and use slow charging. This lowers energy loss and prolongs the life of the battery.

While battery swapping offers many advantages, there are also hurdles. First, due to a lack of BEV battery standardization, batteries vary in shape, size, and their location in the vehicle. This limits the interoperability of batteries in the swap ecosystem. Second, the cost to develop a battery-swapping station is high due to significant initial investment needed for battery inventory and associated infrastructure (Pulse Energy, 2024). Studies have found that battery inventory accounts for as much as half of the cost of setting up a swapping station, while equipment, cables, and transformers make up the balance (Cui et al., 2023). There were about 2,500 battery-swapping stations in India as of March 2024, and these primarily cater to the recharging needs of two- and three-wheelers (Harel Mitra Chenoy et al., 2024). Under the FAME scheme, only wired charging stations were incentivized.

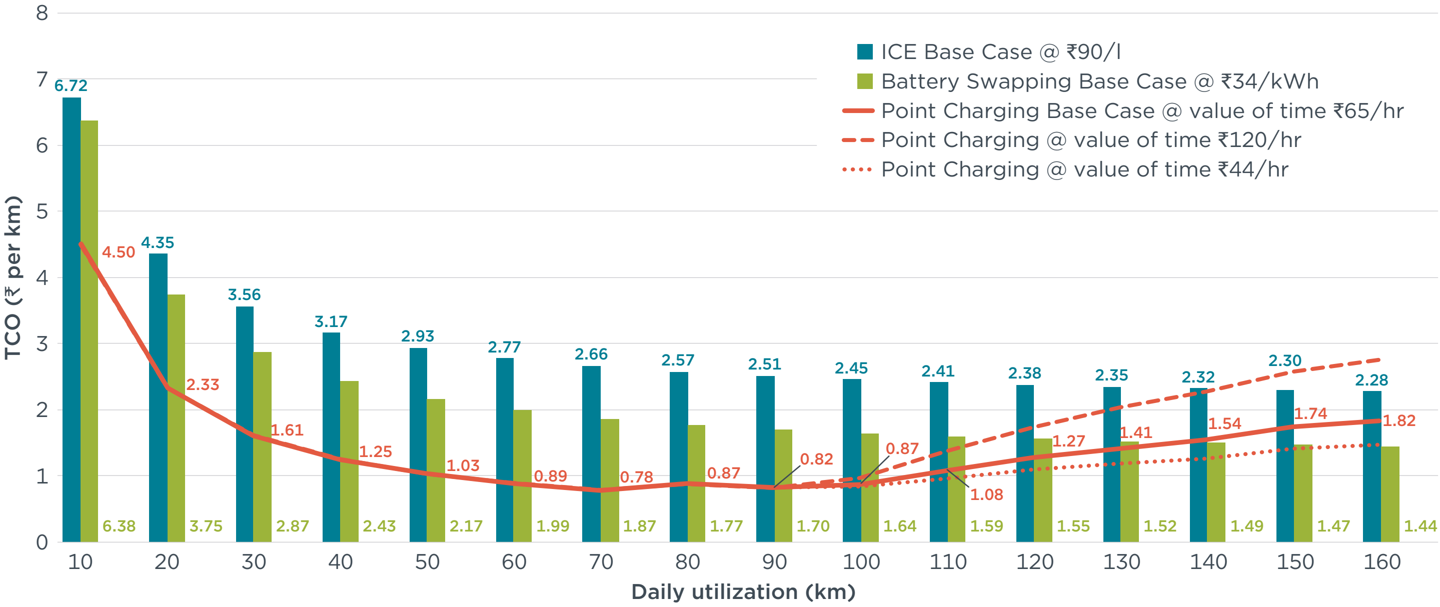
The following sub-sections discuss the advantages that battery swapping could offer for the two-wheeler, three-wheeler, truck, and bus segments in specific use cases. While battery-swapping technology has been developed for all vehicle segments, it is easier to implement in the two-wheeler and three-wheeler segments owning to the smaller battery size and lower battery weight than trucks and buses.

ELECTRIC TWO-WHEELERS

As shown in Figure 5, past ICCT research has assessed that for electric two-wheelers (E2Ws), battery swapping is more economical than using point charging or using a gasoline two-wheeler when daily utilization levels are high (Gode et al., 2022). The 5-year total cost of ownership (TCO) analysis for E2Ws under daily utilization levels ranging from 10–160 km found that at a utilization level of 140 km/day, battery swapping was the most economical option. Such high levels of daily utilization are observed in commercial two-wheeler use cases such as last-mile delivery and ride-hailing operations. The gasoline two-wheeler was the most expensive at all utilization levels considered.

