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CHARGING INDIA'S TWO- AND THREE-WHEELER TRANSPORT

A Guide for Planning Charging Infrastructure for Two- and Three-Wheeler Fleets in Indian Cities

Shyamasis Das, Chandana Sasidharan, Anirudh Ray

September 2020

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Suggested citation:

Das, S., Sasidharan, C., Ray, A. (2020). Charging India's Two- and Three-Wheeler Transport. New Delhi: Alliance for an Energy Efficient Economy.

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Acknowledgement:

The authors would like to express their sincere gratitude to Shikha Rokadiya and Anup Bandivadekar (both from the International Council on Clean Transportation) and Shilpi Samantray and Aishwarya Raman (both from Ola Mobility Institute) for their critical feedback on the report.

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1. Introduction

1.1 Context

Motorised road transport in India has two distinct characteristics, as exhibited in the population's preferences in the choice of vehicles for transport (NITI Aayog & World Energy Council, 2018). The first notable feature is the dominance of two-wheelers (Department of Heavy Industries, 2012). Two-wheelers, constituting the largest share of vehicles in India, are the preferred mode of personal transport in both rural and urban areas. This a fact confirmed by the registration statistics (Figure 1) on road transport vehicles in India from 1951-2013 (MoRTH, 2016). Tracing the domestic auto sales trend from 2013 (Table 1), it is clear that two-wheelers continue to maintain their dominance in the vehicular mix (SIAM, 2019). A modelling exercise by the International Council on Clean Transportation (ICCT) estimated that two-wheelers were responsible for 60% of annual vehicular fossil fuel consumption from 2016 to 2019 (Anup & Yang, 2020). Two-wheelers are also the source of 20% of carbon dioxide (CO_2) emissions and 30% of particulate emissions in India (IEA, 2020).

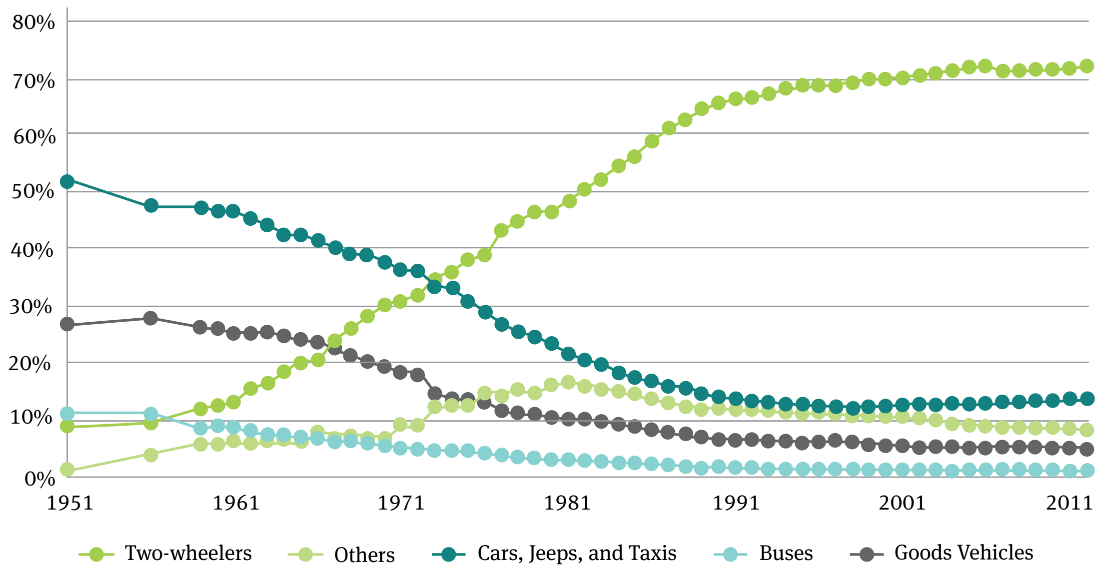


FIGURE 1: SHARE OF DIFFERENT VEHICLE CATEGORIES FOR ALL REGISTERED VEHICLES IN INDIA (1951-2013)

Note:

- *Others include auto rickshaws and tractors*
- *Auto rickshaws were included in the two-wheeler category in 1959-1969. For the remaining years, auto-rickshaws are included in the Others category, along with tractors, trailers, and other miscellaneous vehicles.*

Source: Ministry of Road Transport & Highways (MoRTH, 2016)

TABLE 1: DOMESTIC AUTOMOBILE SALES TRENDS

Domestic Sales (in thousands)	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
Two-wheelers	14,807	15,976	16,456	17,590	20,200	21,181
Three-wheelers	480	533	538	512	636	701
Other passenger and commercial vehicles	3,136	3,216	3,475	3,762	4,145	4,385
Grand Total	**18,423**	**19,724**	**20,469**	**21,863**	**24,981**	**26,268**

Source: Society of Indian Automobile Manufacturers (SIAM, 2019)

The second noteworthy feature is the presence of three-wheelers, which serve as commercial vehicles for passenger and goods transport (Jhunjhunwala, Kaur, & Mutagekar, 2018). Three-wheelers cater to the mobility needs of those not using private transport and not being served by the existing mass transit system (iTrans, 2009). Three-wheelers are also popular for goods transport for short distances (International Council on Clean Transportation, 2019). Though there are data-related challenges in estimating the historical penetration of three-wheelers[1], the recent sales figures (Table 1) show that the share of these vehicles is increasing. Within the three-wheeler segment, the share of passenger vehicles is higher than that of goods vehicles, as shown in Figure 2 (MoSPI, 2018).

FIGURE 2: THREE-WHEELER PRODUCTION STATISTICS FROM 2001-2017

Source: Ministry of Statistics and Programme Implementation (MoSPI, 2018)

Electrification of two- and three-wheelers is recognised as a low hanging fruit for clean mobility in India, based on the market readiness, cost-competitiveness, ease of charging, and emission reduction potential (NITI Aayog & Rocky Mountain Institute, 2017). It has been estimated that, together, two-wheelers and three-wheelers constitute 83%[2] of all vehicles in India (NITI Aayog & World Energy Council, 2018). Considering the electric vehicle (EV) penetration potential in these segments, the second edition of the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) scheme includes significant budgetary allocation for demand incentives for electric two-wheelers (e-2Ws) and electric three-wheelers (e-3Ws), as illustrated in Figure 3 (National Automative Board, 2018) (Department of Heavy Industry, 2020). Incidentally, 99% of all EVs sold in India are e-2Ws and e-3Ws (Wadhwa, 2019).

1 The data on three-wheeler registration is not available. Auto-rickshaws were included in the two-wheeler category for 1959-1969. For the remaining years, auto-rickshaws are included in the Others category, along with tractors, trailers, and other miscellaneous vehicles that are not classified separately (MoRTH, 2016).

2 Of all the vehicles on Indian roads, 79% are two-wheelers and 4% are three-wheelers (passenger and goods), based on sales data.

The EV sales trend (Figure 4) in the past couple of years shows that the pace of e-2W adoption is much higher than that of electric four-wheelers (e-4Ws), even after accounting for the fact that annual two-wheeler sales have been almost 6-7 times those of four-wheelers in recent years[3]. Though the corresponding sales figures for e-3Ws are not documented, the estimated sales of e-rickshaws were around 90,000 units in fiscal year (FY) 19-20 (SMEV, 2020). The growing adoption of e-2Ws and e-3Ws is expected to continue with the right policy elements focusing on the upfront cost reduction. For example, NITI Aayog mooted a proposal to ban sales of internal combustion engine (ICE) powered two-wheelers and three-wheelers starting from 2025 and 2023, respectively (Ministry of Road Transport & Highways, 2019). According to NITI Aayog estimates, 80% EV sales penetration is achievable in the two-wheeler and three-wheeler segments by 2030. At this level of penetration, e-2Ws and e-3Ws could potentially lead to a total reduction of 507.2 million tons of CO_2 over the vehicles' lifetime (NITI Aayog & Rocky Mountain Institute, 2019).

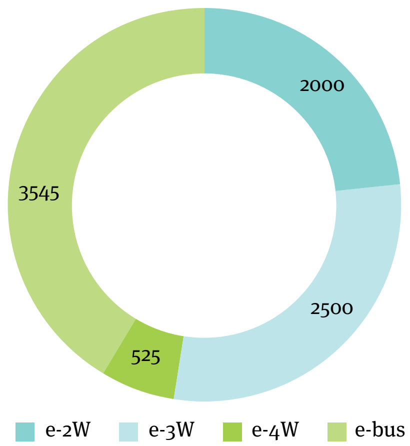


FIGURE 3: SHARE OF FUNDS (₹ CRORES) ALLOCATED FOR DEMAND INCENTIVES FOR DIFFERENT EV SEGMENTS UNDER FAME SCHEME

Source: National Automotive Board (National Automotive Board, 2018)

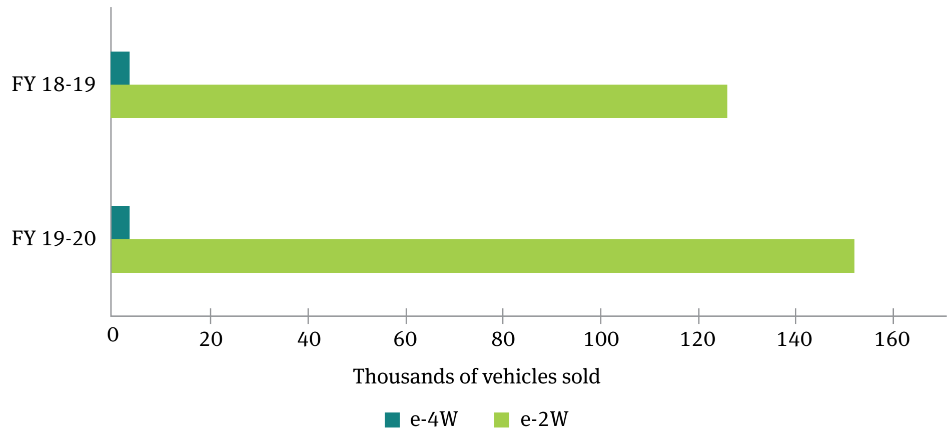


FIGURE 4: COMPARISON OF ELECTRIC TWO-WHEELER AND ELECTRIC FOUR-WHEELER SALES

Source: Society of Manufacturers of Electric Vehicles (SMEV, 2020)

1.2 Recent market developments

The e-2W and e-3W segments provide market opportunities in three areas: vehicle manufacturing, mobility services, and charging services. Not surprisingly, e-2W and e-3W manufacturing has generated a lot of interest among the existing local vehicle manufacturers, as well as new entrepreneurs. The erstwhile ICE two- and three-wheeler manufacturers, such as TVS Motors, Hero Motorcorp, Mahindra Electric, Hero Electric, and Bajaj Auto, have already introduced or are at an advanced stage of introducing EV models (TVS Motors,

3 In FY 19-20, a total of 174 lakh two-wheelers and 6.3 lakh three-wheelers were sold domestically (SIAM, 2020).

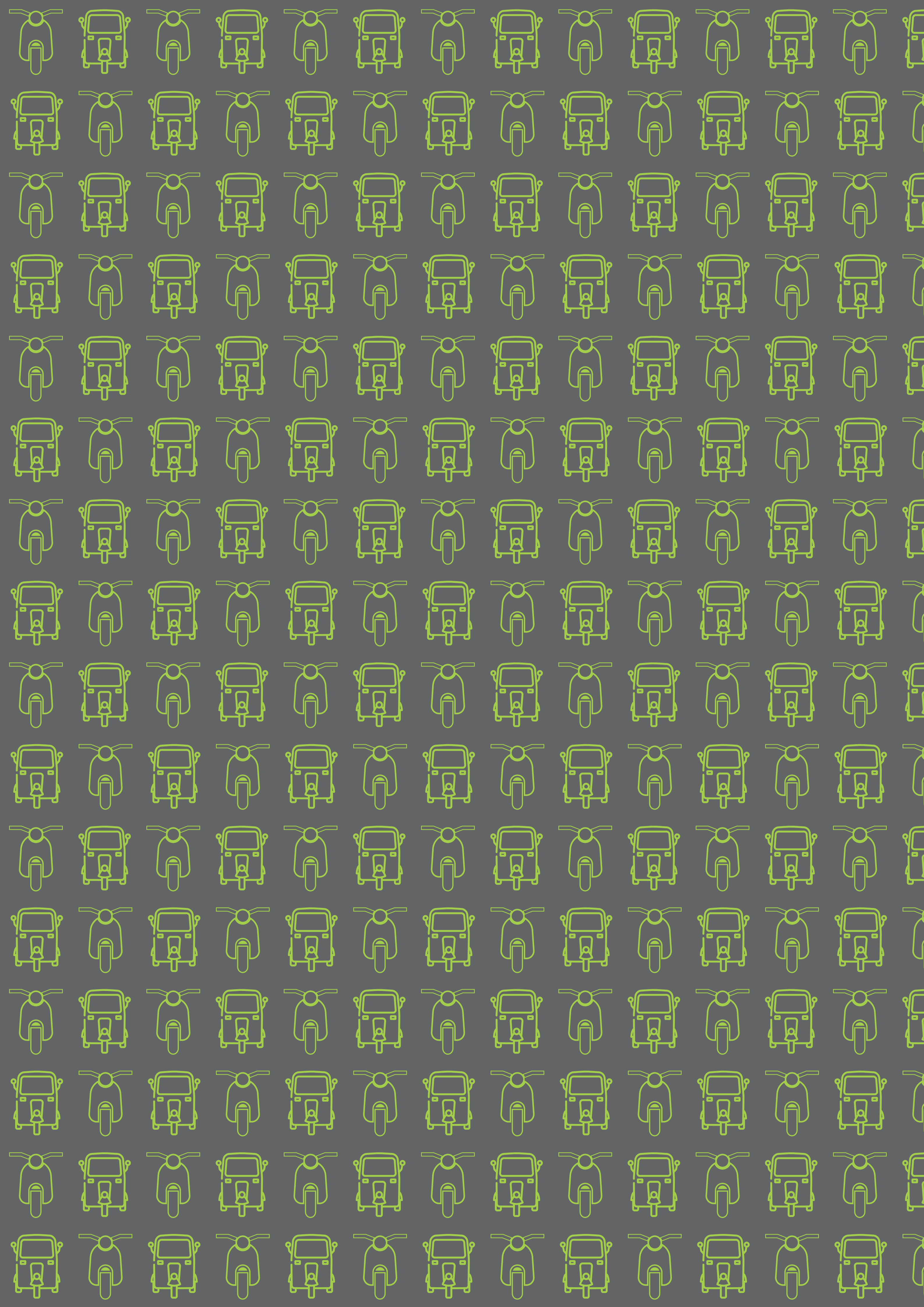
2019) (Hero Electric, 2019) (Bajaj, 2019) (M, 2019). However, most of the new e-2Ws on the market are from a range of new players, such as Ather Energy, Okinawa, Tork, Revolt, and Pure EV (Ather Energy, 2019) (Okinawa, 2019) (Tork Motors, 2019) (Revolt, 2019) (Pure EV, 2019). Fleet operators are also venturing into EV manufacturing. DOT and Ola Electric are fleet operators that are manufacturing/planning to manufacture their own e-2Ws for logistics and passenger transport, respectively (ET Tech, 2020) (DOT, 2020). In the case of e-3Ws, there are manufacturers like Kinetic Green focusing on e-rickshaws and e-autos for passenger transport, and others solely focused on goods carriers, such as Savy Electric and Gayam Motor Works (Kinetic Green, 2019) (Savy Electric, 2019) (Gayam , 2019).

