# Can Indian Highways Support Zero-Emission Trucking?

## Assessment of Charging Infrastructure on Delhi-Agra Highway (NH44)

### Annexure

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# 1. Annexure

## 1.1. Data collection and synthesis

*Figure A1: Primary and secondary data collected, compiled, and harmonised*

*Source: Authors' analysis*

*Note: LULC-Land use and land cover, PoI- Point of Interest, PV-Photovoltaic*

The framework maps the primary and secondary data sources in traffic and existing infrastructure categories. Surveys are conducted at truck rest areas, industrial clusters, mandis, and fuel stations to capture vehicle characteristics and travel patterns. Fast tag IHMCL and other literature sources capture the approximate vehicle flow in the highway corridor. A road network intelligence survey with web scraping through Google API and OSM is conducted to capture the existing infrastructure along the highway corridor.

## 1.2. Vehicle-in-se and inventory survey (VIUS)

*Table A1: Vintage to origin-destination: 6 major themes from fuel station and focal point freight survey*

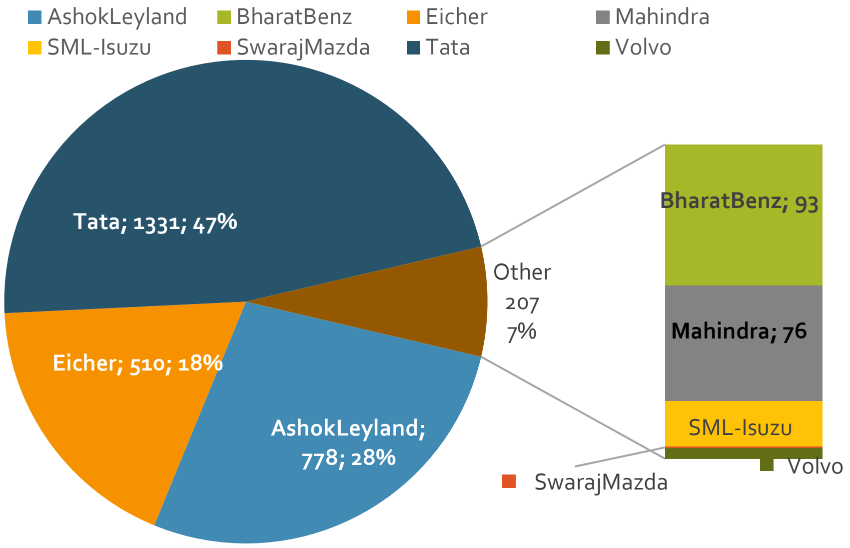
| Theme | Questions | Data type |
|---|---|---|
| Vintage | 1. Axles<br>2. GVW and age<br>3. Fuel type<br>4. Make and model<br>5. Mileage<br>6. Odometer | 7. Numeric<br>8. Numeric<br>9. Categorical<br>10. Open-ended<br>11. L or kg per km<br>12. Numeric |
| Commodity | 13. Commodity transporting | 14. Categorical |
| Trip metrics | 15. Trip distance<br>16. Trip frequency<br>17. % share of tonne-km on city roads<br>18. % share of tonne-km on highways | 19. Numeric<br>20. Numeric[&]<br>21. Categorical<br>22. Categorical |
| Refuelling | 23. Fuel tank level when typically refuelled<br>24. Refuelling frequency | 25. Categorical<br>26. Numeric[&] |
| O-D | 27. Origin – city and landmark<br>28. Destination – city and landmark | |
| Tolls, Stops and Dwelling times* (Average daily) | 29. Number of tolls passed-through<br>30. Number of stops<br>31. Dwell time per stop | Numeric |

[&]weekly/monthly/daily as options to select

*Source: Authors' analysis*

### 1.2.1 Descriptive summaries

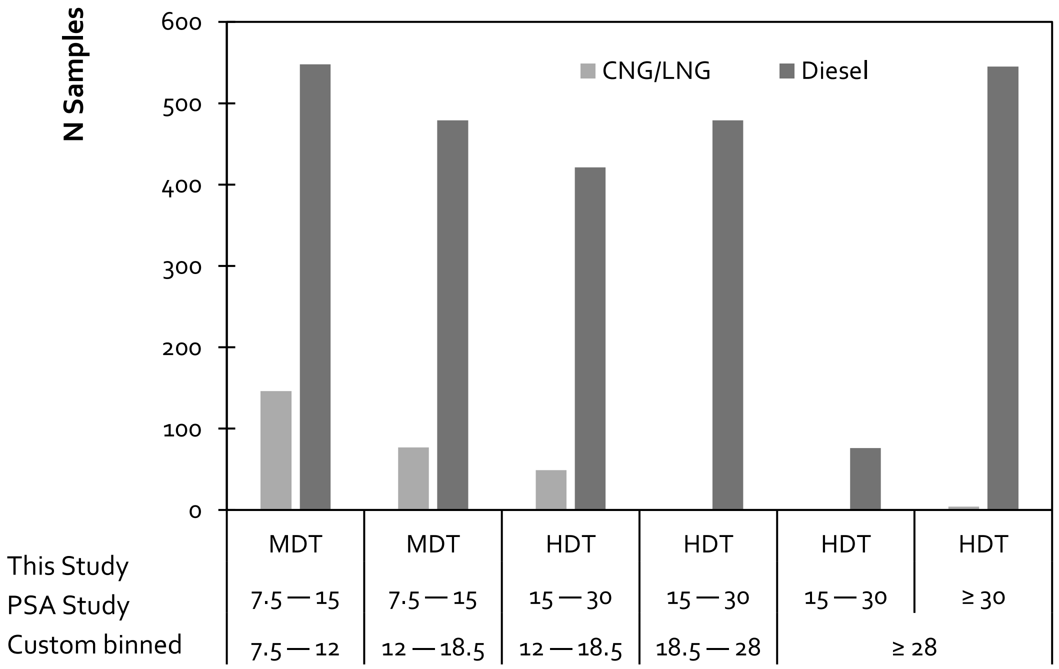
*Figure A2: 75% of MHDT segment represented by TATA Motors and Ashok Leyland*



*Source: Authors' analysis*

This pie chart shows that the sample is concentrated among three dominant manufacturers: Tata (47 per cent), Ashok Leyland (28 per cent), and Eicher (18%), which together account for over 90 per cent of the total. Other OEMs like BharatBenz, Mahindra, and SML-Isuzu make up a much smaller share, reflecting the real-world concentration in India's commercial vehicle sector.

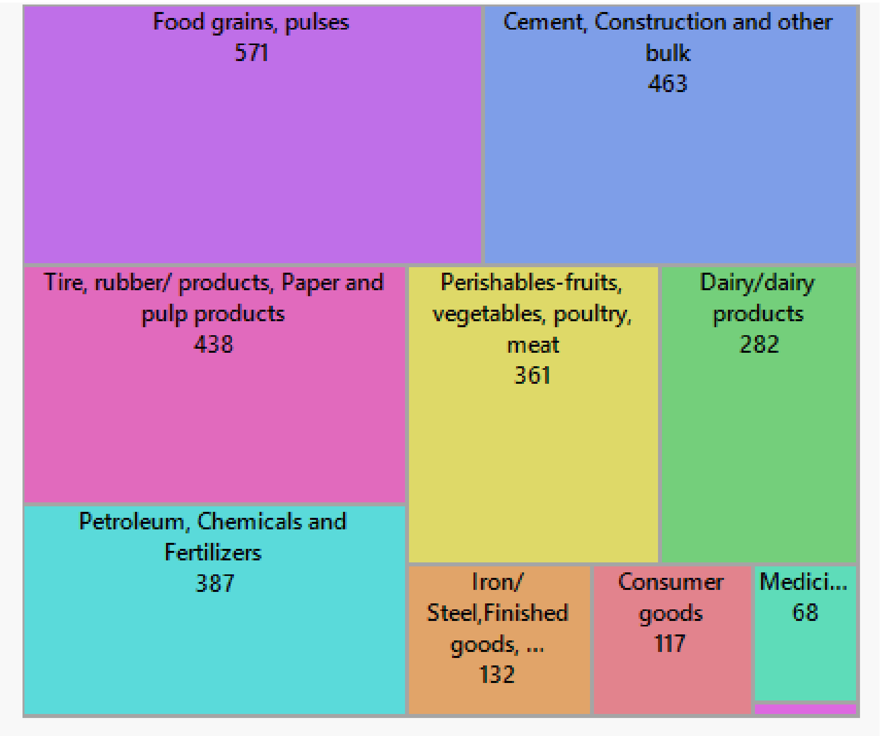
*Figure A3: Diesel-powered trucks dominate across all tonnage bins, especially in heavy-duty segment*



*Source: Authors' analysis*

The bar chart highlights that diesel-powered trucks dominate across all tonnage bins, particularly in the medium-duty (7.5–15T) and heavy-duty (≥30T) segments. The custom binning aligns with both PSA and study-specific categories, helping harmonise regulatory and practical classifications.