Figure 5

Five-year total cost of ownership of two-wheelers using point charging, battery swapping, and gasoline with daily utilization ranging from 10 km to 160 km



Source: Gode et al. (2022)

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PASSENGER ELECTRIC THREE-WHEELERS

A 2023 study estimated that the average time required to charge a passenger three-wheeler[6] is about 4 hours, and this impacts the number of passenger trips the driver can undertake in a given day (Nimesh et al., 2023). This high charging downtime lowers the earning potential of the passenger electric three-wheeler (E3W) driver.

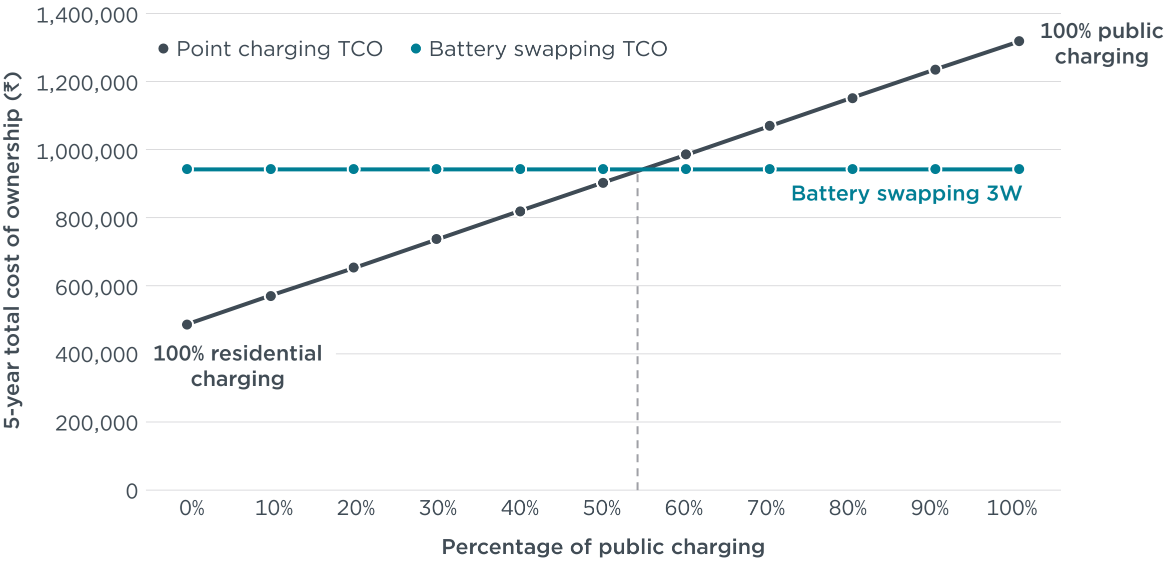
Figure 6 compares the 5-year TCO of representative passenger E3W models using battery swapping or a combination of public and residential charging. For the analysis, we use a daily vehicle utilization of 141 km (Nimesh et al., 2023). Assuming the driver takes 1 day off per week, the number of operational days in a year is considered to be 313. Details on vehicle models, cost components, and assumptions are included in the appendix. The x-axis of Figure 6 represents the share of public charging in the total charging needs of the E3W, with the rest being met by residential charging. When most of the charging is done through residential charging, point charging is the most economical method. However, battery swapping is more economical for a passenger

6 This corresponds to the L5M vehicle category under Central Motor Vehicles Rules, 1989, defined as a three-wheeler on account of its technical features intended to carry passengers.

E3W when reliance on public charging is greater than 55% of total energy needs. As noted earlier, public charging is generally more expensive than residential charging. Further, there is an opportunity cost associated with point charging: the loss of earnings to the E3W driver due to the time spent at the public charging station, which was considered be ₹99 per hour for this analysis (Nimesh et al., 2023). In contrast, battery swapping offers savings in opportunity cost, as a depleted battery can be replaced with a fully charged one within minutes.

Figure 6

Five-year total cost of ownership of a passenger electric three-wheeler using a combination of residential charging and public charging versus battery swapping



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It can thus be inferred that residential charging offers the most attractive TCO for the passenger E3W. However, studies have found that for a vast share of passenger E3W drivers, access to residential charging is a challenge due to a lack of dedicated parking spaces (Roychowdhury & Roy, 2022; Roychowdhury et al., 2023). Additionally, drivers who have access to dedicated parking spaces may not have access to the required electricity connections, electric equipment, and other infrastructure at their home required for setting up residential charging. These factors increase the reliance of passenger E3Ws on public charging, which escalates the TCO. Hence, in cases where there is a lack of access to residential charging and a significant reliance on public charging, battery swapping is the most economical charging option.