Commercial adoption of these vehicles for passenger and goods transport has been found to be cost-competitive. Pilot programmes indicated that e-2Ws and e-3Ws have reasonably low total costs of ownership when used in commercial fleet operations (Arora & Raman, 2019). While some fleet operators—e.g. DOT, eBikeGo, SmartE, and eFleet Logix—offer transport services with fully electric fleets (Kashyaap, 2019; Chengappa, 2019; ET Auto, 2019), many others, such as Bounce, Vogo, Ola Electric, Amazon, Bigbasket, Flipkart, and GATI, are making efforts to increase the share of e-2Ws and e-3Ws in their fleets (PTI, 2019; D'Cunha, 2018; Russell, 2019) (EVreporter, 2020).

1.3 Motivation for the study

e-2Ws and e-3Ws are going to play a central role in achieving "shared, connected, and electric" mobility in India. To support the rapid pace of commercial adoption of e-2Ws and e-3Ws, availability of widespread charging infrastructure will be a crucial factor. The need of the hour is to carry out research on innovative and practicable "made-in-India" and "made-for-India" solutions. This study endeavours to help answer the following questions:

- What are the different segments of two-wheeler and three-wheeler commercial fleets, from the perspective of assessing the charging requirements of electric variants?
- What are the possible ways to charge e-2W and e-3W batteries, and how are they currently being charged? Are there any standards for e-2W and e-3W charging?
- What are the important design aspects of e-2Ws and e-3Ws that impact their charging?
- What are the infrastructural requirements for setting up a charging or swapping facility?
- Is battery swapping a practical alternative to normal e-2W and e-3W charging?
- Going forward, what kind of public charging infrastructure will be required for commercial light electric vehicles in Indian cities?



2. Objective, scope, and approach

This study aims to facilitate the establishment of ubiquitous charging facilities for commercial e-2W and e-3W fleets in Indian cities. To this end, this research has two main objectives:

1. To map the charging practices associated with commercial e-2W and e-3W fleets
2. To provide useful guidance for the establishment of e-2W and e-3W charging facilities

The study acknowledges that the planning of charging facilities for e-2Ws and e-3Ws requires an examination of the nuances of the Indian EV ecosystem. There is a need to understand how various players involved in e-2W and e-3W commercial operations, such as the vehicle manufacturers, fleet operators, and charging service providers, are managing the charging requirements.

THE INVESTIGATION THUS COMPRISES THE FOLLOWING MAJOR STEPS:

- Understanding the different segments of commercial e-2W and e-3W fleets, based on a review of current mobility patterns in Indian cities
- Undertaking a market assessment of current e-2W and e-3W models to understand charging-related aspects
- Carrying out an assessment of the charging methods for e-2Ws and e-3Ws in India
- Examining the salient approaches considered by market players for charging e-2W and e-3W fleets, based on case studies
- Identifying the possible kinds of public charging facilities for e-2Ws and e-3Ws and undertaking a multi-criteria assessment of these options
- Carrying out a survey with key stakeholders to understand their preferences regarding charging infrastructure

The outcome of this exercise should be considered in the context of the Indian e-2W and e-3W market and is based on an assessment of the current charging practices observed.

3. Electric 2-wheeler and 3-wheeler segments in India

3.1 Electric two-wheeler segments

The operation of a typical commercial e-2W fleet varies significantly based on the purpose of mobility, trip attraction or generation models, service/ business catchment area, etc. Based on careful scrutiny of different kinds of operations, these fleets can be broadly divided into two categories, based on the type of load they carry, i.e. passengers or goods. Each of these two broad segments is further categorised, as shown in Figure 5.

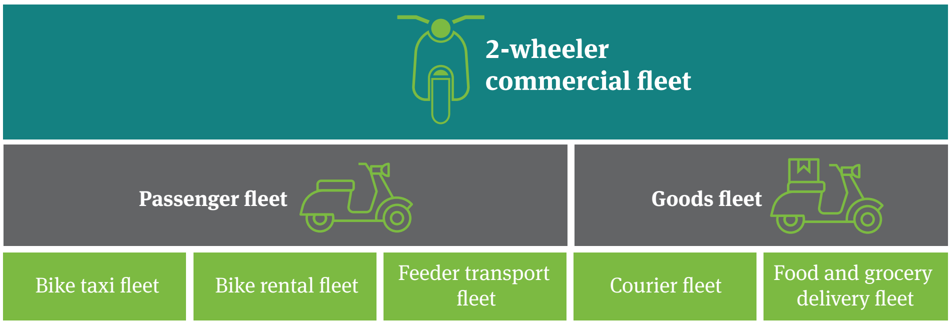


FIGURE 5: E-2W COMMERCIAL FLEET SEGMENTS

A. Passenger segment: The operation of this segment entails transportation of passengers from one point to another. This segment can be further classified into two categories:

1. **Bike taxi fleet:** This ride-hailing fleet caters to the mobility demand of the public in an urban area. This service is mostly available through apps. The fleets operate in two patterns, as explained below:
    - **Single node operation:** Here, the starting point for a bike (motorcycle) is fixed and is also the point to which it will return after completing one or more trip(s) (Vacano, 2017). Usually, people in need of bike taxi services hail a ride using a mobile application. The app connects the passenger with a nearby two-wheeler in the fleet. The bike picks up the passenger, completes the trip, and then waits for subsequent trips. In the absence of further trips, the bike may also return to its starting point.
    - **Double node-buffer zone operation:** In this case, a bike's movement generally centres around two nodes: the starting point (bike's initial location) and ultimate destination (often the resting place, as pre-set by the bike driver). An individual who wishes to avail of the bike service also follows similar two-node movement (Riejos, 2019). The bike and the rider get connected based on the preference of the driver and requirement of the rider. For example, a driver may wish to go from point A to point D, and a rider may want to travel from point B to point C. If the trip from B to C falls within a reasonable buffer zone of the trip from A to D, the driver first moves from point A to point B to pick up the rider and then drops the rider at point C. After completing the trip, the driver continues to point D. Similarly, requests for pick-up and drop-off that are on the way from A to D and do not require significant detours are assigned to the bike (Schiller & Kenworthy, 2017). There could be cases where the driver does not set a preferred destination, and, hence, connection with the prospective rider becomes *simpler.*

In the Indian context, bike taxi services are provided by mobility service providers such as Ola Bike, UberMOTO, and Rapido in Tier-I cities such as Delhi, Bengaluru, and Mumbai and Tier-II cities such as Surat, Pune, and Jaipur.

2. **Bike rental fleet:** Passengers prefer to rent bikes to leverage higher flexibility in terms of travel distances and times. Bike rentals, on the supply side, entail agencies or vendors providing bikes to the users. These agencies operate from rental stations where the bikes are housed. The users form the demand side in the rental equation. Users can either pick up (and drop off) the bike at a rental station or ask for it to be delivered to them at a specific location in the city. It should be noted that the travel patterns of these bikes can vary from user to user, based on the travel demand. Therefore, these bikes are quite similar to privately-owned two-wheelers, due to their flexible user-determined usage.

> The bike rental segment in India includes private entities like Bounce, Drivezy, and Vogo. A majority of the bike rental start-ups are located in Bengaluru but operate across multiple cities.

3. **Feeder transport fleet:** This fleet serves public transit operations in urban areas. In order to facilitate last-mile and first-mile connectivity for public transport routes, feeder transport fleets are deployed at different transit nodes/ stations, based on the travel demand/ footfall.

> In India, Yulu, Ola Pedal, Zoomcar PEDL, Letscycle, Mobycy, Ofo, and Mobike are some feeder transport platforms that rely on motorised or non-motorised two-wheelers to enable first-mile or last-mile connectivity to transit services.

B. **Goods segment:** The operation of this segment entails the transportation of goods from one point to another. This segment can be further divided into the following three categories:

1. **Courier fleet:** These fleets are used to transport goods from one point to another in a city. Here, the demand for transport is largely generated through transactions on e-commerce platforms. The goods are generally non-perishable items. The operation is based on a hub-and-spoke model (Lun, Lai, & Cheng, 2010), wherein the goods are stored at different levels of warehousing hubs (and nodal delivery centres) and transported along different levels[4] of "spokes" (roads), such as highways and arterial roads or collector and local roads.

> Various goods delivery service providers currently offer their services in India, including Delhivery, Ecom Express, GoJavas, and GetGo Logistics. They rely on hub-and-spoke models for end-to-end delivery of goods.

2. **Grocery and food delivery fleet[5]:** e-2W fleets that are used for delivering groceries, perishables, household items, and pre-cooked food in an area fall under this category. It should be noted that grocery delivery fleets operate between local businesses & local households (or third-party vendors) and typically cover an area as large as 15 - 20 neighbourhoods[6], whereas food delivery fleets shuttle between local consumers (offices/ households/ etc.) and

4 The different levels of roads present in urban centres in India are arterial, sub-arterial, collector, and local roads. In some cities, state or national highways pass through the urban areas.

5 Grocery and food delivery fleets do not explicitly follow a hub-and-spoke model, as the origin and destination points of each trip/ shift/ delivery vary.

6 Neighbourhoods are defined as socio-spatial residential entities with a population of 10,000 residents (Delhi Development Authority, 2007). The communities that these residents live in may be gated or not gated, with varying densities. A definite shape and size (in terms of radius or side length) cannot be predicted, due to variations in density and topography.

local businesses (restaurants, delivery joints, etc.), to cover about 10 - 15 neighbourhoods. In case a delivery location falls beyond the catchment area of one fleet and its associated businesses, another fleet from the same mobility service provider serves that location, along with the relevant local businesses. For a food delivery fleet, the delivery time is generally in the range of 20-60 minutes.

A fleet operated by Grofers, BigBasket, Zopnow, or Nature's Basket will resemble a grocery delivery fleet, as explained above. Zomato, Swiggy, and Domino's are examples of operators of food delivery fleets.

3.2 Electric three-wheeler segments

In Indian cities, three-wheeler fleets are used for different purposes, and their operating parameters, such as travel pattern, load type, etc, vary. Consequently, the charging requirements of these fleets may also differ. Figure 6 shows the different types of three-wheeler commercial fleets.

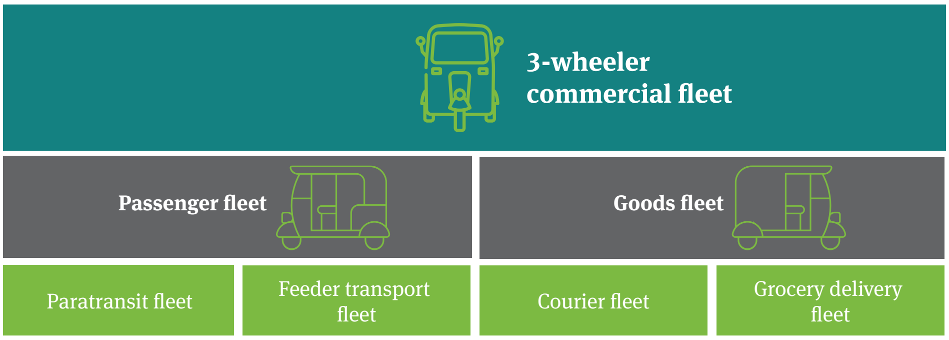


FIGURE 6: THREE-WHEELER COMMERCIAL FLEET SEGMENTS

A. **Passenger segment:** This segment involves three-wheeler-based transportation of passengers from one point to another.

   1. **Paratransit fleet:** This category caters to the intermediate mobility demand of the public in an urban area. The services of this fleet can be hailed on the street or via a mobile application. It operates in the following three ways:

      - **Single node operation:** In this case, the starting point (node) for a three-wheeler is fixed and is also the point to which it will return after making one or more trip(s) (Rodrigue, Comtois, & Slack, 2013). The operation is such that a driver returns to a set point, which may be a three-wheeler stand. The travel demand usually extends beyond the local area and is intra-city in nature.

        The auto rickshaws hailed from auto rickshaw stands and halt-and-go points in Indian cities fall into the above sub-category. E-rickshaws are rarely used in such a mode of operation, due to their slower speeds and lower driving ranges.

      - **Double node-buffer zone operation:** Here, a three-wheeler's movement generally revolves around two nodes, i.e. its starting point (the initial location) and ultimate destination (often the last resting place (in a day), pre-set by the driver). An individual who wishes to avail of the three-wheeler's service also follows similar two-node movement (Riejos, 2019). The three-wheeler and the rider get connected, usually via underlying app-based routing algorithms, based on the overlap between the rider's route and the vehicle's routes/ nodes. This mode of operation may also be dependent on roadside ride-hailing by passengers, in which case mobile applications are not involved.

> In India, such three-wheeler-based services are provided by service providers like Ola Auto, UberAuto, and Jugnoo. Here also, e-rickshaws have a very limited use case, compared to traditional auto rickshaws, due to their slower speeds and lower driving ranges.

- **Fixed route operation:** In this case, the three-wheeler plies on a fixed route between two or more points, and passengers availing its services board and deboard along the designated route. The terminals of the fixed routes usually operate as three-wheeler stands. This mode of transport is highly popular in cities lacking bus- and metro-based public transport options and cities where three-wheelers offer greater convenience for commuters.

> This mode of operation is prevalent in the Indian cities of Amritsar, Bhubaneswar, Ranchi, and Kochi, where bus- and metro-based public transport options have to compete with three-wheelers. The three-wheelers are mostly auto rickshaws, rather than e-rickshaws.

2. **Feeder transport fleet:** This fleet serves public transit operations in urban areas. In order to facilitate last-mile and first-mile connectivity for public transport routes, feeder transport fleets are deployed at different transit nodes/ stations, based on the travel demand/ footfalls.

> Mobility service providers like SmartE in Delhi augment first-and last-mile connectivity to Delhi's metro stations, by ferrying passengers to and from various points in areas surrounding a metro station. The vehicles do not necessarily operate along fixed routes. In this mode of operation, e-rickshaws are frequently used.

B. **Goods segment:** For this segment, the operations entail the transportation of goods from one point to another.

1. **Courier fleet:** This fleet supports courier delivery services in a city. The delivery may result from an e-commerce transaction, intra-city cargo transport, or traditional mail coming from outside the city. The operation is based on a hub-and-spoke model (Lun, Lai, & Cheng, 2010), wherein the goods are stored at different levels of warehousing hubs (and nodal delivery centres) and transported along different levels of "spokes" (roads), such as highways and arterial roads or collector and local roads.

> Companies like Euler Logistics and GATI rely on three-wheelers for intra-city goods deliveries in India.

2. **Grocery delivery fleet:** Three-wheeler fleets that are used to deliver groceries, perishables, and related household items in an area fall into this category. Grocery delivery fleets transport goods between local businesses & local households (or third-party vendors) and typically

cover an area as large as 15 - 20 neighbourhoods. In case a delivery location falls beyond the catchment area of one fleet and its associated businesses, another fleet of the same service provider covers that location, along with the relevant local businesses. The delivery usually happens in pre-fixed time slots, as per the convenience of the consumers.