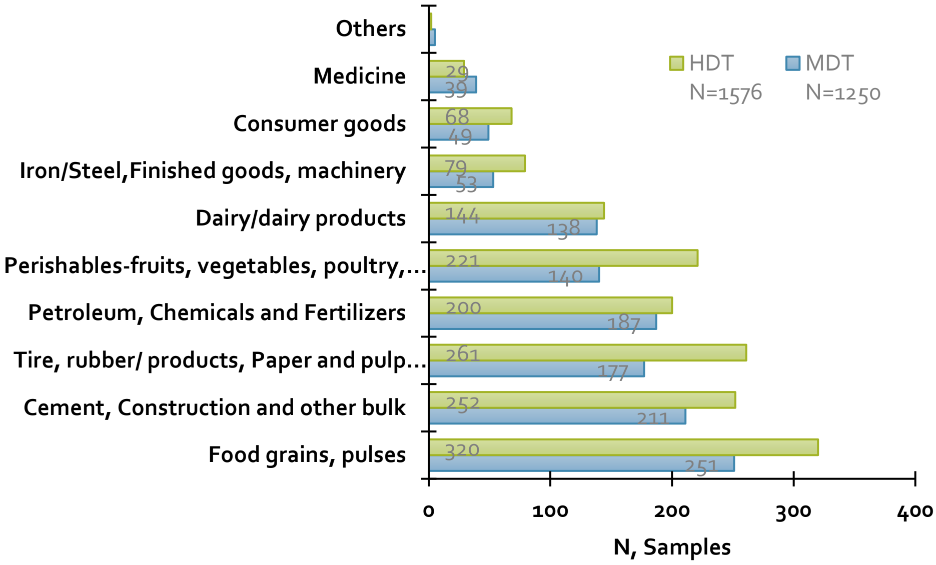
*Figure A4: Food grains to cement: Breaking down sample by commodity transported (N=2,826)*



*Source:* Field survey conducted by CEEW, 2025

This tree map illustrates the diversity of freight types. Leading categories include food grains (571), construction bulk (463), and rubber/paper products (438), followed by petroleum/chemicals (387), and perishables (361). This spread mirrors profile of India's industrial, construction, and agro-logistics sectors.

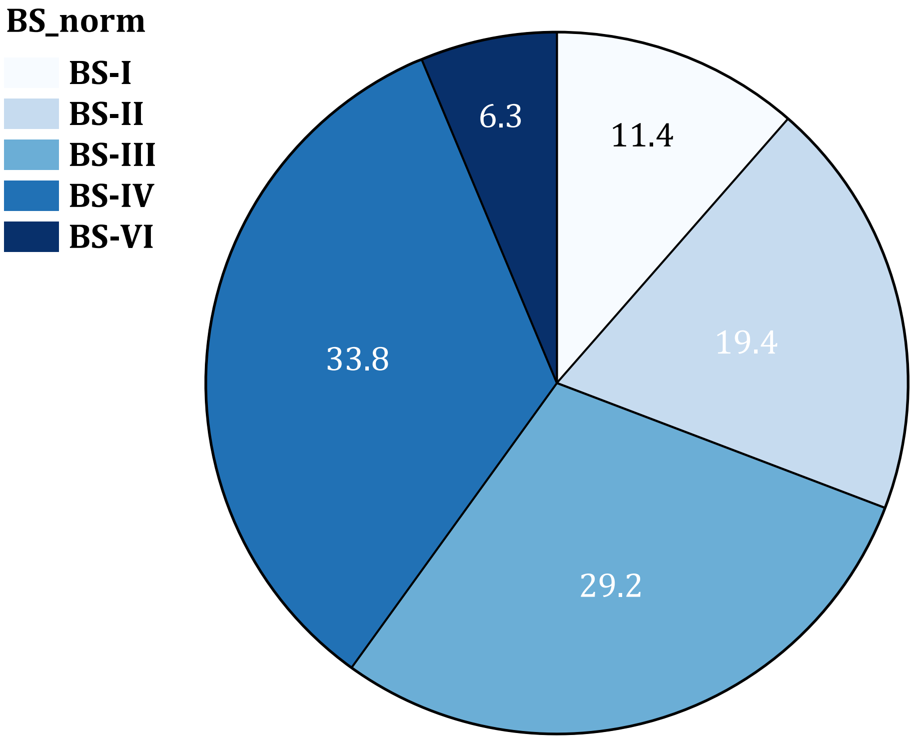
*Figure A5: HDTs dominate construction-bulk transport. Slim medicine lead for MDTs*



Source: *Field survey conducted by CEEW, 2025*

This bar chart disaggregates commodity types by vehicle class. HDTs dominate heavier goods like food grains, construction materials, and perishables, while MDTs are more involved in urban or mid-range goods such as dairy and consumer items. The clear separation reinforces segment-specific use cases.

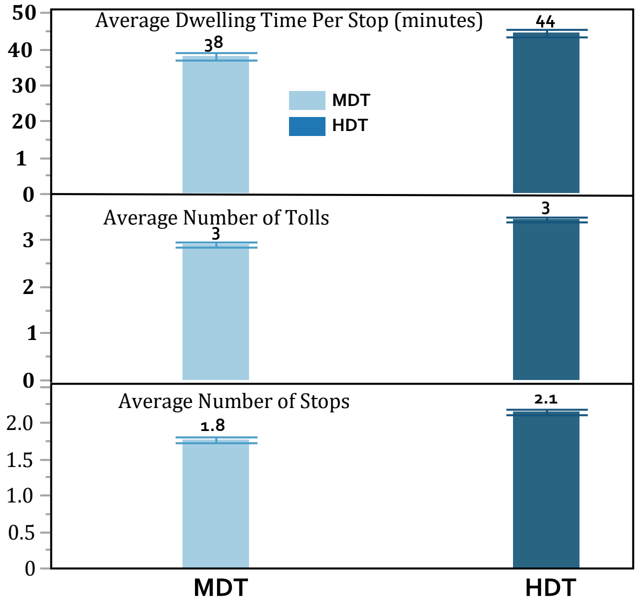
*Figure A6: Just 40% of trucks registered at  BS-IV & above*



*Source: Field survey conducted by CEEW, 2025*

The pie chart reveals a skew towards older emissions categories: BS-III (29.2 per cent) and BS-IV (33.8 per cent) together account for over 63 per cent, while BS-VI adoption is just 6.3 per cent, underscoring the slow fleet modernisation and persistence of polluting legacy trucks.

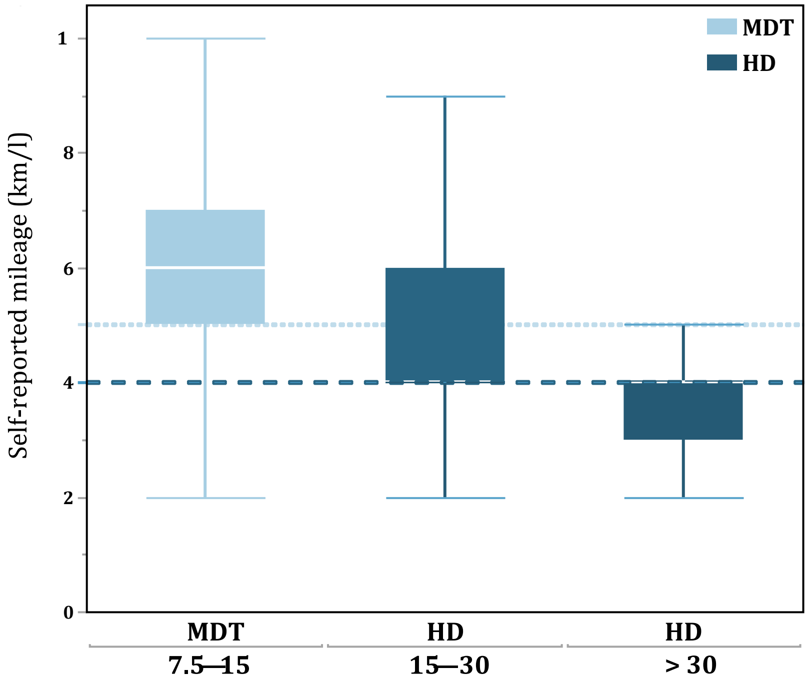
*Figure A7: HDTs experience longer dwell times per stop*



*Source: Authors' analysis*

Three stacked bar plots compare MDT and HDT vehicles. HDTs experience longer dwell times per stop (44 vs. 38 mins) and more stops (2.1 vs. 1.8), which indicates longer rest, loading, or refuelling durations. Both segments pass through an average of three toll plazas. The error bars are small, suggesting consistent responses across the sample. These differences highlight marginally higher operational downtime and stop frequency for HDTs.