TRUCKS AND BUSES

The high upfront cost of battery electric buses and battery electric trucks is a major challenge to their uptake. For electric buses, the purchase cost is 2–4 times higher than that of conventional buses (Convergence Energy Services Limited, 2022). The upfront cost of electric trucks is about 3.5 to 4.5 times higher than conventional trucks (Kaur & Narla, 2023).

Batteries account for about 40% of the cost of electric buses and electric trucks (Melissa, 2023; Kaur et al., 2024). Using battery swapping for BEVs in these segments can significantly lower the upfront cost of the vehicle and enhance their cost competitiveness with conventional vehicles. Point charging for trucks and buses takes several hours using a slow charger and about 40 minutes using a DC fast charger. In comparison, battery swapping takes only about 3–6 minutes (India Energy Storage

Alliance, 2019; Cui et al., 2023). Thus, battery swapping can significantly reduce the charging downtime of electric trucks and buses and allow these vehicles to operate for longer, potentially generating greater profits.

China, the world's largest market for electric trucks and buses, has been exploring battery swapping technology since 2020 (Cui et al., 2023). Swap-capable trucks are mainly being used for short-haul applications at ports, mining sites, and in urban logistics. In 2021, the national government launched a 2-year pilot program to promote battery swapping, with an aim to deploy at least 100,000 swap-capable vehicles and develop at least 1,000 battery-swapping stations (Ministry of Industry and Information Technology, Government of China, n.d.). Eleven cities were selected for the pilot, of which three would focus solely on battery-swapping truck applications and the other eight would focus on battery swapping for both electric cars and trucks.

Chinese provinces and cities have also been exploring battery swapping for electric trucks and buses. The province of Hainan, for instance, offered a subsidy of 15% of the total construction cost of battery-swapping stations from January 2021 to December 2022 (The People's Government of Hainan Province, 2021). The city of Qingdao adopted the "vehicle body-battery separation" model, wherein the municipal government purchases electric buses without batteries and delivers them to the bus operator (United Nations Economic and Social Commission for Asia and the Pacific, 2023). The Qingdao Electric Power Company purchases batteries from the battery manufacturers and leases them to bus operators, while construction of battery-swapping stations is mainly funded by the State Grid Corporation of China. In 2022, 49.5% of electric trucks sold in China were swap-capable (Sealand Securities, 2023).

FAME II did not offer incentives for battery swapping. As these use case analyses suggest, battery swapping could potentially help in overcoming charging-related challenges in certain segments and applications. As charging infrastructure technology continues to evolve, creating a level playing field for all charging solutions is important. Technology-neutral incentives that apply to all types of charging, including wired charging and battery swapping, could thus be part of an effective policy mix to support EV uptake. Finally, it could be left to the market to determine which charging solutions work best for specific EV use cases and applications. For instance, in China's city of Shanghai, a subsidy of 30% is offered for the construction of both wired charging stations and battery-swapping stations. In the city of Hangzhou, a subsidy of 30% of the actual investment amount was offered to public and shared wired charging stations and battery-swapping stations (Yue et al., 2021).

ADDITIONAL CONSIDERATIONS FOR THE DESIGN OF FISCAL INCENTIVES

Over the last few months, the ICCT conducted interviews with charging infrastructure providers, including charge point operators and battery-swapping operators, to learn about challenges in the development of charging infrastructure. We used the information gathered to develop considerations for the design of fiscal incentives in the PM E-DRIVE scheme.

FAME II subsidized up to 50%–100% of the cost of an EVSE, depending on the type of charging station. Apart from the EVSE, charging infrastructure entails several other costs pertaining to upstream charging infrastructure, land lease costs, civil works, manpower, marketing and promotion, and software.[7] The interviews revealed that

7 Manpower costs include compensation paid to construction workers, electricians, and technicians for the installation, repair, and maintenance of the EVSE.

the high cost of upstream charging infrastructure and land lease rental were major challenges faced in the development and expansion of charging infrastructure.

An electric mobility pilot by the Ola Mobility Institute in Nagpur found that the land lease rental was the largest operating cost component of the charging station, accounting for 31%–43% of the overall operating cost (Arora & Raman, 2019). The pilot also showed that the high land lease rental cost was one of the factors adversely affecting the economic viability of the project and discouraging the scaling up of operations.

Another study by RMI India found that for the deployment of charging stations in Delhi by Energy Efficiency Services Limited (EESL), a public sector undertaking, land cost was the largest cost component (Fitzgerald & Ningthoujam, 2019). According to the Ministry of Heavy Industries, upstream charging infrastructure accounts for up to 60% of the overall cost of setting up a public charging station.