A fleet operated by Grofers, BigBasket, Zopnow, or Nature's Basket is a grocery delivery fleet, as explained above. These players operate in Indian cities.

4. The e-2W and e-3W market in India

In this study, a market assessment was undertaken as the first step of investigation to understand the e-2W and e-3W market in India. India's e-2W and e-3W market is typically characterised according to two types of battery chemistries – lithium-ion and lead acid. For commercial operation, lithium-ion battery packs are more suitable, as their charging time and cycle life are higher than those of lead acid battery packs[7]. As the prices of lithium-ion battery packs are decreasing rapidly, more and more lithium-ion based EVs are entering the market. Moreover, the policy support in India is targeted towards lithium-ion batteries. Only EVs with advanced batteries such as lithium-ion ones are eligible to receive the demand incentives under FAME II[8] (Ministry of Heavy Industries and Public Enterprises, 2019). This report consequently focuses on e-2Ws and e-3Ws with lithium-ion batteries.

The e-2W and e-3W market is dominated by small original equipment manufacturers (OEMs), fleet operators, and charging service providers. It should be noted that often the defined role of each of these players is fuzzy, i.e. a manufacturer may also operate a commercial fleet or run a plug-in charging or battery swapping service.

4.1 Electric two-wheelers

As of 25th June 2020, there are approximately 72 e-2W models[9] with lithium-ion batteries, manufactured by 23 different automakers in the Indian market. The e-2Ws used in commercial operations are mostly electric variants of scooters. e-2Ws are typically classified based on their average speed, i.e. low-speed or high-speed.

- **Low-speed[10]:** Low-speed e-2Ws, which do not require registration, represent 90% of the total market share of e-2Ws in FY 2020 (SMEV, 2020). Two-wheeled battery-operated EVs, including pedal assisted vehicles, with a maximum speed of 25 kilometres per hour (kmph) and motor power of less than 250 watts (W), are not defined as motor vehicles (MoRTH, 2014).
- **High-speed:** As per the Central Motor Vehicle Rules (CMVR), high-speed e-2Ws are broadly classified into the same groups as their ICE counterparts (National Informatics centre, 2020) (Vahan, 2020), which are:
    - **L1:** Motorcycle with maximum speed not exceeding 45 kmph and motor power not exceeding 0.5 kilowatts (kW) if fitted with an electric motor
    - **L2:** Motorcycle that does not meet the criteria for Category L1

e-2Ws for logistics

The study found that there are limited e-2W models that are custom built for logistics operations[11] (Kashyaap, 2019). There is no common template among manufacturers for reporting e-2W specifications, especially with respect to

7 Typically, the charging time and cycle life of lithium-ion batteries are better than those of lead acid batteries by a factor of two (Keshan, Thornburg, & Utsun, 2016).

8 Phase-I of the FAME scheme provided subsidies to EVs with both lead acid and advanced batteries (Anup & Yang, 2020).

9 Source: AEEE internal analysis. Out of these models, only 19 e-2W models with lithium-ion batteries are eligible for demand incentives under FAME II (Department of Heavy Industry, 2020).

10 The low-speed vehicles do not qualify for demand incentives under the FAME II scheme (Ministry of Heavy Industries and Public Enterprises, 2019).

11 DOT manufactures a goods carrier model that is used for their fleet operations, and other manufacturers like Hero Electric and Jitendra New EV Ventures have showcased models capable of retrofits for logistics operations.

the battery and charging. The battery capacity is reported for all available models in their corresponding websites, but for analysis of other battery-charging related aspects, the report takes into account 15 e-2W models based on stakeholder consultation and the availability of information in the public domain. The major findings are summarised in the following section.

Battery capacity

The charging requirement depends on the battery capacity. Figure 7 maps the battery sizes for e-2Ws currently on the market. Most e-2W models have battery capacities between 1.2 and 2.2 kilowatt-hours (kWh).

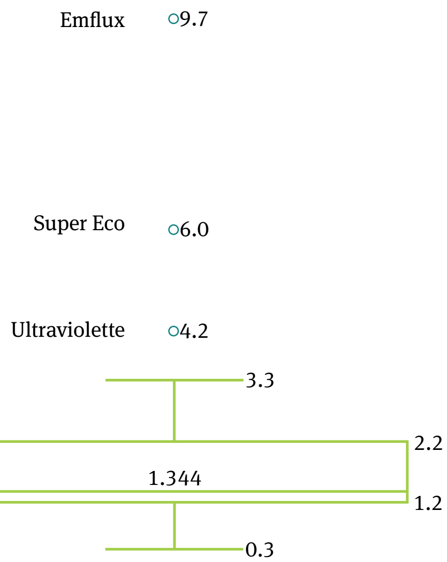


FIGURE 7: BOX PLOT OF BATTERY SIZES (KWH) IN E-2W MODELS WITH LITHIUM-ION BATTERIES

Battery voltage

Battery voltage is important, as it determines the charging voltage for the battery. The study of e-2W batteries found that the battery voltage varies between 48 volts (V) (lower limit) and 72 V (upper limit). This is an important observation, since the current guidelines specify 48 V as the output voltage for e-2Ws and e-3Ws (Ministry of Power, 2019). The reason for adoption of 48 V as the standard voltage is linked to previous EV designs with lead acid batteries[12]. It was easier to retrofit models that had 48 V lead acid battery packs with corresponding lithium-ion battery packs. But as new EV models are emerging with lithium-Ion battery packs, it is important to consider the reality that there will be e-2Ws with higher voltage battery packs on the market. High voltage battery packs are more energy-efficient, as the higher the voltage, the lower the current and corresponding thermal losses. A sampling study of 15 EV models on the market showed that there are vehicle models with 60 V and 72 V battery packs (Figure 8). There is therefore a need to develop standards and deploy charging facilities suitable for e-2Ws with battery voltages above 48 V.

12 Lead acid battery banks are manufactured in packs of 12 V, and the 48 V pack (4 x12 V) was common in EVs.

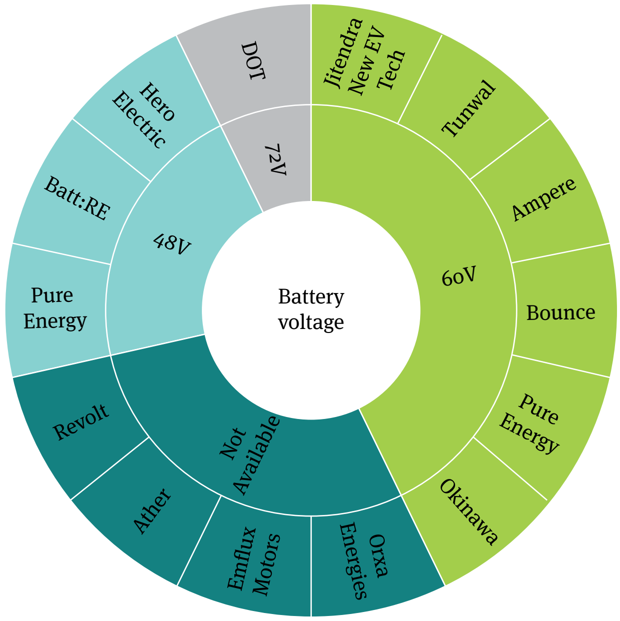


FIGURE 8: BATTERY VOLTAGE IN E-2W MODELS

Battery configuration

The batteries in these vehicles are either fixed or detachable. Figure 9 shows the prevalence of fixed and detachable batteries across OEMs. The choice of charging technologies or methods depends primarily on battery configuration. For instance, if the battery is detachable, battery swapping appears to be a preferred charging option, according to feedback from stakeholders. Hence, for the purpose of studying charging technologies, classification should be based on whether the vehicles have fixed batteries or not. In the case of e-2Ws with fixed batteries, plug-in charging is the only possible way of charging the vehicle, whereas both plug-in charging and battery swapping are possible for e-2Ws with detachable batteries.

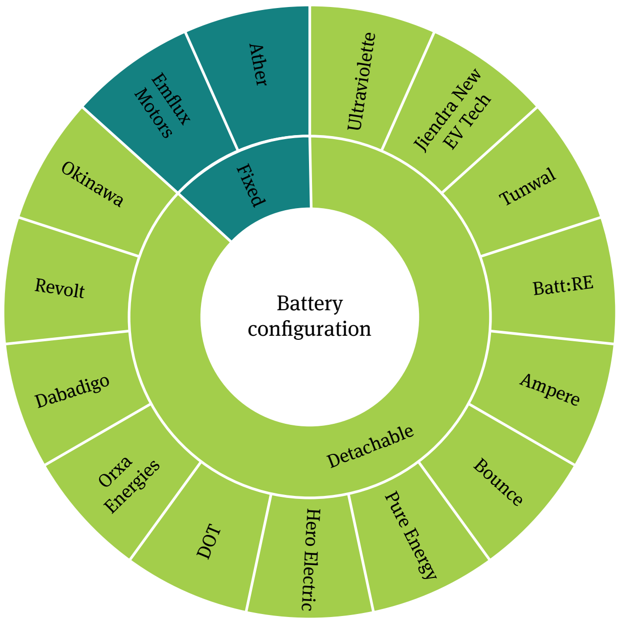


FIGURE 9: BATTERY CONFIGURATION IN E-2W MODELS WITH LITHIUM-ION BATTERIES

Another interesting observation is that on-board chargers[13] are not a common technology for e-2W charging in India. Survey results reveal that there are very few vehicles with on-board chargers, as shown in Figure 10. Many manufacturers provide portable chargers, which perform the same function as that of on-board chargers.

FIGURE 10: ON-BOARD CHARGER AVAILABILITY IN E-2W MODELS

4.2 Electric three-wheelers

Electric three-wheelers aid in passenger and goods transport. In comparison with e-2Ws, the penetration of lithium-ion batteries is relatively low in the e-3W segment. Nevertheless, there is an increasing trend of retrofitting e-3Ws with lithium-ion batteries. The change in battery electrochemistry has reduced the charging time and improved earnings (Arora & Raman, 2019). There are currently more than 30 e-3W models with lithium-ion batteries[14] on the market. Based on publicly available data and extensive stakeholder consultation, the study has identified several important aspects of the e-3W sector, which are summarised below.

e-3W classification

The e-3W models for commercial use can be e-rickshaws or e-autos suitable for passenger or logistics transport. As of 25th June 2020, there were roughly 35 e-3W models with lithium-ion batteries, of which 75% were e-rickshaw models. Only 20 e-3W models are eligible for demand incentives under FAME II (Department of Heavy Industry, 2020). These e-3Ws are classified into the following categories, as per the CMVR:

- E-rickshaw: An e-rickshaw is a special-purpose battery-powered vehicle with power not exceeding 4 kW, having three wheels for carrying either goods or passengers (Ministry of Road Transport and Highways, 2015) (Shandilya, Saini, & Ghorpade, 2019). These vehicles are not mandated by law to be equipped with regenerative braking systems (Ministry of Heavy Industries and Public Enterprises, 2019).

13 On-board chargers are chargers that are mounted onto the vehicles themselves.

14 Source: AEEE internal analysis

- E-cart: E-rickshaws for goods transport are called e-carts (Vahan, 2020).
- E-auto: A three-wheeled motor vehicle with maximum speed exceeding 25 kmph and motor power exceeding 0.25 kW, if fitted with an electric motor, is an e-auto (ARAI, 2018). E-autos for passenger transport are classified as L5M.
- E-cargo: E-cargo vehicles are e-autos for goods transport. They are classified as L5N (Vahan, 2020).

Battery capacity

A mapping of battery capacities for goods and passenger e-3Ws is presented in Figure 11. It is interesting to note that the battery capacity is not the same for passenger and goods vehicles. In the case of e-3Ws, battery capacity is determined by the vehicle application.

- The e-rickshaws used in passenger transport have battery capacities between 2.8 kWh and 6.6 kWh. E-autos have a higher battery capacity, 3.8-7.4 kWh. The average difference in capacity between them is around 2 kWh (refer to Figure 11).
- The goods carrier e-carts have battery capacities between 4.2 kWh and 5.2 kWh. E-cargo goods carriers have batteries between 4.8 and 7 kWh. The average capacity difference between them is about 1.5 kWh (refer to Figure 12).

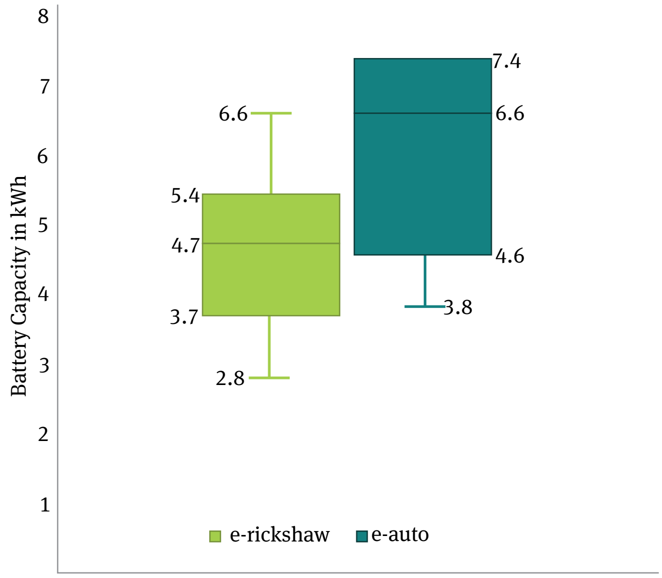


FIGURE 11: BOX PLOT OF PASSENGER TRANSPORT E-3W BATTERY CAPACITY

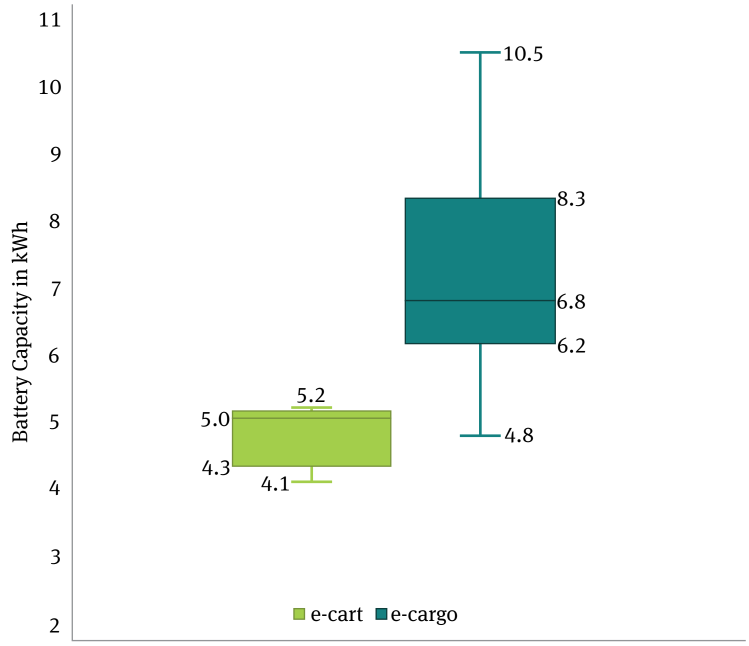


FIGURE 12: BOX PLOT OF GOODS TRANSPORT E-3W BATTERY CAPACITY

Other highlights

As observed in the case of e-2Ws, other than battery capacity, the specifications of batteries used in e-3Ws are not commonly reported by manufacturers. Hence, these details have been captured based on stakeholder consultation and publicly available information. On many fronts, the market characteristics of the e-3W segment are similar to those of the e-2W segment, as highlighted below:

- Similar to e-2Ws, e-3Ws also have fixed or detachable batteries (refer to Figure 13).