*Figure A8: Self-Reported Mileage is 6 km/l for MDT and 4 km/l for HDT*

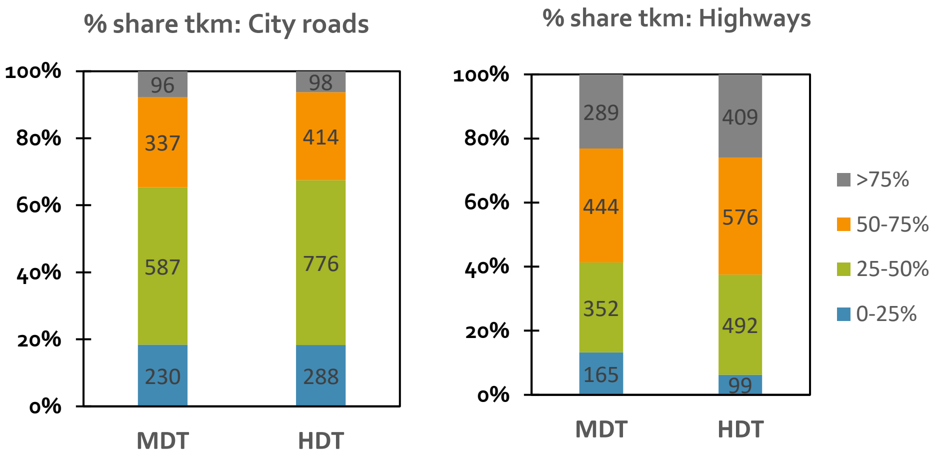


*Source: Field survey conducted by CEEW, 2025*

*Note: Dashed lines inset shows the assumed fleet average mileage for MDT and HDT*

Mileage is inversely related to tonnage. MDTs (7.5–15T) show higher median mileage (~6 km/l) than HDTs, especially those >30T, where mileage drops to below 4 km/l. The range of values is also wider for MDTs, suggesting more variability based on use-case or driver behaviour. HDTs in the 15–30 t range show a lower median around 4 km/l, but with considerable spread. HDTs above 30 t have the lowest and most tightly clustered mileage, with a median near 4 km/l and limited variability.

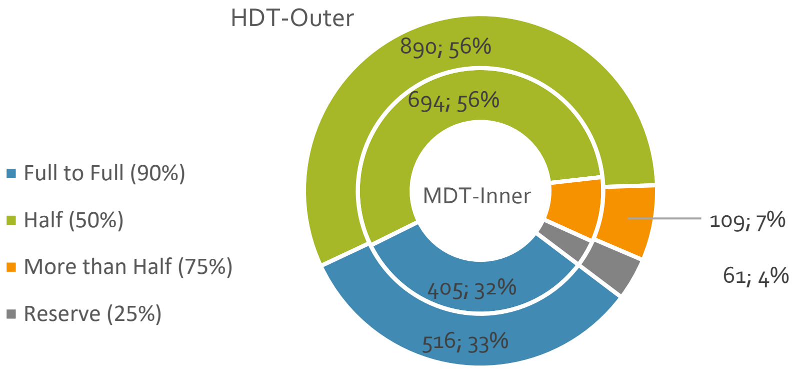
*Figure A9: Nearly 60% of HDTs and MDTs surveyed accomplish over two-thirds of tonne-km on highways*



*Source: Field survey conducted by CEEW, 2025*

*This set of stacked bars distinguishes tonne-km distribution across city roads and highways. For both MDT and HDT, the majority of freight (>50 per cent) falls in the 25–75 per cent share range. However, HDTs show a greater share of >75 per cent tonne-km on highways, indicating long-haul dominance. shows the distribution of tonne-kilometres (tkm) by road category and intensity for MDTs and HDTs. On city roads, the majority of movement falls within the 25–50 per cent tkm share bracket, with MDTs reporting 587 samples and HDTs, 776. Higher-intensity city usage (>75 per cent) is rare across both segments. On highways, however, a larger proportion of HDT trips fall into the >50 per cent t-km categories, particularly >75 per cent (409 samples) and 50–75 per cent (576), highlighting their dominance in long-haul freight. These reflect clear operational differentiation, with HDTs more concentrated on highways and MDTs straddling both city and inter-city freight movement.*

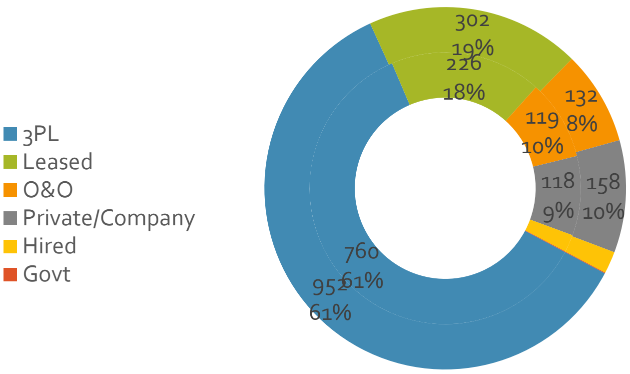
*Figure A10: Over 50% MHDTs report refuelling at half-tank level: How it informs charging assumptions*



*Source: Field survey conducted by CEEW, 2025*
*Note: Data labels show N samples; per cent of respective share. Inner/Outer ring for MDT/HDT respectively*
*Full, Half, More than Half and Reserve refer to the tank levels*
*Values within parentheses of legend are the equivalent SoC assumptions with respect to charging*

The figure illustrates the self-reported refuelling behaviour of MHDTs surveyed, which informs charging behaviour assumptions. For both segments, over half the respondents (56 per cent) reported refuelling at the half-tank level, corresponding to a 50 per cent state-of-charge (SoC) assumption for charging. Among MDTs, 33 per cent (546 respondents) reported refuelling full to full. This share is slightly lower at 32 per cent (405 respondents) for HDTs — translating to charging SoC of 90 per cent. Fewer respondents reported “more than half” (109; 7 per cent) and “reserve” (61; 4 per cent) behaviour, equivalent to 75 per cent and 25 per cent SoC, respectively. These self-reported refuelling levels were proxied for estimating ZET charging demand.

*Figure A11: Third-party logistics providers dominate MHDT ownership profile*



*Source: Field survey conducted by CEEW, 2025*
*Note: O&O-owned and operated, 3PL-hird-party logistics/LSPs. MDT-Inner and HDT-Outer*

The figure presents the ownership profile of MDT and HDT respondents. Third-party logistics providers (3PLs) dominate both categories, comprising 61 per cent of the sample in each (760 MDT, 952 HDT). Leased vehicles are the next most common, accounting for 19 per cent of MDTs and 18 per cent of HDTs. Other ownership types such as owned-and-operated (O&O), private/company, and hired represent smaller shares across both segments. Government-owned vehicles are minimal. The pattern mirrors the high degree of intermediation in the trucking segment. Though macro-level industry data indicates that O&O trucks account for a significant share of the overall market, the higher proportion of 3PL-managed fleets in this sample reflects a bias stemming from the sampling strategy. Specifically, information on the truck's home base or operator location was not captured during data collection, limiting the ability to trace ownership origin. However, this limitation does not affect the core analytical outcomes, as the results are based on trip-level operational data (flows, stops, refuelling behaviour) rather than ownership-based modelling.