Both charge point operators and battery-swapping operators expressed an interest in having the government support costs pertaining to upstream charging infrastructure and land. If expansion of charging infrastructure is a government objective, incentives could be designed to subsidize the cost of upstream charging infrastructure and land to facilitate the economic viability of charging infrastructure projects.

CONCLUSIONS AND POLICY CONSIDERATIONS

The need for more charging infrastructure is one of the major barriers to widespread adoption of EVs. This study examined the charging infrastructure component of the FAME II scheme, offered an overview of the current state of charging infrastructure availability in India, and described possible areas that could be supported under PM E-DRIVE.

Of the ₹839 crore allocated for charging infrastructure development under the revised outlay for FAME II, 75% was utilized by the end of the scheme. As policymakers iron out the details of the PM E-DRIVE scheme, continued fiscal support aimed at rapid development of a robust charging infrastructure network could be part of an effective policy toolkit to help accelerate EV adoption across various vehicle segments. This analysis supports several policy considerations as presented in Table 6.

Table 6
Charging infrastructure policy considerations for the PM E-DRIVE scheme

Focus areas	Policy considerations
Light-duty vehicles (two-wheelers and passenger cars)	• Prioritize the development of charging infrastructure in multi-dwelling units in major urban hubs
	• For EV users without access to overnight residential charging, develop curbside charging facilities or shared overnight charging facilities in nearby public parking spaces
Medium- and heavy-duty vehicles (trucks and buses)	• Consider prioritizing the development of HDV DC fast chargers on the Golden Quadrilateral highway corridor
	• Consider developing overnight HDV charging infrastructure in major urban nodes on the Golden Quadrilateral highway corridor
Battery swapping	• Technology-neutral incentives that apply to all charging solutions, including wired charging and battery swapping, could be offered to create a level playing field among various charging solutions
Fiscal incentives design	• Incentives could be designed to subsidize the cost of upstream charging infrastructure and land to facilitate the economic viability of charging infrastructure projects

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APPENDIX

Table A1

Fixed battery electric passenger three-wheeler and swappable battery electric passenger three-wheeler costs

TCO factors		Passenger three-wheelers		Notes/sources
		Electric, fixed battery	Electric, swappable battery	
		Piaggio Ape E-city 8 kWh	Piaggio APE E-City 4.5 kWh	
Taxes and fees	GST rate	5%	5%	SIAM (2024a)
	Registration fee	—	—	Several states in India have waived the registration fee for electric vehicles.
	Road tax	—	—	Several states in India have waived the road tax for electric vehicles. For conventional passenger three-wheelers, a road tax of ₹305 per year is considered (Transport Department, Government of NCT of Delhi, 2023).
	Permit fee	0	0	Several states in India have waived the permit fee for electric vehicles (Acko, 2024).
	Other state taxes (municipal tax/ parking fee)	₹2,000	₹2,000	—
Vehicle utilization	Vehicle life	10 years	10 years	—
	Vehicle first ownership period	5 years	5 years	—
	Daily vehicle kilometers traveled	141 km	141 km	Nimesh et al. (2023)
	Annual operational days	313 days	313 days	Considering 365 days in a year and 1 non-operational day per week.
Charging cost	Residential electricity rate	₹6.5/kWh	—	Energy consumption slab of 401–800 units was considered for the state of Delhi (Delhi Capital, n.d.).
	Annual escalation in residential electricity rate	5%	—	—
	Public charging rate	₹15/kWh	—	Switch Delhi (2024)
	Annual escalation on public charging rate	5%	—	—
	Real-world energy consumption adjustment factor	25%	25%	It was assumed that real-world range/mileage is 25% lower than the certified value.
	Cost of battery swapping (per kWh)	—	₹45	—
	Annual escalation in battery swapping rate	—	-8%	Goldman Sachs (2023)
Earnings	Earnings per hour	₹99	₹99	Nimesh et al. (2023)
Maintenance and repair cost	Maintenance and repair cost (in first year)	₹10,500	₹10,500	The maintenance and repair cost of electric three-wheelers was assumed to be 40% lower than that of conventional three-wheelers (Roychowdhury & Roy, 2022)
	Annual maintenance and repair cost escalation	10%	10%	—
Insurance cost	Insurance cost	₹7,924 annually	₹6,889 annually	Policymeter.com (2024)
Financing cost	Interest rate	23% per annum	12% per annum	Roychowdhury and Roy (2022)
	Repayment period	3 years	3 years	—
	Financed amount	85%	85%	—
Depreciation	Depreciation by year 5	70%	50%	Values are assumed to be the same as that for two-wheelers (Rokadiya et al., 2021).

Note: The swap-capable battery model considered was the highest selling swap-capable battery electric passenger three-wheeler in India in FY 2023–24. The fixed battery model considered is the fixed battery variant of the same model.

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