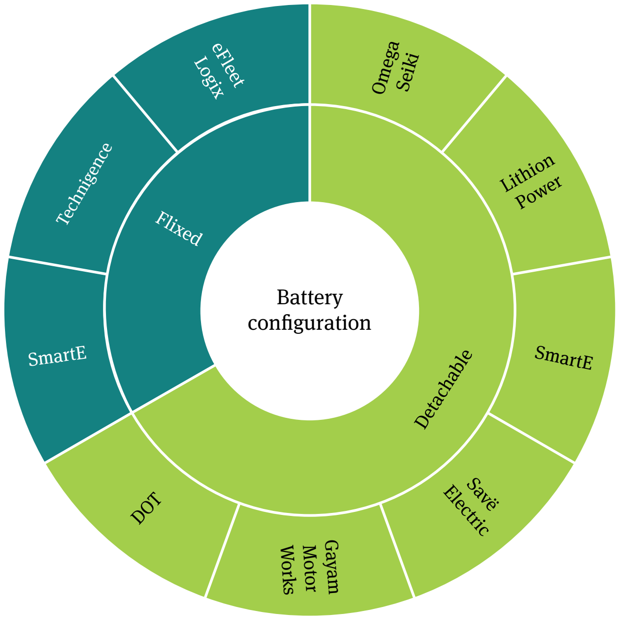


FIGURE 13: E-3W BATTERY CONFIGURATION

- The voltage of the battery packs is between 48 V and 60 V (see Figure 14).

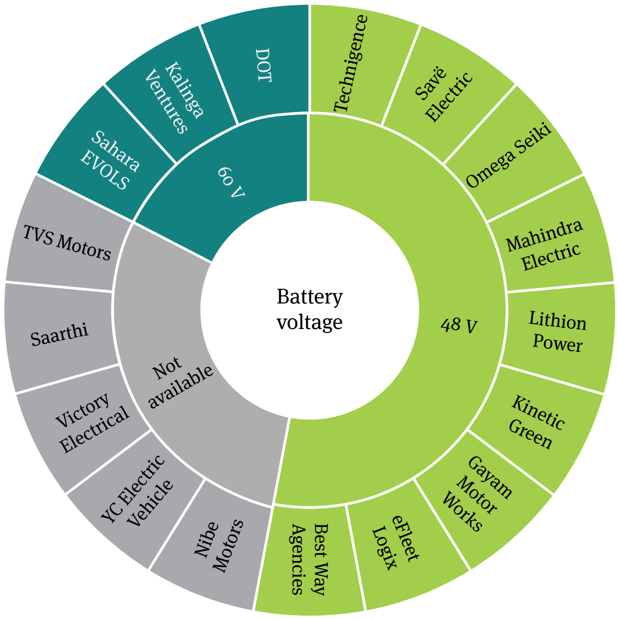


FIGURE 14: E-3W BATTERY VOLTAGE

- On-board chargers are not commonly used (refer to Figure 15).

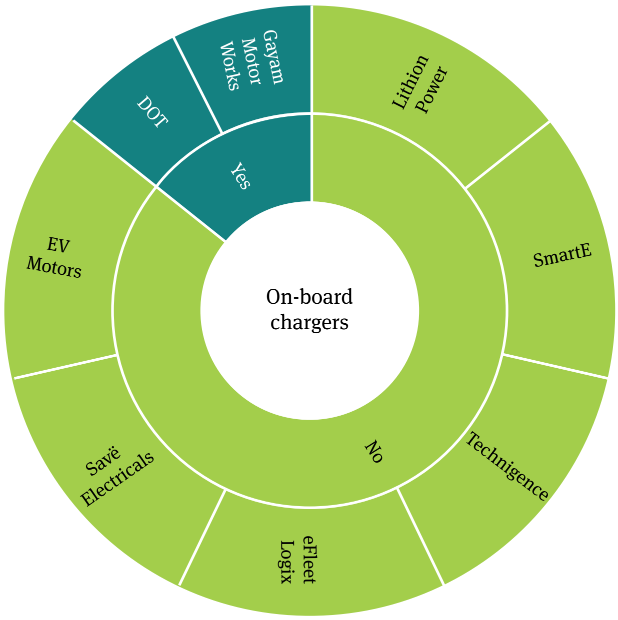


FIGURE 15: ON-BOARD CHARGER AVAILABILITY IN E-3W MODELS

5. e-2W and e-3W charging methods

E-2Ws and e-3Ws are distinct in design from the other classes of EVs in both their powertrain and battery related aspects. There are hardly any international standards governing the design of e-2Ws and e-3Ws. Hence, there is no standardisation of charging practices worldwide for these vehicles. The regional charging standards[15] in prominent EV markets such as the US, Europe, and China are mostly associated with e-4W charging. In contrast, India has two standards[16] for EV charging that are applicable to low voltage e-4Ws, e-3Ws, and e-2Ws. The Indian market presents an opportunity to develop effective home-grown charging solutions for e-2Ws and e-3Ws. Hence, it is useful to understand how these light EVs are currently being charged in India.

As highlighted above, e-2Ws and e-3Ws have fixed or detachable batteries, which can be charged inside or outside the EV. Both fixed and detachable batteries can be charged inside EVs with fixed or portable chargers. This method of EV charging through a plug-in connection[17] is called plug-in or conductive charging. If the vehicle has an on-board charger, it can be plugged into the nearest power outlet to charge the battery. An alternative for vehicles without on-board chargers is to use off-board fixed or portable chargers.

If the battery is detachable, there is an additional option for charging, namely, battery swapping. Battery swapping entails removing the depleted battery from the EV, replacing it with a spare recharged battery, and recharging the depleted battery outside the EV with a battery charger. The battery recharging can be done individually using a portable charger or in a pack using a fixed stack battery charger. The e-2W and e-3W charging methods are presented in Figure 16.

Plug-in Charging (Fixed or Detachable Battery)*		Battery Swapping (Detachable Battery)#	
Fixed EVSE	Portable EVSE	Individual Battery Charging	Stack Battery Charging

FIGURE 16: E-2W AND E-3W CHARGING METHODS

** Charging inside EV   # Charging outside EV*

5.1 Plug-in charging: battery charging inside EVs

The selection of charging options for e-2Ws and e-3Ws depends on the following four key considerations:

- **On-board vs. portable charger:** Typically, EVs have on-board chargers that can be plugged into any suitable outlet for charging. Quite frequently, e-2Ws and e-3Ws do not have on-board chargers. As an alternative, portable chargers provided by the manufacturers can serve the same purpose.
- **Alternating current (AC) vs. direct current (DC) charging:** Plug-in EV charging is further classified as AC or DC charging (Figure 17). AC charging entails charging EVs using on-board or portable chargers plugged into AC power sockets. In the e-2W and e-3W categories, portable chargers are more prevalent than on-board chargers. The other

15 For details on the regional standards, please refer to An overview of EVSE classification practices worldwide.

16 For more details, refer to Bharat AC 001 and Bharat DC 001.

17 Alternatively, it is also possible to charge batteries inside EVs wirelessly through induction. However, there are currently no reported use cases for this technology in the e-2W and e-3W segments. Hence, inductive charging technology is not considered here.

method of charging uses off-board fixed DC chargers. DC charging is gaining momentum in this segment, as it enables faster charging in comparison with AC charging. However, the DC charging rate depends on the thermal management capability and ambient temperature conditions.

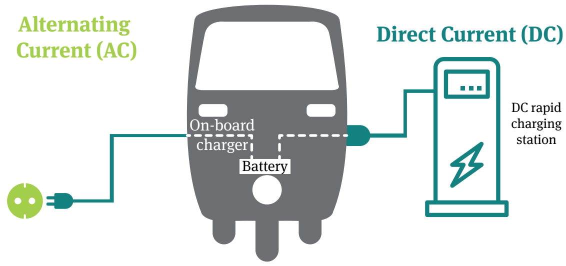


FIGURE 17: AC VS. DC RAPID CHARGING

- **Battery thermal management:** e-2Ws and e-3Ws generally do not have active cooling mechanisms or heating, ventilation, and air conditioning (HVAC) systems. Charging the batteries produce heat, and the charging rate of these batteries is often limited by the thermal management capability. This is particularly important given the tropical climatic conditions in India. There are only a few vehicles[18] that can be charged to up to 80% of their battery capacity in under an hour.
- **Battery voltage:** Chargers are designed to cater to the required battery voltage. 48 V batteries need chargers that can provide 48 V output, and, similarly, 72 V batteries require chargers that can provide 72 V output. Charging a low voltage battery with a high voltage charger could damage the battery.

Portable chargers for e-2Ws and e-3Ws

Fleet operators commonly use portable chargers for e-2W and e-3W batteries. These chargers typically have AC input and DC output. The output power of these chargers varies depending on the EV battery capacity. In this category, two types of chargers are available -- programmable and non-programmable. The programmable chargers[19] have advanced charging control and protection functions. The non-programmable chargers are relatively simple and inexpensive. The use cases for programmable chargers are mostly for e-3Ws with bigger batteries, rather than e-2Ws. The typical power capacity and costs associated with these chargers are given in Table 2.

TABLE 2: TECHNICAL SPECIFICATIONS AND COST ESTIMATE FOR PORTABLE CHARGERS

Specification	Non-programmable charger	Programmable charger
Input/ Output	AC/DC	AC/DC
Input Voltage (V)	230/415	230/415
Output Voltage Range (V)	40 – 72	40 – 72
Maximum Output Current (A)	30	50
Output Power Range (kW)	1 – 2	1 – 3.3
Cost of Charging Equipment (₹)	3,000 – 10,000	25,000 – 50,000

18 EV Motors and Emflux Motors manufactured vehicles are capable of getting fully charged within 36 minutes.

19 These chargers enable different modes of charging, such as Constant Current (CC) and Constant Voltage (CV), based on the state of charge of the battery.

Fixed off-board chargers

Fixed off-board chargers for e-2Ws and e-3Ws are quite common in the market. The applicability of this type of charger depends on the EV design. These chargers are generally wall-mounted chargers. The rated output power and other technical parameters are different for e-2Ws and e-3Ws. The connectors used for such chargers are sometimes different, because some manufacturers only allow the use of proprietary connectors. The technical specifications for these chargers are presented in Table 3. Cost estimates for such chargers are not available in the public domain.

TABLE 3: TECHNICAL PARAMETERS OF FIXED CHARGERS

Specification	e-2W charger[20]	e-3W charger[21]
Input/ Output	AC/AC or AC/DC	AC/DC
Input Voltage (V)	230	230 / 415
Output Voltage Range (V)	48 – 72	42 – 58
Maximum Output Current (A)	60[22]	187
Output Power Range (kW)	1 - 2.5	6-9

Indian standards for e-2Ws and e-3Ws

In 2017, a committee was constituted by the Department of Heavy Industries to develop Bharat standards for public EV charging. These standards – Bharat AC 001 and Bharat DC 001 – are for plug-in or conductive charging via AC and DC power, respectively. Both standards are applicable to e-2W and e-3W charging (DHI, 2017).

Bharat AC 001

Bharat AC 001 (BAC) is a special type of AC charging point that requires a three-phase input but has a single-phase output, which is suitable for e-2Ws and e-3Ws. AC charging entails plugging in the EV to an AC power outlet. With a 10 kW input power supply, Bharat AC 001 can charge three EVs at the same time at an output power of 3.3 kW. The technical specifications and cost estimates for this charger are presented in Table 4 (DHI, 2017). The BAC charger is a wall-mounted charger with three industrial plug output connectors. The ancillary equipment needed to install this charger includes a suitably rated electrical cable and circuit breaker.

TABLE 4: TECHNICAL SPECIFICATIONS AND COST ESTIMATES FOR BHARAT CHARGERS

Specification	Bharat AC 001	Bharat DC 001
Input/Output	AC/AC	AC/DC
Input Voltage (V)	415	415
Output Voltage (V)	230	48 - 72
Maximum Output Current (A)	16	200
Output Power Range (kW)	3.3	3.3[23]/10/15
Cost of Charging Equipment (₹)	40,000 - 50,000	1,80,000 - 2,60,000

20 Specifications of Ather home and grid chargers

21 Specifications for Exicom make Ultima chargers

22 Estimated for 48 V, 2.5 kW charger for 1C rate

23 Applicable for e-2Ws

Specification	Bharat AC 001	Bharat DC 001
Cost of Ancillary Infrastructure (₹)	1,800 - 2,500	2,800 - 3,500
Total Cost of Charging Equipment (₹)	41,800 - 52,500	2,02,800 - 2,63,500

It is important to remember that the maximum charging rate is more restricted by the charger's power capacity than the power output that can be provided by the socket in this EV segment. For example, e-2W chargers are typically ~1 kW, and the charging rate will therefore correspond to 1 kW, even if the charger is plugged into a 3.3 kW power outlet.

Bharat DC 001

Bharat DC 001 is a special category of electric vehicle supply equipment (EVSE) that is specifically designed for India. This charger is designed with two output power levels suitable for charging the existing EV models[24] in India. One of the standard outputs is 3.3 kW and meets the requirements of e-2Ws and e-3Ws[25]. These chargers are wall-mounted and have a high current output at a low voltage. The ancillary equipment needed for these chargers is similar to Bharat AC 001 chargers, but the costs are higher due to higher capacity. The technical specifications, along with the cost of the charger and ancillary equipment, are given in Table 4.

Upcoming charging standards for small EVs

Recognising the delay in development of international standards[26] for small electric vehicles, the Department of Science and Technology (DST) is spearheading a campaign to formalise Indian standards in FY 2020. These standards are intended to aid in the development of cost-effective charging infrastructure, without compromising on the communication[27] and safety aspects. The main idea is to ensure the installation of charging points with low-cost connectors suitable for e-2Ws and e-3Ws. Many of the vehicle manufactures, including TVS Motors and Bajaj Auto, are piloting the connectors under the 'Normal Charging Standard Initiative'[28]. The maximum charging power under this standard will be 22 kW, in accordance with the electricity infrastructure in India (DST-PSAO, 2020) (DST, 2020).

Recognising the significant opportunity to focus on AC charging and considering factors unique to India, such as use condition, infrastructure, affordability, and environment, there is a rapid push to develop the standards to uniquely cater to Indian customers. The focus is on developing a safe and economical AC power supply point for public deployment that will enable easy charging of e-2Ws and e-3Ws. These 'Low Power AC Charging Points' are designed with a power level of 3.3 kW. These chargers will have basic over voltage, overcurrent, short circuit, surge, and ground fault protection (DST-PSAO, 2020) (DST, 2020).

24 There are e-4Ws in India with battery voltage ≤72V. However, typically, the e-4W battery voltages are well above 150 V in established EV markets.

25 These types of chargers are currently not used for e-2Ws and e-3Ws, primarily because connectors have not been developed for these chargers.

26 International standards are expected in FY 2022.

27 These chargers are expected to follow the existing Combined Charging System (CCS) or CHArgedeMOve (ChadeMO) protocols for DC charging.

28 Initiative to develop charging standards for Light Electric Vehicles, i.e. e-2Ws and e-3Ws. These may include AC or DC charging points.