*Table A2: Summary statistics of key vehicle, operation, and driving attributes*

| | **Overall** | **MDT** | **HDT** |
|---|---|---|---|
| | *N=2,826* | *N=1,250* | *N=1,576* |
| | Mean (μ) ± Standard Deviation (σ) | | |
| veh_age (years) | 12.8 ± 5.3 | 12.9 ± 5.5 | 12.7 ± 5.3 |
| trip_distance (km) | 327 ± 220 | 298.1 ± 196.0 | 349.9 ± 235.0 |
| num_rest_stops | 1.97 ± 1.45 | 1.76 ± 1.33 | 2.1 ± 1.5 |
| rest_time_per_stop (minutes) | 41.5 ± 38.8 | 37.8 ± 35.8 | 44.3 ± 40.7 |
| num_tolls | 3.2 ± 2.05 | 2.8 ± 1.9 | 3.40 ± 2.1 |
| veh_mileage | 5.42 ± 2.2 | 6.4 ± 2.2 | 4.6 ± 1.9 |

*Source: Authors' analysis*
*Note: MDT > 7 t & ≤ 15 t and HDT > 15 t GVW; mileage is km/l*

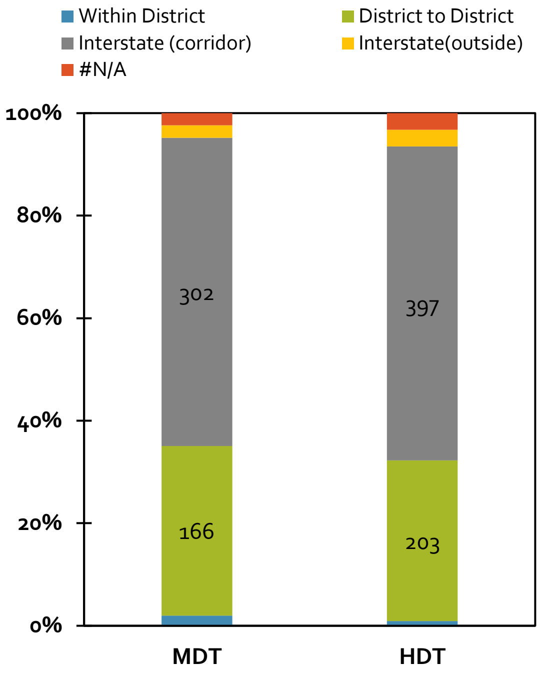
*Table A3: Test for statistical significance: pairwise non-parametric Wilcoxon/Kruskal-Wallis method*

| | **3PL** | | **O&O** | | **Leased** | | **Company** | | **Hired** | |
|---|---|---|---|---|---|---|---|---|---|---|
| *M/HDT segment* | MDT | HDT | MDT | HDT | MDT | HDT | MDT | HDT | MDT | HDT |
| *N samples* | 952 | 760 | 132 | 119 | 302 | 226 | 158 | 118 | 31 | 26 |
| veh_age (years) | | | | | 🟦 | 🟦 | | | ▨ | ▨ |
| trip_distance (km) | 🟦 | 🟦 | | | | | | | ▨ | ▨ |
| num_rest_stops | 🟦 | 🟦 | | | | | 🟦 | 🟦 | ▨ | ▨ |
| rest_time_per_stop (minutes) | 🟦 | 🟦 | | | | | | | ▨ | ▨ |
| num_tolls | 🟦 | 🟦 | | | | | 🟦 | 🟦 | ▨ | ▨ |
| veh_mileage | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | ▨ | ▨ |

| | |
|---|---|
| 🟦 *p-val < 0.03, 95% confidence interval* | *statistically significant, d ≥ 0.5 and statistical power ≥ 85%* |
| ▨ | *Excluded due to low sample size and or statistical power* |

*Source: Authors' analysis*
*Note: The table presents the results of Wilcoxon/Kruskal-Wallis non-parametric tests for statistically significant difference between MDTs and HDTs by ownership type: 3PL, owned & operated (O&O), leased, company, and hired. Blue-shaded cells indicate a statistically significant difference between MDT and HDT within that ownership category for the corresponding variable, with p < 0.03, effect size ≥ 0.5, and statistical power ≥ 85%.*

*Figure A12: 60% of the MHDT trips are interstate, with O-D locations along highway corridor*



*Source: Authors' analysis*

*Note: Interstate (corridor) refers to trip origin and destination within Delhi/NCR, UP, and Haryana. Outside refers to trips that either originated from or culminated in any other state/UT.*

The figure shows that the majority of MDT (302) and HDT (397) trips are classified as interstate (corridor) movements. This is followed by district-to-district trips — 166 for MDTs, and 203 for HDTs. Other categories — within district, interstate (outside corridor), and N/A — are reported by relatively fewer respondents. The selected corridor serves as a primary freight artery where both MDTs and HDTs are largely used for inter-district and corridor-level movement.

## 1.3 Logistics services provider survey

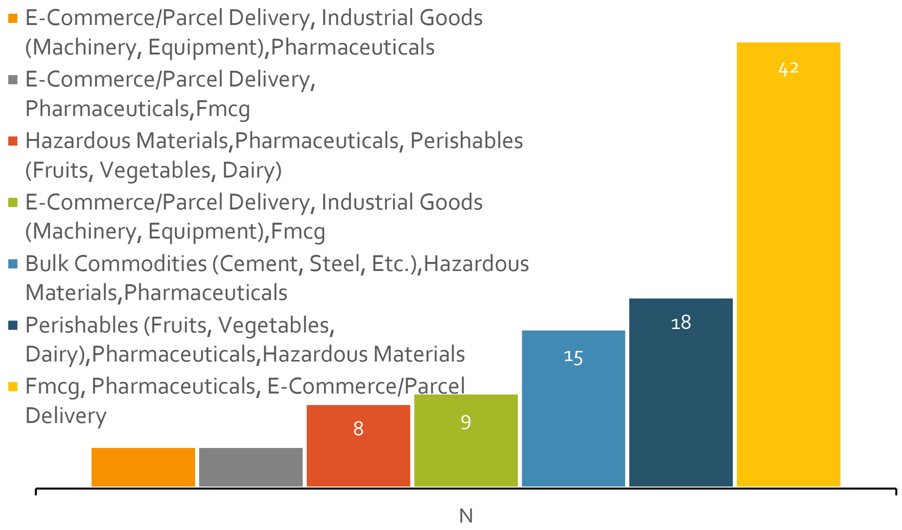
*Table A4: Fleet profile to ZET expectations: Key themes captured*

| Theme | Questions | Data type |
|---|---|---|
| Fleet profile | 1. Number of vehicles (LCV, ⅔, and MATs)<br>2. GVW, fuel mix, and age distribution<br>3. Business model | 4. Numeric<br>5. Categorical<br>6. Categorical |
| Operations | 7. Commodities transported<br>8. Most frequent O-D<br>9. Typical loading/unloading locations<br>10. Daily driving distances | 11. Multiple choice<br>12. Open-ended<br>13. Categorical<br>14. Numeric |
| EV adoption and perceptions | 15. Major barriers<br>16. Willingness to adopt EV<br>17. Policy support needed | Categorical, select up to 3 |
| ZET expectations* | 18. Candidate ZET to replace<br>19. Ideal specifications: range, warranty, battery size, power, top speed, charging, payload | Categorical |

*Source: Authors' analysis*

*Note: Analysis limited to this theme for reasons mentioned* in Data and Methods section

*Figure A13: E-commerce to FMCG: Major commodities transported by LSPs surveyed (N=100)*



*Source: Field survey conducted by CEEW, 2025*

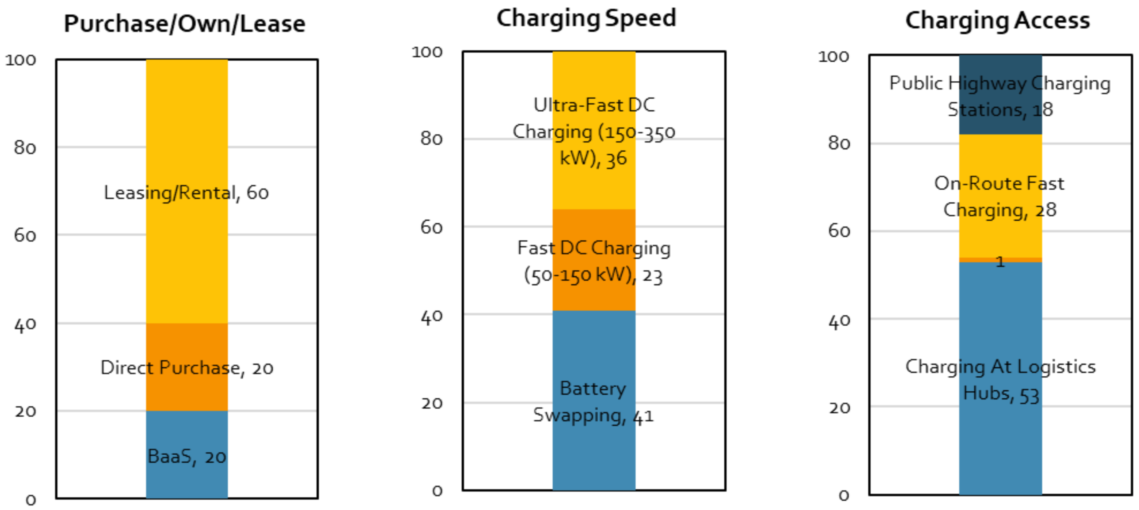
*Table A5: A fifth of LSP fleets older than 15 years, over a third of all trips empty*

| | **Mean** | **Std Dev** |
|---|---|---|
| Share of fleet older than 15 years | 21% | 11% |
| Avg. Capacity_Utilization | 77% | 17% |
| Share_Empty_trips | 35% | 23% |
| Average Fleet size | 26 | 11 |
| Average_N_all trucks | 18 | 9 |
| Average_N_4-6Ax_MAT | 7 | 5 |
| Average_N_2/3Ax | 11 | 5 |
| Average_N_LCVs | 8 | 4 |
| | | |
| | **N** | |
| Sum Fleet size | 2,563 | |
| Sum_N_all trucks_2-6Ax | 1,796 | |
| Sum_N_4-6Ax_MAT | 653 | |
| Sum_N_2/3Ax | 1,143 | |
| Sum_N_LCVs | 767 | |
| | | |
| | **N** | |
| Sum_N_Diesel vehicles | 1,842 | |
| Sum_N_CNG/LNG vehicles | 721 | |

*Source: Authors' analysis*

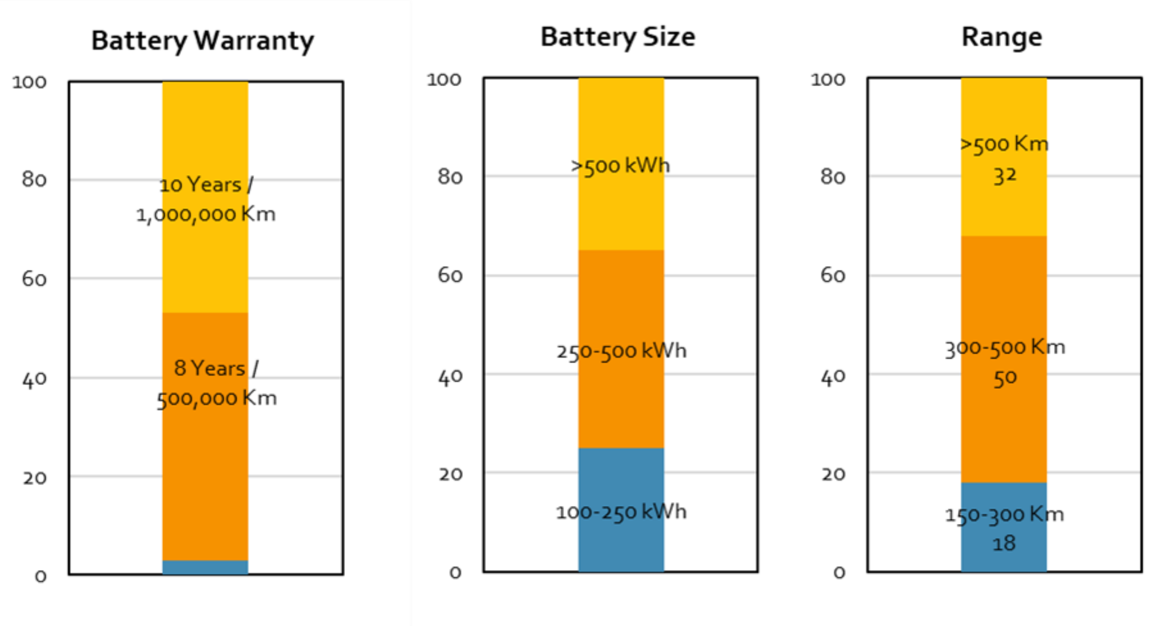
*Note: Ax- Number of axles; MAT – Multi-axle trucks*

*Figure A14: Vehicle ownership and charging characteristics*



*Source: Field survey conducted by CEEW, 2025*

*Figure A15: The battery warranty, battery size, and range LSPs seek for ZET uptake*



*Source: Field survey conducted by CEEW, 2025*

*Table A6: 40% LSPs prefer battery capacity of 250–500 kWh*

| | Options | No | Maybe | Yes | N |
|---|---|---|---|---|---|
| **Battery capacity** | 100–250 kWh | 13 | 9 | 3 | 25 |
| | **250–500 kWh** | **20** | **9** | **11** | **40** |
| | > 500 kWh | 13 | 17 | 5 | 35 |
| **Driving range** | 150–300 km | 8 | 4 | 6 | 18 |
| | **300–500 km** | **22** | **19** | **9** | **50** |
| | > 500 km | 16 | 12 | 4 | 32 |
| **Battery warranty** | 5 Years / 200,000 km | 1 | 2 | 0 | 3 |
| | **8 Years / 500,000 km** | **24** | **12** | **14** | **50** |
| | **10 Years / 1,000,000 km** | **21** | **21** | **5** | **47** |
| **Body type** | Box truck/enclosed cargo | 1 | 0 | 0 | 1 |
| | Open flatbed | 6 | 5 | 7 | 18 |
| | **Refrigerated truck** | **32** | **21** | **11** | **64** |
| | Tanker | 7 | 9 | 1 | 17 |
| **Axle configuration** | 4x2 | 1 | 0 | 0 | 1 |
| | 6x2 | 5 | 3 | 6 | 14 |
| | **6x4** | **31** | **21** | **8** | **60** |
| | 8x4 | 9 | 11 | 5 | 25 |
| **Maintenance** | In-house maintenance | 1 | 1 | 0 | 2 |
| | OEM-provided maintenance contract | 7 | 5 | 6 | 18 |
| | Per-km AMC-Based fees | 12 | 12 | 2 | 26 |
| | **Third-party service provider** | **26** | **17** | **11** | **54** |
| **Ownership model** | BaaS | 9 | 6 | 5 | 20 |
| | Direct purchase | 5 | 10 | 5 | 20 |
| | **Leasing/rental** | **32** | **19** | **9** | **60** |
| **Vehicle type & size** | LCV (3.5T GVW) | 3 | 1 | 0 | 4 |
| | MDT (3.5–12T GVW) | 9 | 3 | 6 | 18 |
| | **HDT (>12T GVW)** | **24** | **16** | **11** | **51** |
| | Bus (passenger transport) | 10 | 15 | 2 | 27 |
| **Charging speed** | **Battery swapping** | **17** | **18** | **6** | **41** |
| | Fast (50–150 kW) | 9 | 8 | 6 | 23 |
| | **Ultra-fast (150–350 kW)** | **20** | **9** | **7** | **36** |
| **Charging time (0–100%)** | < 1 hour | 1 | 2 | 0 | 3 |
| | 1–2 hours | 7 | 2 | 5 | 14 |
| | **2–4 hours** | **33** | **26** | **13** | **72** |
| | Overnight charging (>6 hours) | 5 | 5 | 1 | 11 |
| **Charging access** | Dedicated depot | 1 | 0 | 0 | 1 |
| | Highway | 13 | 1 | 4 | 18 |
| | **Logistics hubs** | **22** | **17** | **14** | **53** |
| | On-route | 10 | 17 | 1 | 28 |

*Source: Authors' analysis*

*Note: No/Maybe/Yes grouping based on response to 'Would Your Fleet Consider Adopting ZET in The Next 3 Year*

## 1.4 Toll plaza metadata and traffic composition trends

*Table A7: Toll plaza metadata*

| Plaza code | Plaza name | Plaza type | Plaza subtype | Concessionaire type | City | Latitude | Longitude |
|---|---|---|---|---|---|---|---|
| 312027 | Badarpur-Faridabad | Toll | Plaza | PF | Faridabad | 28.47620 | 77.30548 |
| 312050 | Gadpuri | Toll | National | DBFOT | Palwal | 28.24915 | 77.29085 |
| 312049 | Karman | Toll | National | DBFOT | Palwal | 27.85537 | 77.40259 |
| 62002 | Mahuvan | | Toll | Conc. | Mathura | 27.33718 | 77.73745 |
| | Tundla | | | | Firozabad | 27.21827 | 78.27244 |

| Plaza code | Plaza name | Design capacity (PCU) | Traffic (PCU/day) | Rest areas | WIB | Average monthly (all vehicle classes and segments) | Trucks 2, 3 and MATs |
|---|---|---|---|---|---|---|---|
| 312027 | Badarpur-Faridabad | 100000 | 65053 | | | 1526952 | 41425 |
| 312050 | Gadpuri | | 56579 | yes | yes | 748957 | 83049 |
| 312049 | Karman | | 67209 | yes | yes | 544553 | 148148 |
| 62002 | Mahuvan | 120000 | 59967 | yes | yes | 584136 | 201822 |
| | Tundla | 120000 | 49978 | | | 432125 | 98093 |