5.2 Battery swapping: battery charging outside EVs

Battery swapping entails the swapping of depleted vehicle batteries with fully charged batteries. Battery swapping is a charging method that can be effectively applied for e-2Ws and e-3Ws, as many of the e-2W and e-3W models already have detachable, lightweight batteries. The battery swapping system consists of the battery charging system and battery swapping mechanism. In the case of e-2W and e-3W battery swapping systems, the swapping can be done manually, which enables less complex and more cost-effective swapping operations than in the case of e-4Ws or e-buses.

The weight of the battery pack is an important factor when it comes to swapping operations. This weight depends on the battery capacity and energy density of the battery pack. Battery pack energy density is not a parameter that is commonly reported by manufacturers in their product brochures. The specific battery energy densities of FAME-II approved e-2W and e-3W models (Department of Heavy Industry, 2020) are plotted in Figure 18. The plot shows that energy densities of 200 Wh/kilogramme (kg) and 125 Wh/kg are good representative indicators of the FAME-II approved e-2W and e-3W models, respectively. The FAME guidelines have set a density of 70 Wh/kg as the minimum threshold for eligibility for demand incentives (Department of Heavy Industry, 2020).

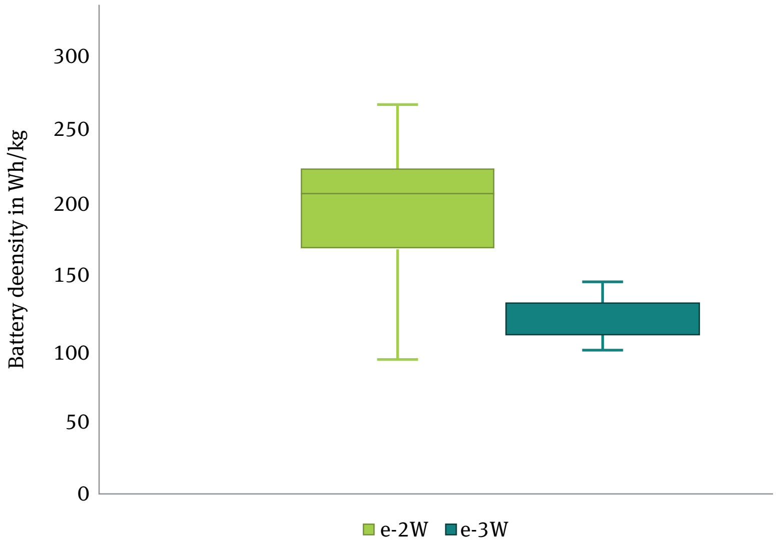


FIGURE 18: ENERGY DENSITY OF FAME-II APPROVED E-2W AND E-3W MODELS

With higher energy density and lower battery capacity, the e-2W battery packs are typically lighter than the e-3W battery packs. A typical 2 kWh e-2W battery weighs anywhere between 8.8 and 11.4 kg[29]. The lower the battery weight, the easier it is to manually lift it. It is also possible to split a battery into two smaller battery packs of 1 kWh each; this improves the ease of battery lifting and handling.

In the case of e-3Ws, the battery size is around 3 kWh for passenger e-rickshaws and 5 kWh for goods carriers. The associated weights of these batteries are 20 - 30[30] kg and 33 - 50[31] kg, respectively. The weight

29 Calculated with 175 Wh/kg and 225 Wh/kg as lower and upper limits, respectively.

30 Calculated with 100 Wh/kg and 150 Wh/kg as lower and upper limits, respectively.

31 Calculated with 100 Wh/kg and 150 Wh/kg as lower and upper limits, respectively.

complicates e-3W battery swapping operations. Additional measures are required to reduce the battery weight to a manageable level.

- One possibility is to manage the swapping in the passenger segment with an assisted two-person operation at the swapping station. However, this option is only possible up to a certain battery weight.
- Alternatively, it is possible to adopt a design with multiple battery packs that can be easily lifted. A standard size used for the battery packs is 1.5 kWh, which corresponds to 10 - 15[32] kg in weight.

FIGURE 19: INDIVIDUAL BATTERY CHARGER FOR SWAPPABLE BATTERIES

Generally, battery charging can be done at the same location as the swapping facility, with the help of portable or fixed chargers. An example of an individual battery charger for swappable batteries is shown above in Figure 19. The specifications for fixed battery chargers are quite similar to those of portable EV chargers. In the stack chargers, sometimes also called modular or bulk chargers, there are many dockets where the individual batteries are placed for charging. The technical specifications for stack and individual chargers are presented in Table 5. The typical area required for installation of a bulk charger for 20 batteries is about 1 square metre (sqm). In the case of individual charging, 1 sqm is also typically the standard area requirement for a charger.

TABLE 5: TECHNICAL SPECIFICATIONS FOR STACK AND INDIVIDUAL BATTERY CHARGERS

Specification	Stack battery charger[33]	Individual battery charger[34]
Input AC Voltage (V)	415	230
Output DC Voltage Range (V)	50 – 69	48/72
No. of Output Sockets	20	3
Maximum Output Current per Socket (A)	22	8/12
Output Power per Socket (kW)	1.32	0.6

It is also possible to develop a hub-and-spoke model for battery swapping. In this case, centralised charging is done in a remote location, and the swapping facilities only dispense the charged batteries. In such cases, a high tension (HT) grid connection may be needed, based on the number of batteries. The ancillary infrastructure includes the suitably rated transformer, circuit breaker, and cables. The charged battery dispenser for 20 batteries can be installed in an area of 1 sqm.

The costs associated with battery swapping infrastructure depend on the number of batteries charged. The cost of an individual charger[35] is around ₹ 4,000 - 5,000. The chargers also have monitoring equipment, which constitutes about 3-5% of the capital cost.

32 Calculated with 100 Wh/kg and 150 Wh/kg as lower and upper limits, respectively.

33 The technical details provided are for a bulk charger manufactured by Exicom, available on the market.

34 The technical details provided are for the Multiport DC charger manufactured by EVQ Point.

35 Based on stakeholder interactions

Example- Gogoro e-2W battery swapping stations

Gogoro is a Taiwanese e-2W manufacturer that has grabbed headlines for its battery swapping network. The company, with assistance from Panasonic, manufactured portable lithium-ion batteries that weigh 9.8 kg each (Gogoro, n.d.). A typical battery swapping station has the appearance of a vending machine and holds a minimum of 10 batteries (Chou, 2017). The company has successfully deployed their battery swapping infrastructure in the Asian and European markets. Gogoro works on a subscription model, wherein the consumers are charged a fee for using the swapping stations. It also provides individual battery chargers to users.

Example- BPCL e-Drive initiative for e-3Ws

e-3W battery swapping facilities are being set up at petrol pumps across Indian cities. Bharat Petroleum Corporation Limited (BPCL) has recently launched its e-Drive initiative in Kochi and Lucknow. BPCL will reportedly maintain a stock of about 200 batteries, and the drivers of e-3Ws will be able to exchange their discharged batteries for charged batteries. Two standardised battery packs for an e-rickshaw are needed, and three for an e-auto. The venture is being launched in association with e-3W manufacturer Kinetic Green and Indian Institute of Technology (IIT) Madras (The Hindu Business Line, 2020).

6. Salient approaches to e-2W and e-3W charging tested by market players

The e-2W and e-3W charging service sector in India is developing in its own unique manner and quite differently from the e-4W market. For example, because of the much smaller battery sizes compared to those of e-4Ws, not only can e-2Ws and e-3Ws, i.e. Light Electric Vehicles (LEVs), be charged in a reasonable time without sophisticated fast plug-in charging technologies, but, due to the lighter weight of their batteries, they can also be easily charged using battery swapping techniques. Additionally, as there is less space required for LEV parking than for e-4W parking, e-2W and e-3W charging facilities can be deployed in areas with less available space and low voltage electricity connections (15 A sockets are sufficient). The average service/ business catchment area for LEVs is also much smaller than the area for e-4Ws. e-2Ws and e-3Ws are used for first- and last-mile connectivity, for example, whereas e-4Ws hardly have a role to play in this activity.

Due to the inherent flexibility in e-2W and e-3W charging, market players have been testing out unique charging methods, and such methods influence the choice of charging technology. This study highlights these different approaches through case studies on the current charging (or swapping) practices adopted to cater to commercial e-2W and e-3W fleets. It should be noted that an OEM or a fleet operator often plays the additional role of providing charging services for its vehicles and, sometimes, other vehicles as well.

6.1 Network charging stations for e-2Ws

e-2W | Passenger | Plug-in charging

In the e-2W segment, it is uncommon for a manufacturer to set up its own charging facilities for its vehicles. Ather Energy is one exception, as an e-2W manufacturer in India that provides both home and public charging solutions for its vehicles. The e-2Ws have fixed 2.4 kWh[36] lithium-ion batteries. While the home charging solution is based on AC charging, the public charging stations have DC chargers manufactured by Ather Energy. The DC public charging network, called 'Ather Grid', is currently available in a few cities, including Bengaluru and Chennai. Ather Grid is capable of charging e-2Ws at a rate equivalent to 1 km/ minute[37]. Ather Energy partners with local business owners to establish these proprietary charging stations. The company provides the equipment (Figure 20) and compensates the partner for the charging service. The 2.5 kW chargers are powered using the partners' existing electricity connections. The company offers its charging service on a subscription-based model ("Ather Energy," n.d.). The charging stations are also able to charge other e-2Ws using the standard 5/15A socket.

FIGURE 20: ATHER GRID CHARGING POINT

Picture courtesy: Ather Energy

36 2.4 kWh "usable" capacity of battery

37 Subject to ambient temperature and until 80% of the battery capacity is reached

Case Study Summary	
Type of solution	Distributed plug-in EV charging
Vehicle segment	e-2W
Battery capacity	2.4 kWh
Type of charging	DC charging
Charger capacity	2.5 kW
Charging time	1 km/ minute
Charging cycle	Not available
Area requirement (m x m)	Not available
Operating model	Subscription model for customers; tie-ups with shops
Stakeholder category	EV manufacturer and charging service provider
Connected load at charging/swapping facility	3.3 kW[38]

6.2 Kirana store battery swapping solution for e-2Ws

e-2W | Passenger | Plug-in charging and swapping

Renting e-2Ws is popular in some Indian cities like Bengaluru. Bounce is a key player in this space. With an aim to make its fleet 100% electric by 2030, Bounce is part of EV100, a global initiative to bring together companies committed to accelerating the transition to EVs and making electric transport the new normal by 2030. Currently, Bounce is testing all the existing e-2Ws in the market for adoption in its fleet. Some of these e-2Ws have fixed batteries, whereas others have swappable ones. The company is planning to operate e-2Ws with both battery swapping and plug-in charging technologies. According to its current charging plan, the percentage of battery swapping will be significantly higher (90%) than that of plug-in charging (10%). Bounce has a strategic plan to deploy over 100 swapping facilities in partnership with local kirana store (small shop) owners (Figure 21) and also launch a mobile application for locating the nearest battery swapping station. Each of these swapping stations will have 2-3 spare batteries ready for swapping anytime; a battery is typically recharged in two hours. A few of these swapping

FIGURE 21: KIRANA STORE BATTERY SWAPPING FACILITY

Picture courtesy: Bounce

38 Estimated for one charger

facilities are already operational.

Case Study Summary	
Type of solution	Individual battery swapping
Vehicle segment	e-2W
Battery capacity	28 - 35 Ah
Charger capacity	3.3 kW
Charging time	1-3 hours
Charging cycle	Not available
Area requirement	Not available
Operating model	Tie-up with kirana stores
Stakeholder category	EV rental and charging service provider
Connected load at charging/swapping facility	Not available

6.3 Battery swapping facility for e-2W passenger fleet

e-2W | Passenger | Swapping

Dabadigo provides an e-2W rental service in Kolkata. They have adopted a battery swapping solution for their fleet. The bike rental outlets also serve as battery swapping stations. The e-2Ws in their fleet have 1.2 kWh detachable batteries. The batteries are generally charged at a 0.5 C-rate[39] using individual chargers at the bike rental outlets. The current operation is such that every battery is charged twice a day. They are not undertaking overnight battery charging.

The energy requirement associated with a single battery is around 2 kWh per day, and the total charging time for a battery per day is 4 hours. These swapping stations operate without any air conditioning. The power required for setting up a swapping facility with ten batteries is around 6 kW, and the required area is 100 square feet (sq ft). The estimated energy consumption corresponding to charging 10 batteries per day is around ~25 kWh.

Case Study Summary	
Type of solution	Individual battery swapping
Vehicle segment	e-2W
Battery capacity	1.2 kWh
Charger capacity	6 kW for 10 batteries
Charging time	2 hours
Charging cycle	2 charges per day
Area requirement	10 sqm for 10 batteries
Operating model	Swapping facilities set up by fleet operator
Stakeholder category	EV rental and charging service provider
Connected load at charging/swapping facility	6 kilo-volt-amperes (kVA)

39 The battery "C-rate" is the rate at which the battery is charged or discharged. 0.5 C corresponds to fully charging the battery in two hours.

6.4 Charging for e-2W and e-3W logistics operations

e-2W & e-3W → Logistics → Plug-in charging

This case study focuses on the charging practices adopted by logistics operators. DOT is a purely electric logistics fleet operator with e-2Ws and e-3Ws. They are operational in over 25 urban areas in India, including Delhi, Mumbai, Bengaluru, Hyderabad, Chennai, Jaipur, and Kolkata. They are the mobility partner for logistics companies in the food and groceries sector. The typical travel distance for their vehicles is 100 km per day. They manufacture their own goods transport vehicles, which have lithium-ion batteries of varying capacities and chemistries. The e-2Ws have Lithium Nickel Manganese Cobalt (NMC) batteries with capacities of 1.5, 2, or 3 kWh, whereas the e-3Ws have 7 kWh Lithium Iron Phosphate batteries. Although the batteries are detachable, the company uses an AC charging solution for their fleet, with portable and on-board chargers.

DOT thinks that the weight of the 7 kWh batteries rules the e-3Ws out as ideal candidates for battery swapping. The reported charging time for the vehicles is in the range of 2-4 hours. DOT has set up charging facilities on their own with a connected load of 40-50 kVA. Their charging cycle is typically 1.5 cycles per day for e-3Ws, including one full cycle overnight and a half cycle at midday. For e-2Ws, one charge is typically sufficient for the desired range. Hence, e-2Ws are not charged at midday, even though they have this window for opportunity charging due to their operational characteristics. They use high-end chargers with advanced protection functionalities.