*Source: (MoRTH 2024a, 2024b)*

| *Note:*<br>*DBFOT – Design-Build-Finance-Operate-Transfer*<br>*PF – Publicly Funded*<br>*Conc. – Concessionaire* | *PCU- passenger car unit equivalent*<br>*Tundla plaza data used as proxy for Agra*<br>*Missing entries indicate data unavailable* |
|---|---|

*The corridor has five major toll plazas at Delhi-Badarpur, Gadpuri, Karman, Mahuvan, and Agra (earlier sections mention 2 at Badarpur, none at Agra). Tundla plaza is used as proxy for Agra due to data unavailability (MoRTH 2024b). Toll plaza descriptive summaries are based on 14-month historical FastTag monthly transactions intermittently collected and reported during March 2022–Oct 2023 (MoRTH 2024a) and GIS metadata of toll plaza locations (MoRTH 2024b; ArcGIS 2024). Historical 14-month average monthly transaction counts and percentage share by vehicle type are depicted in Figure A16.*

*Figure A16: Historical 14-month average toll plaza transactions*

Top: Percentage share of monthly transactions (counts) by vehicle type; Bottom: actual monthly transactions (counts) by vehicle type

This corridor, based on the average monthly toll transaction counts across all five toll plazas (MoRTH 2024a), recorded an average daily traffic (ADT) of ~25,000 vehicles — including around 19,700 cars, jeeps, and vans (CJVs), 3,800 trucks, nearly 500 light commercial vehicles (LCVs), and about 275 buses. Monthly average CJV transaction counts decline from 1.4 million at the Badarpur toll plaza to 323,000 and ~277,000 at Mahuvan and Tundla toll plazas (~20 per cent of Badarpur's counts), respectively. In stark contrast, truck counts (2, 3 and 4-6 axles) increase up to 4–6 times at Mahuvan (30,000–100,000) and 1.5–3.6 at Tundla (18,000–53,000), relative to Badarpur (5,000–20,000). Bus transactions vary by a factor of ~2 to 3—from ~4,300 at Badarpur to 9,300 at Mahuvan and 12,300 at Tundla, respectively. On average, CJVs constitute three-fourths of the transactions along the corridor, followed by trucks (15 per cent), LCVs and mini-LCVs (7 per cent), and buses (1 per cent). Among trucks, 2-axle vehicles account for nearly half, followed by 3-axle (35 per cent); MATs constitute the remainder.

With the exception of Tundla, which has only a truck lay-bye but no rest areas or static weigh bridge, and Badarpur, which has none of these facilities (rest area, truck lay bye or static weigh bridge), Gadpuri, Karman and Mahuvan toll plazas have rest areas and static weigh bridges. The design capacity of the Badarpur toll plaza is 100,000 PCUs, whereas the Tundla and Mahuvan toll plazas are designed for a capacity of 120,000 PCUs.

- <u>Badarpur elevated toll plaza (public-funded)</u>: Located near Sarai Metro Station in Delhi, covering the shortest tollable stretch of 4.4 km on NH2. The daily traffic volume is approximately 65,000 PCUs, with ~92 per cent of transactions from CJV. Due to its location at the exit/entry of NCR, it handles the largest volume (~1.5 million, monthly average).

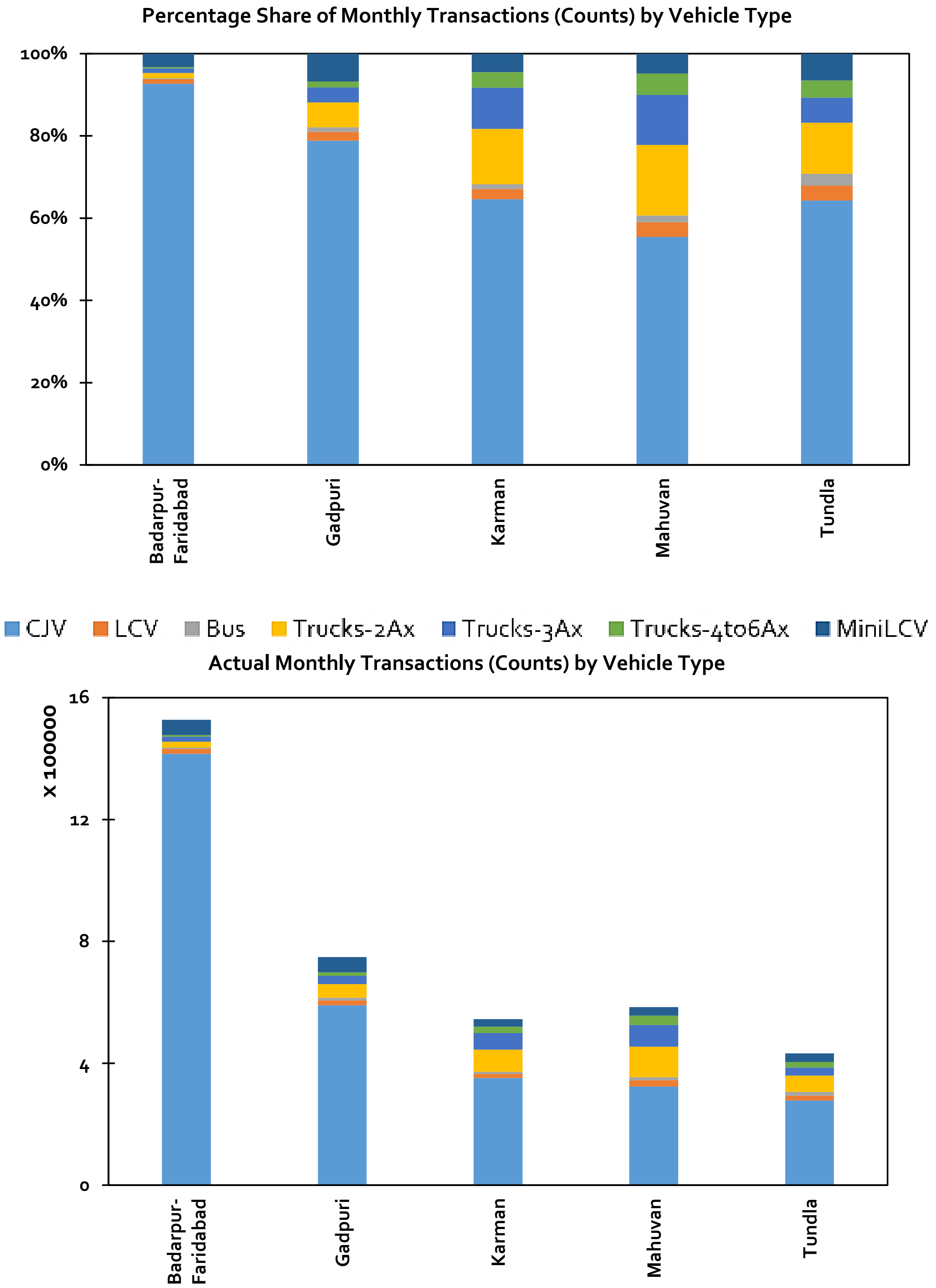
- <u>Gadpuri toll plaza (public-funded)</u>: Located in Palwal, Haryana, on NH19 (formerly NH2), it serves as a key checkpoint along the Delhi-Agra corridor. Covering a tollable stretch of 47.28 km, this plaza experiences a daily throughput of ~56,600 PCUs. The highway passes through Faridabad, Palwal, Hodal, and Mathura, each of which hosts transportation hubs, commercial establishments, and industrial parks — all crucial indicators of vehicular traffic, demand for logistics services, and, thereby, possible charging demand. Monthly average transactions drop by nearly half to ~750,000 at Gadpuri.

- <u>Karman toll plaza (public-funded):</u> Situated at km 94.00 on NH19, this plaza facilitates traffic covering a tollable stretch of 63.22 km, with an estimated daily traffic volume of ~67,200 PCUs. Trucks account for roughly a quarter of all transactions at Karman Plaza.

- <u>Mahuvan toll plaza (build operate transfer, BOT toll):</u> Located at km 164 on NH2 in Uttar Pradesh near Mathura. With a tollable length of 89.75 km, it handles ~60,000 PCUs daily. Its proximity to Mathura's industrial zones, hospitals, and logistics hubs makes it an important transit point. At this plaza, trucks account for approximately 35 per cent of vehicle transactions, the highest proportion among the five toll plazas considered.

- <u>Tundla toll plaza (BOT toll)</u>: Located at km 224.95 on NH2 in Uttar Pradesh, covering a tollable length of 52.59 km. On average it handles ~48,000 PCUs daily. Tundla is used as a proxy for the Agra toll plaza due to unavailability of information about the latter. Tundla is proximal to a key rail-road interchange.

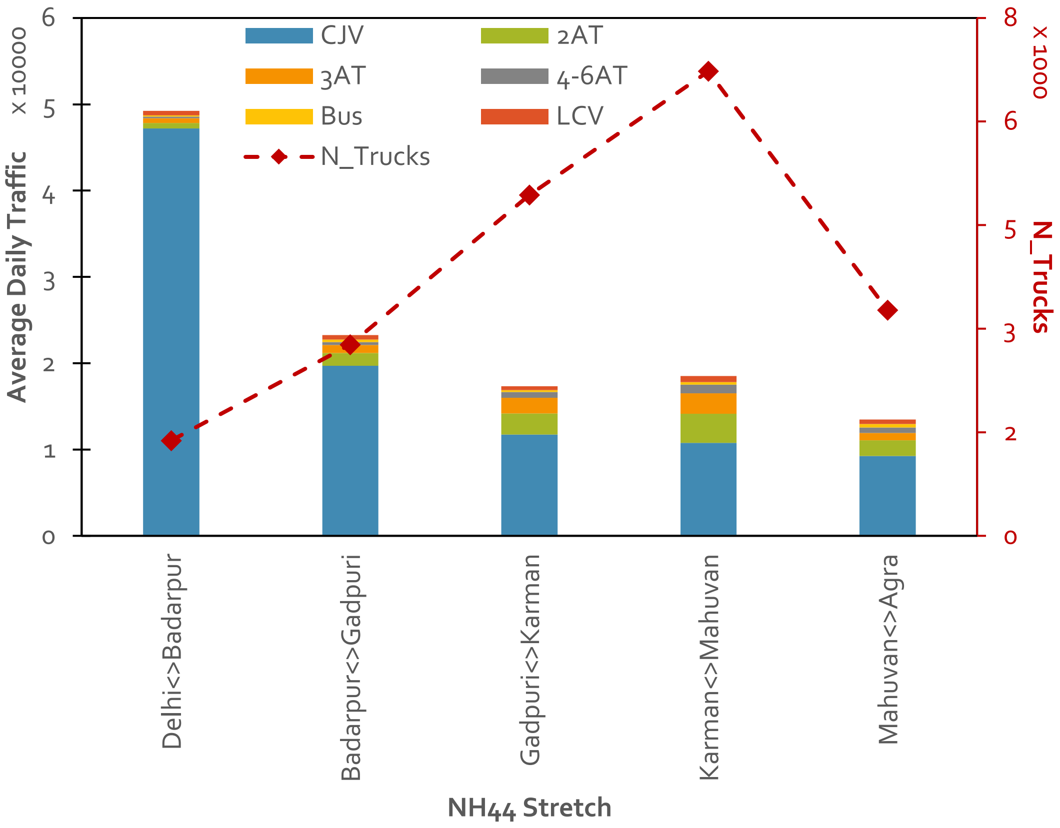
*Figure A16 Historical 14--month average toll Plaza transactions.  Top: Percentage Share of Monthly Transactions (Counts) by Vehicle Type; Bottom: Actual Monthly Transactions (Counts) by Vehicle Type*



*Note: Ax: Number of axles. MAV(T)s are trucks with 4to6Ax trucks. Toll transactions are aggregated at the plaza level irrespective of the travel direction.*

*Source: Authors' analysis of National Highways Authority of India monthly toll transaction reports (MoRTH 2024a, 2024b)*

*Figure A17 Average daily traffic across the five stretches by vehicle type*



*Source: IHMCL monthly report*

### 1.4.1 Corridor segmentation, ADT and peak hour flows

Using toll plazas as breakpoints, the entire corridor is segmented into five stretches — Delhi<>Badarpur; Badarpur<>Gadpuri; Gadpuri<>Karman; Karman<>Mahuvan; and Mahuvan<>Agra/Tundla.

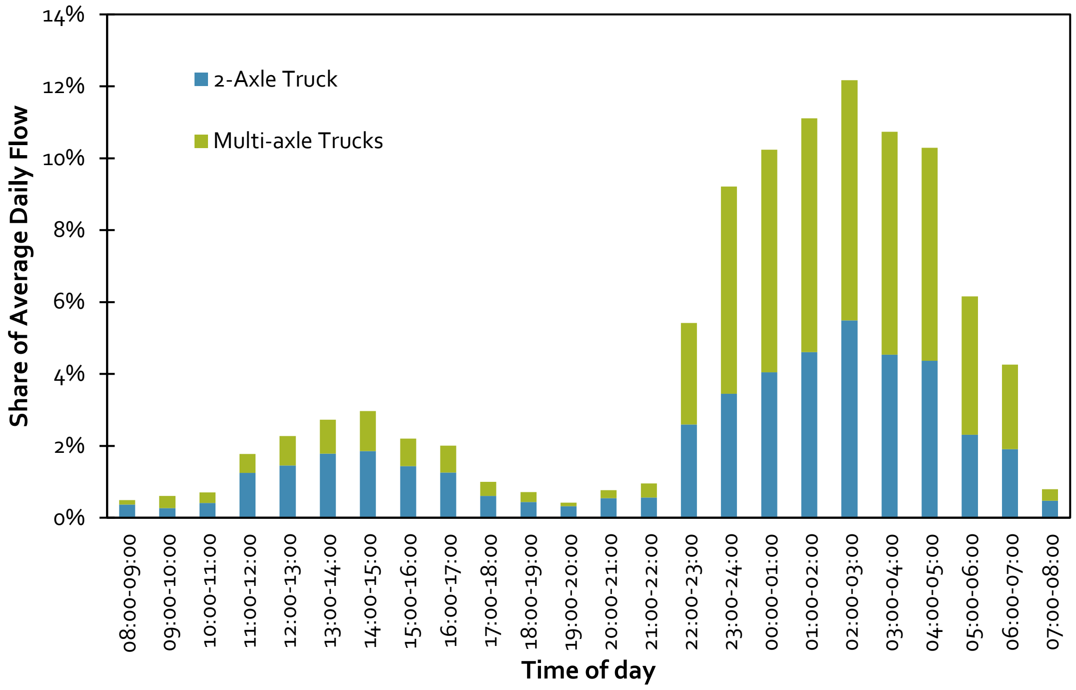
Several interconnected economic, infrastructural, and geographical factors explain these truck flow differentials, which are consistent with regional transportation patterns and supported by available traffic data (CSIR-CRRI 2018; MoHUA 2021). The Delhi-Jaipur corridor forms a critical segment of the Delhi-Mumbai Industrial Corridor (DMIC), extending across six states and expected to attract approximately $100 billion (A. Singh 2024). The Delhi-Jaipur corridor (NH48) is heavily industrialised, featuring major logistics hubs such as Gurugram, Bhiwadi, Neemrana, and Jaipur. This significant industrial concentration generates substantially higher freight movement requirements.

While the Delhi-Agra route serves important economic functions, it lacks the same level of industrial clustering that characterises the western corridor towards Jaipur and, ultimately, Mumbai. The Delhi-Agra route benefits from multiple parallel connectivity options that effectively disperse freight traffic across alternative pathways. This dispersion effect is further amplified by the presence of alternatives via the Yamuna Expressway, NH-19, and Eastern Peripheral Expressway. The Delhi-Agra corridor (NH44/NH19/NH2) has a more balanced mix of passenger and freight transport, with industries concentrated in Faridabad, Palwal, Mathura, and Agra, rather than along the entire corridor. Agra is more tourism-oriented, with commercial activity skewed toward FMCG, regional trade, and agriculture, rather than heavy industry.