Case Study Summary	
Type of solution	Centralised plug-in charging
Vehicle segment	e-2W & e-3W
Battery capacity	1.5/2/3 kWh for e-2Ws
	7 kWh for e-3Ws
Charging time	2-4 hours
Charging cycle	1 charge per day for e-2Ws
	1.5 charges per day for e-3Ws
Area requirement	Not available
Operating model	Captive charging facilities set up by fleet operator
Stakeholder category	EV logistics fleet operator
Connected load at charging/swapping facility	40-50 kVA

6.5 e-3W logistics fleet operation with captive plug-in charging

e-3W | Logistics | Plug-in charging

This is a case study on logistics operations with only e-3Ws. eFleet Logix is a logistics support partner for e-commerce businesses in Jaipur and Gurgaon. Their e-3Ws have fixed 4.8 kWh (48 V, 100 Ah) Lithium Iron Phosphate batteries. Their current operation in the logistics sector involves two shifts: morning and evening. Currently, the vehicles need to be charged twice a day. eFleet Logix has set up a charging facility with 2000 sq ft area for their operations, where 15 vehicles can be charged at the same time.

eFleet logix has put a lot of emphasis on the use of correctly sized chargers (refer to Figure 22), after batteries were damaged by oversized chargers. They use portable chargers of two different capacities to charge their e-3W fleet. The chargers that charge the vehicles at a 0.2-0.25 C-rate (20-25 A current) are non-programmable chargers. eFleet Logix also uses programmable chargers, which can charge the vehicles at a 0.5 C-rate (50A). These chargers have advanced control and protection functionalities. The contract demand for this site is 20 kW, and there is a low tension (LT) electricity connection.

FIGURE 22: EFLEET LOGIX E-3W CHARGER

Picture Courtesy: eFleet Logix

Case Study Summary	
Type of solution	Centralised plug-in charging
Vehicle segment	e-3W
Battery capacity	4.8 kWh
Charger capacity	2 kW
Charging time	2-4 hours
Charging cycle	2 charges per day
Area requirement	200 sqm for 15 vehicles
Operating model	Captive charging facilities set up by fleet operator
Stakeholder category	EV logistics fleet operator
Connected load at charging/swapping facility	20 kW

6.6 e-3W logistics fleet operation with battery swapping

e-3W → Logistics → Swapping

Gayam Motor Works is an EV manufacturer that has ventured into logistics fleet operations with their EVs. They provide EVs on a rental basis to logistics partners in Hyderabad. They have also set up six swapping stations in the city to support their operations. The 4 kWh batteries are charged at a 0.5 C rate. The vehicles are charged twice a day, with one charge taking 2-3 hours. The company operates with smart charging infrastructure, and remote monitoring helps them monitor the charging level of the EV batteries throughout the day. Their vehicles are also equipped with on-board chargers.

Each swapping station usually has 20 batteries. A 40 kVA (HT) electricity connection is taken to operate one station, and an area of 100 sq ft is required to accommodate these batteries, stacked vertically in 3 layers. Charging stations are equipped with an HVAC system, though air conditioning is only required in the summer.

Case Study Summary	
Type of solution	Stack battery swapping
Vehicle segment	e-3W
Battery capacity	4 kWh
Charger capacity	2 kW
Charging time	2-3 hours
Charging cycle	2 cycles per day
Area requirement	10 sqm for 20 batteries
Operating model	Captive swapping facilities set up by fleet operator
Stakeholder category	Equipment manufacturer and swapping service provider
Connected load at charging/swapping facility	40 kVA

6.7 Open infrastructure for battery swapping for e-3W passenger transport

e-3W → Passenger → Swapping

Lithion Power is an open platform battery charging & swapping service provider catering to the e-2W & e-3W segments in Delhi National Capital Region (NCR). They offer battery charging with assisted swapping solutions for passenger vehicles. The unique feature that distinguishes them from other charging service providers is related to the battery ownership. They have developed an operating model wherein the swapping service provider does not necessarily have to be the owner of the batteries. In the initial phase of their operations, they procured and supplied the batteries themselves. However, they realised that there was a need to establish an 'open ecosystem' for batteries in the swapping model. In their current operations, they provide charging and swapping services for any batteries manufactured by any OEM, provided the batteries satisfy minimum criteria. Standardisation of connectors and communication can enable such an open system for EV battery charging and swapping.

Lithion charges 48V 72Ah batteries at a 0.5 C-rate. The associated modular charging infrastructure (Figure 23) is intelligent and connected, enabling remote battery monitoring. The charger specifications vary according to the number of batteries. An individual battery charger for 3.4 kWh batteries is of 1-2 kW power. A 3x3 module can charge 9 batteries at once and has a corresponding rated power of ~15 kW. Similarly, a 5x5 module, which can charge 25 batteries simultaneously, has a rated power of ~42.5 kW.

FIGURE 23: LITHION POWER E-3W BATTERY SWAPPING INFRASTRUCTURE

Picture courtesy: Lithion Power

Case Study Summary	
Type of solution	Stack battery swapping
Vehicle segment	e-2W & e-3W
Battery capacity	3.4 kWh for e-3Ws
Charger capacity	15 kW for 9 batteries
	42.5 kW for 25 batteries
Charging time	6-8 hours (2-3 mins. per battery swap)
Charging cycle	Not available
Area requirement	5 ft x 5 ft
Operating model	Battery swapping service *
Stakeholder category	EV swapping service provider
Connected load at charging/swapping facility	15-50 kVA

*Including battery charging

6.8 Fast charging and battery swapping for passenger transport

e-2W & e-3W → Passenger & logistics → Swapping

SUN Mobility is an energy infrastructure provider for EVs currently offering its services to e-2Ws, e-3Ws, and e-buses. It has adopted the approach of battery swapping, wherein vehicles are purchased without batteries by users, and standard batteries and charging infrastructure are bundled as a service (energy-as-a-service). The operating model entails the establishment of individual swapping facilities (Quick Interchange Stations - QIS) that can charge and dispense batteries. Each QIS (Figure 24) for e-2Ws & e-3Ws has 15 slots and can charge 14 batteries[40]. The batteries are standardised, with 1.5 kWh capacity and a weight of around 12-13 kg. The same batteries are used for e-2Ws and e-3Ws. While an e-2W only requires one battery, the e-3Ws may need 2 or 3 batteries, depending on the passenger/logistics vehicle or range requirement.

These batteries can be charged in an air-conditioned environment in a QIS in one hour. The QIS is designed to dispense fully charged batteries every hour. A typical QIS with battery charging, AC, and monitoring equipment has a connected load of 28 kVA. The electricity connection required for a charging facility with one QIS is LT, whereas a facility with multiple QISs requires an HT connection, along with the associated electrical equipment. The area requirement for a facility with a single QIS is typically 100 sq ft, increasing to 200 sq feet for a facility with three units. While some of the stations avail of EV charging tariffs, many are charged for electricity at commercial rates for the energy required to charge the batteries inside the QIS.

FIGURE 24: SUN MOBILITY BATTERY SWAPPING FACILITY

Picture Courtesy: SUN Mobility

Case Study Summary	
Type of solution	Stack battery swapping
Vehicle segment	e-2W & e-3W
Battery capacity	1.5 kWh for e-2Ws
	2 x 1.5 kWh for e-3Ws (e-rickshaw)
	3 x 1.5 kWh for e-3Ws (e-auto)
Type of charging/swapping	Manual swapping
Charging time	1 hour for 14 batteries in 1 QIS
Charging cycle	Not available
Area requirement	10 sqm for 14 batteries 20 sqm for 42 batteries
Operating model	Provides swapping service to vehicles using its proprietary batteries
Stakeholder category	EV swapping service provider
Connected load at charging/swapping facility	28 kVA

40 One free slot is required to deposit a battery. Hence, only 14 batteries can be charged at a time.

6.9 Charging for e-rickshaw passenger transport

e-3W → Passenger → Plug-in charging

This case study showcases the charging practices in e-3W passenger fleet operations in Delhi. SmartE is an e-3W passenger fleet operator based in Delhi NCR. They have set up their own charging facility for their fleet of over 1000 e-rickshaws. The fleet initially consisted of EVs with lead acid batteries, which were subsequently retrofitted with 2.8 kWh (72 Ah) lithium-ion batteries. The vehicles are fully charged overnight, with top-up charging provided midday. These vehicles thus undergo a charging cycle of 1.5 times per day. The vehicles, when charged with 2 kW chargers, take 2-2.5 hours to get fully charged.

Case Study Summary	
Type of solution	Centralised plug-in charging
Vehicle segment	e-3W
Battery capacity	2.8 kWh
Charger capacity	2 kW
Charging time	2-2.5 hours
Charging cycle	1.5 charges per day
Area requirement	Not available
Operating model	Captive charging facilities set up by fleet operator
Stakeholder category	EV passenger fleet operator
Connected load at charging/swapping facility	20 kW for charging 10 vehicles[41]

SmartE is also piloting battery swapping solutions for their fleet in partnership with Sun Mobility. The vehicles are retrofitted with two 1.5 kWh detachable batteries.

6.10 Swapping facilities for e-rickshaw passenger fleet

e-3W → Passenger → Swapping

Ola Electric launched India's first multimodal electric mobility (e-mobility) project involving a fleet of e-rickshaws and electric cars in Nagpur in 2017. The e-3Ws with detachable 2.8 kWh lithium-ion batteries were charged using bulk chargers and portable chargers. The reported charging times using the rack/bulk charger (Figure 25) and portable charger (Figure 26) were 2 hours and 6 hours, respectively. The Nagpur pilot introduced battery swapping because it had the potential to eliminate driver wait time at charging stations and thereby increase their opportunities to earn revenue. They also found that the area required to set up battery swapping stations was a fraction of the

41 Estimated using capacity of one charger, i.e. 2 kW

area needed for a park-and-charge solution. The Nagpur pilot demonstrated that battery swapping can be an effective charging mechanism for e-3Ws in particular and LEVs in general. Ola has also set up swapping facilities in Gurugram (Arora & Raman, 2019) (Quartz, 2019).

FIGURE 25: BULK BATTERY CHARGER USED BY OLA ELECTRIC IN NAGPUR

Picture courtesy: Ola Electric

FIGURE 26: PORTABLE BATTERY CHARGER USED BY OLA ELECTRIC IN NAGPUR

Picture courtesy: Ola Electric

Case Study Summary	
Type of solution	Stack and individual battery swapping
Vehicle segment	e-3W
Battery capacity	2.8 kWh
Charger capacity	1.5 kW for bulk charger and 0.5 kW for portable charger[42]
Charging time	2 - 6 hours
Charging cycle	Not available
Area requirement	Not available
Operating model	Captive swapping facilities set up by fleet operator
Stakeholder category	EV passenger fleet operator & swapping service provider[43]
Connected load at charging/ swapping facility	15 kW for a bulk charger for 10 batteries[10]

42 Estimated at a 0.5 C-rate for stack chargers and a 0.16 C-rate for portable chargers, corresponding to charging times of 2 and 6 hours, respectively.

43 Estimated for 10 batteries at a capacity of 1.5 kW per battery.

6.11 Summary of the case studies

Table 6 summarises the key aspects of the different charging practices adopted for commercial e-2Ws and e-3Ws in India.

TABLE 6: SUMMARY OF THE CASE STUDIES

Operating Entity	Plug-in EV Charging	Battery Swapping	Vehicle Category	Operational Category	Charging Service Operating Model
Ather	Distributed EV charging		e-2W	Passenger	Subscription model for customers; tie-ups with shops
Bounce		Individual battery swapping	e-2W	Passenger	Tie-up with kirana stores
Dabadigo		Individual battery swapping	e-2W	Passenger	Swapping facilities set up by fleet operator
DOT	Centralised EV charging		e-2W, e-3W	Logistics	Captive charging facilities set up by fleet operator
eFleet Logix	Centralised EV charging		e-3W	Logistics	Captive charging facilities set up by fleet operator
Gayam Motor Works		Stack battery swapping	e-3W	Logistics	Captive swapping facilities set up by fleet operator
Lithion Power		Stack battery swapping	e-3W	Passenger, Logistics	Battery charging and swapping
SUN Mobility		Stack battery swapping	e-2W, e-3W	Passenger, Logistics	Provides swapping service to vehicles using its proprietary batteries
SmartE	Centralised EV charging		e-3W	Passenger	Captive charging facilities set up by fleet operator
Ola Electric		Individual and stack battery swapping	e-3W	Passenger	Swapping facilities set up by fleet operator

7. Different types of e-2W and e-3W charging facilities

The case studies on the different charging practices for commercial e-2Ws and e-3Ws not only shed light on the various key aspects of these models, but also provide an idea of how market players are leveraging them in their businesses. In this chapter, the study attempts to determine market players' rationale for adopting specific charging methods and technologies.

7.1 e-2W passenger fleet charging facilities

In the case of passenger e-2Ws, it is found that on one hand, Ather has used a distributed plug-in charging model, wherein it has tied up with shop owners in many instances to use part of their space for the chargers. On the other hand, Bounce and Dabadigo, two key e-2W fleet operators, have set up individual battery swapping facilities. Bounce has also tied up with kirana stores for battery swapping. From the passenger e-2W charging operating models, it is evident that all of them have opted for decentralised charging systems to charge their vehicles, where they have set up either e-2W chargers or individual battery swapping kiosks. A key reason for this could be to cover the relatively large catchment area of passenger e-2W transport.

To put it in perspective, unlike most passenger e-3Ws, e-2Ws are used for passenger mobility primarily in taxi fleets and/ or on rental. Both the bike taxi and bike rental segments do not follow fixed routes and have considerably large areas of operation. The charging requirement of these e-2Ws is not locally concentrated, and, hence, a centralised charging system is not suitable for these fleets. As the charging requirement is dispersed, Bounce and Dabadigo have set up individual battery swapping facilities. Apart from the operation model of an e-2W fleet, the high cost of space rental for a centralised charging facility in a city is a key factor causing companies to choose decentralised charging systems and also a major driver for partnering with shops, where space can be shared and the rental cost can be avoided. In the case of e-2W taxi or rental fleets, minimising vehicle downtime is also an important consideration. Hence, because of the space and time constraints in managing e-2W charging, these fleet operators have set up individual battery swapping facilities. An e-2W battery swapping operation can be performed under 5 minutes, and a battery swapping facility takes up much less space than a plug-in charging station.

In contrast, SUN Mobility has adopted a stack battery swapping model. It should be noted that its charging infrastructure not only caters to e-2Ws, but also e-3Ws, and uses these LEVs for both passenger and logistics transport. Thus, Sun Mobility is not a player in the pure passenger e-2W segment, which explains why its area of operation and charging practices are very different from the other e-2W players.

7.2 e-2W logistics fleet charging facilities

In the logistics e-2W segment, DOT is a fleet operator that has set up centralised captive EV charging facilities for its fleet. This is different from the decentralised pattern observed in the case of passenger e-2W charging. This could be attributed to the fact that the vehicle movement in logistics operations follows a hub-and-spoke model, as highlighted in the Chapter 3.

In such a case, after making a number of trips, the EVs come back to the warehouse. DOT uses the idle time of the e-2Ws for recharging. This makes central captive charging facilities effective, as they are generally housed in the warehouses, and idle time in fleet operations matches the time requirement for plug-in charging. Furthermore, these warehouses have electricity connections with adequate sanctioned demand to meet the charging load, in addition to the power demand for warehouse operations. DOT also has e-3Ws in its logistics fleet, which are charged in the same way.

eFleet Logix, a pure logistics e-3W fleet operator, has adopted a charging solution similar to that of DOT for its fleet. In contrast, Gayam Motor Works has set up a captive stack battery swapping facility to meet the charging requirement of its e-3W logistics fleet. As these logistics vehicles can be conveniently charged at one place, i.e. a warehouse, the fleet operator has chosen the stack battery swapping option, instead of individual battery swapping.

There is a clear similarity in the charging practices of all the logistics fleet operators – central charging places, usually at warehouses, instead of distributed charging systems, which are common in the case of passenger LEVs. However, the charging technologies used by these logistics fleet operators differ – some have opted for plug-in vehicle charging, whereas others have adopted the battery swapping method. The choice depends on the logistics fleets' operational characteristics. When idle vehicle time at a warehouse can accommodate plug-in charging (in the range of 2 to 4 hours), this solution is employed, and in cases where fleet operators cannot afford such downtime, stack battery swapping is preferred.

7.3 e-3W passenger fleet charging facilities

In the case of passenger e-3W fleets, there is a greater preference for battery swapping. SmartE, a passenger e-3W fleet operator currently operating a captive plug-in charging facility for its fleet, is also testing out a battery swapping service. This move can be correlated with the transition made from lead acid to lithium-ion batteries in the company's e-3W fleet. Ola Electric's e-3W fleet charging includes is a mix of individual and stack battery swapping. Lithion Power, whose business entails only providing charging services to passenger e-3Ws, has opted for stack battery swapping.

In a nutshell, one can conclude that the choice of charging method depends entirely on the charging service provider's business model and/ or the e-2W/ e-3W fleet's operational characteristics when the fleet operator manages the charging of its own fleet. Both the business model and fleet's operational characteristics are found to vary. Hence, a "one-size-fits-all" approach to identifying the most suitable e-2W and e-3W charging methods is not appropriate. However, based on the different charging practices currently followed in this segment, the study has identified five salient types of public charging facilities for LEVs, as described below.

7.4 Types of e-2W and e-3W public charging facilities

Given that both plug-in charging and battery swapping are possible for e-2Ws and e-3Ws, the charging facilities for this segment should include these technologies. The more interesting issue to explore is how to adopt different formats for these charging options. The study identifies five types of public charging facilities that can cater to the charging requirements of e-2Ws and e-3Ws. For each type of facility, the major planning-related aspects are explained in detail. The study provides two sets of reference sheets, grouping plug-in charging and battery swapping solutions according to the charging of individual or multiple batteries, with similar formats for easy comparison.

1. **Individual EV charging facility (IEV):** This caters to the charging needs of one EV (e-2W or e-3W) at a time. This kind of facility can be set up anywhere on the side of a road where an e-2W/ e-3W can be parked and charged. Any commercial establishment, such as a kirana store or commercial office building, can provide the electricity required for the individual EV charger. Individual EV charging facilities are easier to set up, as the power requirement for this type of facility is limited to 3 kW and will not typically necessitate increasing the sanctioned demand of the site. A reference sheet (refer to Table 7) highlights the major technical and spatial aspects of this type of charging facility.

TABLE 7: REFERENCE SHEET FOR INDIVIDUAL EV CHARGING AND BATTERY SWAPPING FACILITIES

Aspects	Parameter	Details	
Basic details	Charging facility type	Individual EV charging facility (IEV)	Individual battery swapping facility (IBS)
	Type of charging	AC/DC charging	Battery swapping
	Location	Parking space, kirana store, office, etc.	
Electricity connection requirement	Type of connection	LT single-phase	
	Power requirement (kW)	3.3	
	Connection voltage (V)	230	
	Maximum current (A)	16	
Charger details	Type of charger	Fixed/ portable charger	Battery charger
	Maximum output power (kW)	3	
	Output voltage (V)	230 for AC charging 48-72 for DC charging	48-72 for DC charging
	Installation	Wall/ pole mounting	

Aspects	Parameter	Details	
Required auxiliary equipment	Metering equipment	Electricity meter	
	Protection equipment	Overcurrent and ground fault protection	
	Monitoring equipment	Communication (GPRS/CAN/RS232) device	
	Payment interface	Digital payment facility	
Required space	Parking area for e-2W (m x m)	2 x 1	
	Parking area for e-3W (m x m)	3 x 2	
	Area required for EVSE (sqm)	0.1	0.5

2. **Individual battery swapping facility (IBS):** This type of facillity can cater to the charging needs of an individual e-2W or e-3W that has a swappable battery. Such facilities can be set up at any commercial establishment, such as a kirana store, with a parking space for an e-2W or e-3W and an electricity connection with sufficient power for the battery charger. These facilities are similar to individual EV charging facilities and easy to set up, as the power requirement for this type of facility will not typically necessitate increasing the sanctioned demand of the site. Table 7 summarises the major technical and spatial aspects of this type of swapping facility. It is important to remember that in such facilities, the commercial establishment owner might need to maintain a stock of spare batteries for the e-2Ws and e-3Ws.
3. **Multiple EV charging facility (MEV):** This refers to a charging facility that facilitates the charging of multiple e-2Ws and e-3Ws at the same time. This kind of facility can be set up in any parking area where adequate space is available to install the charging infrastructure. The parking area could be in a public place, such as a public transit hub, mall, shopping centre, business district, hospital, school, community hall, etc. The under-utilised land in urban areas, such as land under flyovers, is also a suitable location for this type of facility. The electricity connection required for such facilities depends upon the number of vehicles that need to be charged at the facility at the same time. A new electricity connection may be required to set up this type of charging facility. A reference sheet on this type of charging facility is given in Table 8.
4. **Stack battery swapping facility (SBS):** This type of facility can cater to the charging needs of multiple e-2Ws or e-3Ws with swappable batteries. It can be set up at any location with a parking space for an e-2W or e-3W. The parking space could be in a public place, such as a public transit hub, mall, shopping centre, business district, hospital, school, community hall, etc. The underutilised land in urban areas, such as land under flyovers, is also a suitable location for this type of facility. The major difference between this type of facility and an MEV is that it requires less parking space. As the swapping operation only takes a few minutes, such facilities can be set up in smaller spaces. The electricity connection required for such facilities depends upon the number of batteries that need to be charged at the facility at the same time. A new electricity connection is typically required to set up this type of swapping facility. A reference sheet on SBS facility is given in Table 8.

5. **Battery swapping-only facility (BSO):** This type of facility offers swapping services without on-site battery charging, serving as a dispenser of charged batteries for swapping operations. In this case, battery charging[44] happens elsewhere. These types of facilities are easier to establish, as they can be set up anywhere without the requirement of an electricity connection at the site. Nevertheless, it should be noted that auxiliary power might be required to monitor the batteries and facilitate swapping. However, the power required for battery monitoring and swapping is significantly lower than that needed for battery charging. This type of facility can be established anywhere with a parking space for an e-2W or e-3W.

TABLE 8: REFERENCE SHEET FOR MULTIPLE EV CHARGING AND STACK BATTERY SWAPPING FACILITIES

Aspects	Parameter	Details	
Basic details	Charging facility type	Multiple EV charging facility (MEV)	Stack battery swapping facility (SBS)
	Type of charging	AC/DC charging	Battery swapping
	Location	Parking areas, shopping centres, hospitals, community centres, etc.	
Electricity connection requirement for charging 10 vehicles	Type of connection	LT three-phase	
	Power requirement (kW)	20-25	
	Connection voltage (V)	415	
	Maximum current (A)	63	
Charger details	Type of charger	Fixed/ portable charger	Stack battery charger
	Maximum output power per charger (kW)	3	
	Output voltage (V)	230 for AC charging 48-72 for DC charging	48-72 for DC charging
	Installation	Wall/ pole mounting	
Required auxiliary equipment	Metering equipment	Electricity meter	
	Protection equipment	Overcurrent and ground fault protection	
	Monitoring equipment	Communication (GPRS/CAN/RS232) device	
	Payment interface	Digital payment facility	
Required space	Parking area for e-2W (m x m)	2 x 1	
	Parking area for e-3W (m x m)	3 x 2	
	Area required for one EVSE (sqm)	0.1	0.5

44 It is expected that the specifications for the charging facilities in this case would be similar to those for SBS facilities in Table 8.

8. Stakeholder feedback on charging options

An online survey was conducted with stakeholders to understand the relative preferences of fleet operators and charging service providers for the different types of charging and swapping facilities. The survey requested that the stakeholders give a weight to each type of charging facility on a scale of 1 to 9 based on their preferences, as shown in Figure 27. "9" represents the highest preference for a certain type of charging/swapping facility, and "1" represents the lowest.

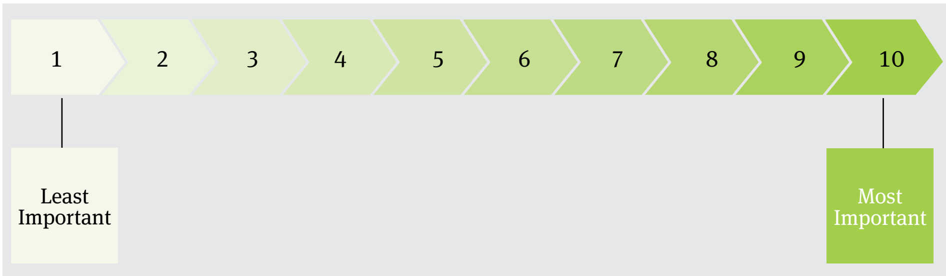


FIGURE 27: SCALE USED IN STAKEHOLDER SURVEY

The stakeholders' responses were anonymised for analysis. The scores from the responses on preference for different charging facilities were aggregated for each type of fleet, i.e. e-2W passenger fleet, e-3W passenger fleet, e-2W logistics fleet, and e-3W logistics fleet. Subsequently, for each group, the average preference for a charging facility was calculated and converted into a percentage value (using the formula $\frac{w_j}{\Sigma w_j} * 100$, where w_j is the average weight of option "*j*") to arrive at the final preference for all charging facilities. The survey results were also analysed by grouping them into plug-in charging and swapping for each respective fleet category.

8.1 Fleet preferences: Plug-in charging vs. battery swapping

From the survey results, it is evident that for e-2W fleets, both battery swapping and plug-in charging are equally preferred by the fleet operators. The reasons for this split choice include the different characteristics of the operating patterns and prevalence of EV models with detachable batteries. There are more distinct preferences in the different segments of the e-3W sector. For e-3W passenger transport, battery swapping is preferred over plug-in charging, whereas in the case of logistics transport, the reverse holds true. For e-3W passenger fleets, the time taken to charge an EV is a lost opportunity to earn revenue, and, hence, it is logical that fleet operators prefer battery swapping, which takes less time. The larger battery size and correspondingly higher weight of the batteries in e-3W logistics transport vehicles compared to e-3W passenger vehicles is the prime factor that influences the preference of logistics fleet operators for plug-in charging. A summary of fleet preferences for plug-in charging and battery swapping is presented in Figure 28.

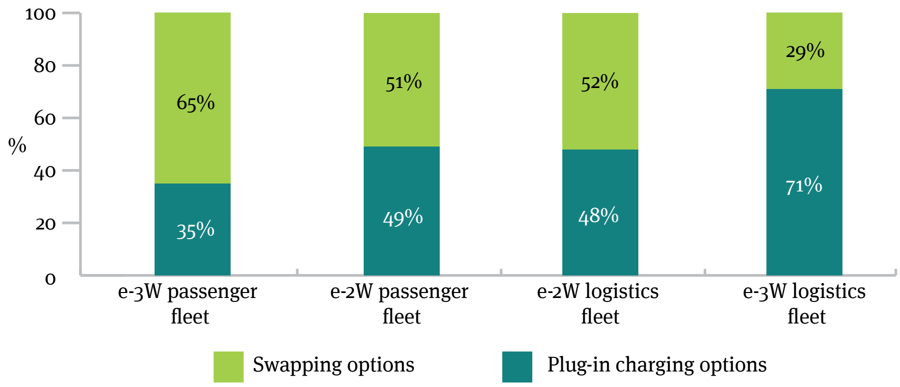


FIGURE 28: FLEET PREFERENCES FOR EV CHARGING AND BATTERY SWAPPING

8.2 e-2W fleet preferences

The relative preferences of e-2W fleet operators are shown in Figure 29. It is evident that logistics fleets prefer MEV facilities over IEV facilities. In the case of passenger fleets, the differences in preference for IEV and MEV facilities are not that pronounced. With respect to the battery swapping options, passenger fleet operators show more preference for IBS than SBS facilities, whereas logistics fleet operators prefer stacked over individual. However, when it comes to swapping-only solutions, the logistics fleet seems to be keener to adopt such solutions than the passenger fleet.

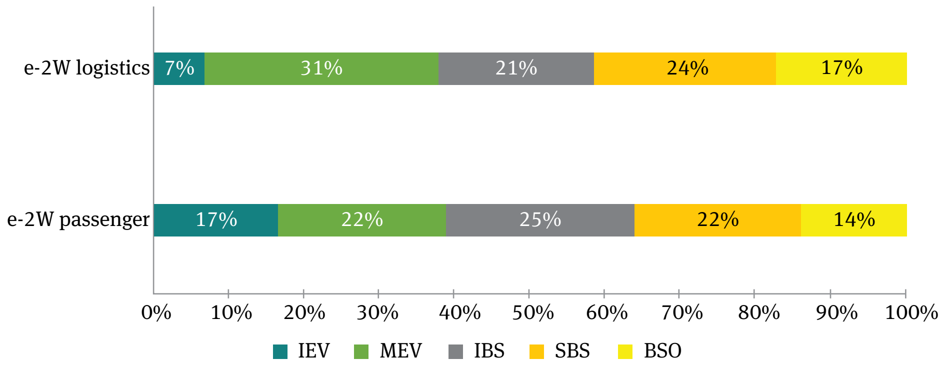


FIGURE 29: SUMMARY OF E-2W FLEET PREFERENCES

8.3 e-3W fleet preferences

The preferences of the e-3W passenger and logistics fleets are quite different from one another (refer to Figure 30). For passenger transport, the battery swapping options, i.e. SBS, IBS, and BSO, constitute the top three preferred options, with the highest preference for SBS.

In the case of logistics operations, there is a strong preference for plug-in charging options, particularly MEV facilities. The relative preferences for all battery swapping options are quite low.

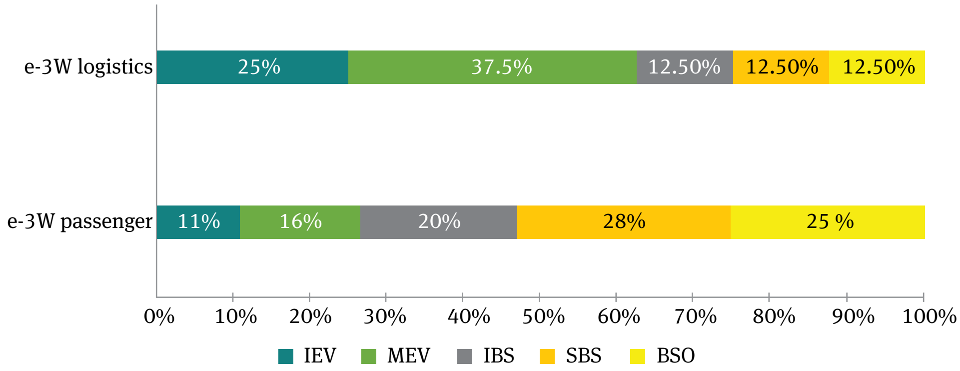


FIGURE 30: SUMMARY OF E-3W FLEET PREFERENCES

9. Multi-criteria assessment of public charging facilities

There are 5 main types of public charging facilities for e-2W and e-3W fleets, and each of them has its unique advantages, and the suitability for a particular fleet depends on how the advantages are leveraged in the fleet operations. Since the operational characteristics of these LEV fleets vary considerably, recommending a particular type of charging facility for all e-2W and e-3W fleets is not a useful exercise. Rather, it is important to carry out a qualitative comparative assessment of these different charging facilities, to help charging service providers and fleet operators make an informed decision when choosing the type of charging facility. Accordingly, they can invest directly in the charging infrastructure for LEV fleets or tie up with a charging service provider or OEM. The BSO option has not been included in this assessment, since this facility only performs the swapping operation and therefore is not comparable to actual charging facilities. The study has identified 6 parameters and a scale of 1 to 5, with 5 being the highest/best, for the comparative assessment of different e-2W and e-3W charging facilities (refer to Table 9).

TABLE 9: COMPARATIVE ASSESSMENT PARAMETERS AND SIGNIFICANCE OF THE SCALE

Parameter	**Significance of the applied scale – what "5" means**
Vehicle downtime	Least vehicle downtime for charging
Cost of space rental	Lowest cost incurred
Cost of infrastructure (excluding space)	Lowest infrastructure cost
Cost of electricity (tariff)	Attracting lowest tariff
Ease of getting electricity connection	Easiest to get electricity connection
Scalability (ability to cater to the charging requirement of numerous fleets)	Easiest to scale up

The competitive advantages of the five types of charging facilities in each parameter are discussed below.

1. **Vehicle downtime:** This parameter considers only the downtime of an e-2W or e-3W and does not include the time to recharge the battery if it is done outside the vehicle. As one can charge an e-2W or e-3W through battery swapping in less than 10 minutes, as compared to a minimum of one hour for plug-in charging, the swapping-based charging facilities score high in this parameter. Figure 31 shows the vehicle downtime scores of the different charging facilities.

Type of charging facility	Score on a scale of 1 to 5
IEV	○
IBS	○ ○ ○ ○ ○
MEV	○
SBS	○ ○ ○ ○ ○

FIGURE 31: VEHICLE DOWNTIME SCORES OF CHARGING FACILITIES

2. **Cost of space rental:** This is an important parameter to consider. Due to space constraints in Indian cities, the cost of space rental is generally very high in urban areas, particularly in commercial areas. Based on the stakeholder consultation, space rental cost constitutes the largest share of recurring operational costs for charging stations. In this regard,

decentralised charging facilities, both plug-in charging and battery swapping, can incur less expenditure for space than centralised facilities like MEV or SBS. A key reason for this is that such distributed charging facilities are generally set up in the premises of large shops (in the case of IEV) or kirana stores (in the case of IBS), where the rental cost is far lower due to co-sharing of the space. Since MEV facilities take up the most space, even more than SBS for charging the same number of e-2Ws and e-3Ws, they have the highest cost of space rental. The space rental cost scores are shown in Figure 32.

Type of charging facility	Score on a scale of 1 to 5
IEV	○ ○ ○ ○
IBS	○ ○ ○ ○ ○
MEV	○
SBS	○ ○ ○

FIGURE 32: SPACE RENTAL COST SCORES OF CHARGING FACILITIES

3. **Cost of infrastructure:** The cost of infrastructure primarily covers the vehicle or battery chargers, spare batteries, battery stack set-up with or without mechanised tools, metering and monitoring equipment, and/or distribution transformer, if applicable. The cost comparison is done at the facility level, not on a per vehicle or battery charging basis. Although both IEV and IBS facilities have similar minimalist designs, an IBS facility requires spare batteries, which incurs additional costs compared to an IEV facility. Similarly, between MEV and SBS facilities, the former would require less investment, as the battery stack set-up costs more and adds to the total investment required in the case of an SBS facility. Both these facilities cost more than the other two options, primarily due to the cost of the distribution transformer, the installation of which might be necessary for the charging facility (depending on the scale of the facility). Figure 33 shows the infrastructure cost scores of the charging facilities.

Type of charging facility	Score on a scale of 1 to 5
IEV	○ ○ ○ ○ ○
IBS	○ ○ ○ ○
MEV	○ ○
SBS	○

FIGURE 33: INFRASTRUCTURE COST SCORES OF CHARGING FACILITIES

4. **Cost of electricity:** In this evaluation, electricity cost scoring has been done based on the tariff that would most likely be applicable to a given charging facility. A public charging facility may attract commercial tariffs or special EV tariffs. Many states have introduced preferential tariffs for EV charging, which are set lower than the commercial rates. Moreover, the regulator may do away with other charges in the case of EV charging. Within each tariff category, a charging facility may have to apply for an LT or HT connection based on the expected power demand at the facility. The difference in tariffs manifests itself in the form of differentiated energy (variable) charges and demand (fixed) charges.

Generally, LT connections attract higher per unit energy charges (₹/ kWh) but lower demand charges (₹/ kW) compared to HT connections.

Availing of special EV tariffs improves the economics of operating a charging station because of the lower energy and demand charges[45]. However, there are eligibility criteria, such as not using the charging station for captive purposes only and having the electricity connection and metering be separate from those for other electricity uses. One should be mindful of the fact that the Supply Code and the Tariff Regulations vary from state to state. Among the four types of charging facilities, IEV and IBS may not be eligible for special EV tariffs, as they are usually set up in premises used for other purposes (e.g. shops). If they are established in the premises of shops, they may be able to avail of the LT tariffs, since the cumulative power demand for EV charging and shop operations may still be in the LT bracket. On the other hand, since MEV and SBS facilities are expected to have dedicated electricity connections and metering, they would be entitled to benefit from special EV tariffs. However, they may have to get HT connections, because of the higher power demand. Considering all these factors, MEV and SBS facilities are expected to attract lower energy charges and almost equal or no demand charges compared to IEV and IBS facilities. SBS facilities offer an additional advantage. Due to flexibility in battery charging with respect to time, they can control the charging power demand by staggering the battery charging over a certain time period and potentially benefit from Time of Day (ToD) tariffs by charging the batteries during off-peak hours. Figure 34 shows the scores of the charging facilities for this parameter.

Type of charging facility	Score on a scale of 1 to 5
IEV	○
IBS	○
MEV	○ ○ ○ ○
SBS	○ ○ ○ ○ ○

FIGURE 34: ELECTRICITY COST SCORES OF CHARGING FACILITIES

5. **Ease of getting electricity connection:** This is an important parameter, because it not only affects the implementation timeline for setting up a charging facility, but may also impact the project cost. The ease of getting an electricity connection depends on the availability of an existing connection with adequate sanctioned load and the ability to cater to the charging requirement without an 11/ 33 kV connection. On this front, the study finds that both IEV and IBS facilities have a clear advantage over MEV and SBS facilities, because the power demand at these facilities is much lower than that of multi-user facilities, and the sanctioned load of the existing connections at the premises is sufficient to meet the charging power demand. MEV and SBS facilities may require HT connections and, hence, the process of getting an electricity connection could be more complex and take more time. Nevertheless, since SBS facilities can manage the load by distributing battery charging over time, the power demand requirement can be reduced to some extent in this case. The scores of the charging facilities on ease of getting an electricity connection are shown in Figure 35.

45 Many states have extended the benefit of not imposing any demand charge to public EV charging stations.

Type of charging facility	Score on a scale of 1 to 5
IEV	○ ○ ○ ○ ○
IBS	○ ○ ○ ○ ○
MEV	○ ○
SBS	○ ○ ○

FIGURE 35: SCORES OF CHARGING FACILITIES ON EASE OF GETTING ELECTRICITY CONNECTION

6. **Scalability:** This parameter refers to the ability of a charging method to cater to the charging requirement of numerous e-2W and e-3W fleets. Due to the modular design, moderate space requirement, flexible power demand, and ability to charge multiple vehicles in a very short period of time, SBS facilities can potentially offer significant scalability, provided that adequate investment is made in creating a pool of batteries. Due to their minimalist designs, IEV and IBS facilities are also potentially scalable options, but since they often entail tie-ups with large shops or kirana stores, they are dependent on the success of such tie-ups with actors not directly associated with or aware of the e-mobility sector in order to scale up. Among all types of charging facilities, scaling up MEV facilities in Indian cities may be the most challenging, primarily due to substantial space requirement and power demand. Figure 36 presents the scores for this parameter. It should be noted that the specific operational characteristics of a fleet and business model adopted by a charging service provider or fleet operator are two critical factors that can potentially impact the scalability of a charging solution.

Type of charging facility	Score on a scale of 1 to 5
IEV	○ ○ ○
IBS	○ ○ ○
MEV	○
SBS	○ ○ ○ ○ ○

FIGURE 36: SCALABILITY SCORES OF CHARGING FACILITIES

Figure 37 depicts the summary of the scores of the different types of LEV public charging facilities for the 6 identified parameters.

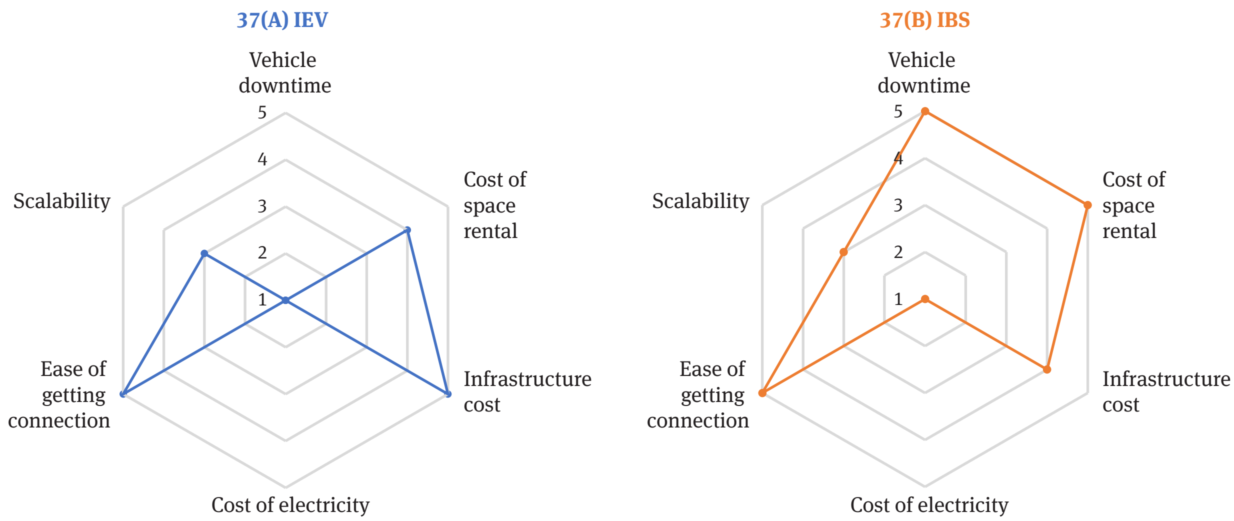


FIGURE 37 (A-B): SUMMARY OF SCORES OF DIFFERENT TYPES OF PUBLIC CHARGING FACILITIES

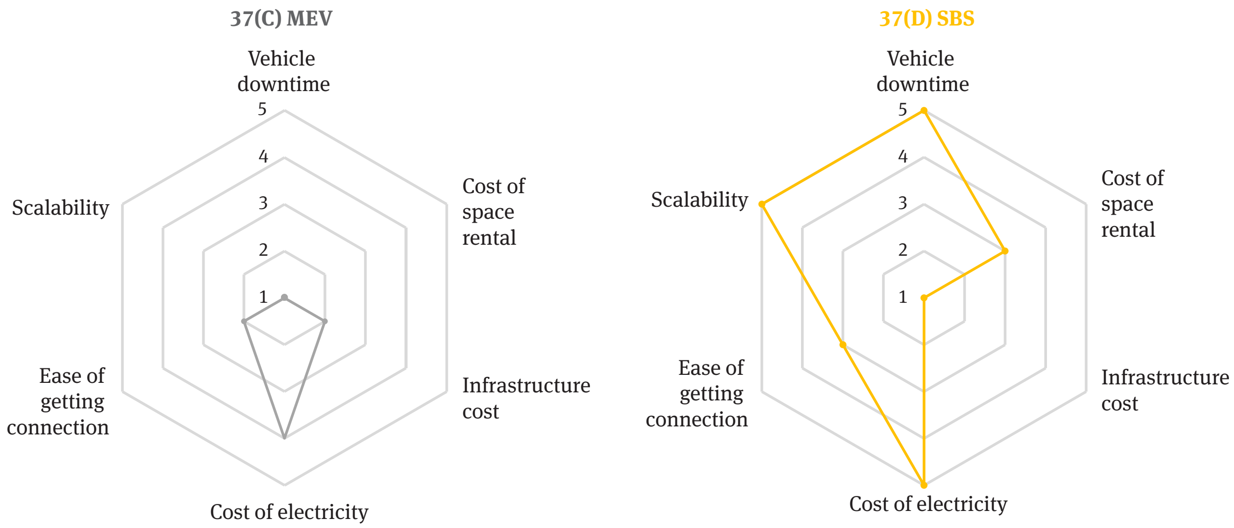


FIGURE 37 (C-D): SUMMARY OF SCORES OF DIFFERENT TYPES OF PUBLIC CHARGING FACILITIES

It should be noted that Figure 37 does not intend to indicate any best-fit charging facility for all e-2W and e-3W fleets. Again, the purpose of this multi-criteria assessment is neither to recommend a particular type of public charging facility nor rank the different options, but, rather, to show the strengths and challenges of the different types of facilities in terms of key parameters.

10. Final thoughts

Undoubtedly, e-2Ws and e-3Ws will be the main segment of electrified transport in India. To support rapid commercial adoption of these LEVs, proper planning and establishment of public charging facilities is critical. This report mapped out the practices followed by the first-movers in the market and identified practicable solutions to sustain the commercial adoption of LEVs. The study finds that the penetration of lithium-ion batteries is increasing for commercial use cases. On close inspection of the different battery configurations, it is evident that, in the LEV segment, many vehicles have detachable batteries. This makes both battery swapping and plug-in charging possible options for battery recharging. Beyond the technical specifications of the batteries, the type of charging facility needed is linked to the EV fleet's operational pattern. Decentralised charging or swapping solutions are suitable for e-2W fleets. For e-3W passenger fleets, battery swapping is an effective solution, as it helps reduce vehicle downtime. Downtime is not as much of an issue for logistics businesses, as they have an operational pattern that naturally includes such downtime and thus allows them to manage fleets with plug-in charging solutions, as well. As swapping becomes difficult with larger, heavier batteries, creative solutions such as using multiple battery packs of optimum weight are needed for this method in the case of e-3W logistics fleets.

Lack of standardisation in the design of chargers and batteries is a factor that will impact the roll-out of charging facilities for this segment. The need of the hour is to design and implement cost-effective, scaleable, and home-grown charging solutions that can meet the charging requirements of this EV segment. To this end, the study has identified 5 types of public charging facilities for e-2W and e-3W fleets, each with its own unique characteristics. Their uptake for different fleets depends on how well they fit into the fleet operations. As such operations vary considerably, a "one-size-fits-all" approach to identifying the most suitable charging solution is not appropriate. The study has therefore developed a multi-criteria comparative assessment tool for these different charging facilities to help charging service providers and fleet operators make informed decisions when choosing the necessary charging solution(s). According to the results of the study, parameters such as vehicle downtime, cost of space rental, infrastructure cost, electricity cost, ease of getting an electricity connection, and scalability should be part of the evaluation of the potential charging solutions.

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