These high-level portraits of corridor volumes and traffic flow composition are drawn from historical monthly toll transaction reports, which are limited in availability. While they reveal key trends in CJV, bus, LCV, and truck movement on the corridor, the absolute magnitudes may not fully capture the current traffic and flow composition. FastTag transaction reports use a completely different schema of vehicle classes (VC_4 to VC_20) compared to MoRTH or OEM (Table 1). Therefore, toll transaction records may not exactly correspond to specific MHDT segments by GVW and/or axle configuration. Nevertheless, they provide valuable insights into the nominal flows, relative share of trucks, and freight density along the NH44. Due to differences in sub-categorisation within the MHDT segment by MoRTH and IHMCL (FastTag transaction data), as well as the lack of disaggregate data on direction of flow, vehicle vintage, truck tonnage, or axle configuration, a heuristic approach is deemed necessary and apropos — even if approximate — as a reasonable middle ground. For these aforementioned reasons, it is justifiable to consider the assumed average number of MHDTs plying on the Delhi-Agra corridor daily as 3,000.

Temporal distribution of truck traffic based on 1-day classified vehicle counts at Badarpur (outer cordon of NCR) conducted by the CRRI (CSIR-CRRI 2018) is used as reference, Figure A18. b (Something missing in sentence)

*Figure A18 Outer cordon 2-Ax and MAT counts by time of day-Badarpur*



*Source: CRRI (CSIR-CRRI 2018)*
*Note: Multi-axle trucks (MATs) include all 3-6 axle trucks*

## 1.5 Geospatial intelligence

Multiple studies have examined factors considered for the siting of EV charging stations. Apart from economic and environmental factors, the studies considered transportation, energy, urbanisation, existing resource utilisation, and driver convenience. Economics includes capital, maintenance, and operational costs. Environmental parameters include green areas, slopes, surface temperatures, floods, landslides, and earthquake-resilient zones. Transportation includes vehicular flow, junctions, parking, and transit zones; Energy includes electricity grids and substations, and the renewable energy potential of existing land parcels. The urbanisation factor includes rest stops, industrial clusters, commercial zones, fuel stations, and other amenities. Existing resource utilisation is the utilisation rate of existing chargers.

*Table A8: Factors considered for determining infrastructure suitability along the NH44 corridor.*

| **S.No.** | **GIS layers** | **Details** | **Source** |
|---|---|---|---|
| 1 | Commercial establishment density | It includes places such as restaurants, food kiosks, commercial areas, repair shops, rest areas, hotels, lodging areas | OSM and Google places API; RNI survey |
| 2 | Office and industrial area density | Industrial hubs near highway stretch, mandis, warehouses, distributions centres, loading/unloading areas | |
| 3 | Fuel station density | Fuel station (petrol, diesel and CNG) along highway | |
| 4 | Level of service and convenience for user | it entails exiting Recreational infrastructure on site which would determine wait time/queue/speed of charging/functioning/operational, type of chargers/no. of chargers | |
| 5* | Building density along highway corridor | This can be used as proxy to the population density | Google earth engine |
| 6* | LULC classification | LULC data to identify Built-up, water bodies, agriculture, green spaces and barren land | Sentinel-2 satellite Imagery |
| 7* | Vacant land apart from agricultural land and forest land | Vacant land is extracted from the LULC data. | |
| 8 | Site distance to highway | Distance of site from the edge of the highway | Arc GIS Buffer tool |
| 9* | Energy infrastructure (HT lines and substation) | More near to electric line/ transmission lines/ substations, higher chances of setting up EVCS | RNI survey |
| 10 | Solar potential of land around the highway stretch | High potential of site to generate renewable energy, near to renewable energy farms, higher chances of setting up EVCS, or connected to RE grid | (SolarGIS 2018) |

*Note: Open Street maps (OSM); Land use and land cover (LULC); Road Network Intelligence survey*
**Except for layers 5, 6, 7 and 9, all the layers are input in point density format. Layers 5,6 and 7 follow a polygon format, while layer 9 is represented in line density format.*

### 1.5.1 Data preparation and normalisation

Each of the 10 input layers in Table A8 were first converted to a raster format with uniform cell size and spatial extent to ensure computational consistency. The native vector datasets were rasterised using conversion parameters in geoprocessing tools in ArcGIS Pro to maintain spatial integrity throughout the corridor. A cell size of 150 m x 150 m is considered for the analysis. Additionally, 11 layers of Sentinel-2 LULC data is reclassified into 5 categories: water bodies (2.81 sq km), green area (2.23 sq km), agricultural land (72.77 sq km), built area (142.02 sq km) and bare/vacant land (4.25 sq km). This classification helps in identifying potential sites for EV charging infrastructure, avoiding green and agricultural areas. Furthermore, building density mapping using Google Earth serves as a proxy for population density along the highway corridor, indicating high urban activity, which can influence electric vehicle charging infrastructure demand. Prior to overlay operations, all input layers underwent reclassification to a standardised suitability scale of 0-1 using min-max normalisation, where higher values represented more favourable conditions for EVCI deployment. This critical normalisation process enables direct comparison and integration of disparate datasets measuring fundamentally different phenomena — from commercial density to electrical infrastructure proximity.

### 1.5.2 Weighted overlay analysis

In contrast to prioritised weighting schemes that assign relative variable importance to different factors, this analysis employed an equally weighted approach, where each layer contributes 10 per cent to the final composite score. This methodological decision reflects either:

- An assumption that all criteria hold equivalent importance in determining EVCI suitability;
- A preliminary exploratory analysis stage before determining optimised weights; or
- A deliberate attempt to minimise subjective bias in the relative importance of different factors

The equal weighting approach mathematically translates to each layer ($L_1$, $L_2$, ..., $L_{10}$) having a weight coefficient of 0.1 in the overlay formula:

$$\text{Suitability Score (SC)} = 0.1\times L_1 + 0.1\times L_2 + 0.1\times L_3 + \dots + 0.1\times L_{10}$$

The weighted overlay operation was executed using GIS spatial analysis functions that perform cell-by-cell mathematical operations across all 10 input layers. For each geographic location (cell) along the corridor, the suitability values from each input layer were multiplied by their respective weights (0.1) and then summed to produce a composite suitability score. This computation essentially represents a discretised linear combination where:

$$SC_{(x,y)} = \sum \quad W_i \times W_{i(x,y)}$$

Where:

$SC_{(x,y)}$ is the suitability score at location (x,y); $W_i$ is the weight of layer i (0.1 for all layers); $Vi_{(x,y)}$ is the standardised value of layer $i$ at location (x,y)

The resultant composite layer reveals the integrated suitability pattern along the Delhi-Agra corridor, with distinguishable variations within specific segments between Delhi, the Badarpur, Gadpuri, Karman, and Mahuvan toll plazas, and Agra. The spatial distribution of suitability scores reflects the combined influence of all 10 criteria at each location.

By synthesising these multiple layers of geospatial intelligence, this study develops a high-resolution suitability framework for EVCI deployment along NH44. This equal-weight overlay methodology provides a balanced assessment of EVCI suitability that integrates commercial, land use, transportation, and energy infrastructure considerations, without predetermined assumptions about their relative importance, for subsequent refinement through sensitivity analysis or stakeholder input. The 10 geospatial layers are as follows:

i. **Commercial establishment density**
Commercial establishments include commercial markets, anaj mandis, shopping malls, rest stops, and utility establishments. These locations are origin/destination spots, or rest stops for a longer trip. These places can be considered suitable options for electric vehicle charging stations. Some of these locations have designated parking lots, which can be used for charging.

ii. **Office and industrial area density**
Offices and industrial areas serve as the economic hubs of cities, facilitating the movement of goods and people. These locations are ideal for setting up charging infrastructure, as they experience high traffic and logistical activity. The closer a charging station is to these areas, the more suitable and efficient its placement becomes.

iii. **Fuel station density**
Fuel stations are high-traffic locations due to a constant flow of vehicles, which makes them important sites to consider when planning for electric vehicle charging stations. For the transition to electric mobility, integrating charging stations within or near fuel pumps ensures accessibility and convenience. The higher the density of fuel stations in an area, the more suitable it becomes for setting up EV charging stations.

iv. **Land-use and land-cover classification**
The classification of LULC is an important factor to consider when planning for electric vehicle charging stations. Areas with green cover, ecologically sensitive areas like forests and rivers, and protected lands should be avoided.

v. **Building density along highway corridor**
Based on the LULC data, only the built-up areas are identified. The density of the population residing near the highways is also a crucial factor while planning for electric vehicle charging stations as it indicates the potential demand. Locations with a high concentration of building area are more suitable.

vi. **Level of service and comfort for user**
Locations with amenities such as rest rooms, food outlets, repair shops, and commercial markets enhance the user experience while the charging is happening. A cluster of such services nearby increases the accessibility of the charging station, and improves user convenience.

vii. **Sites' distance to highway**
Sites closer to the highway ease accessibility for travellers and freight vehicles.A 50-m ring buffer is considered for the GIS input raster shapefile.

viii. **Energy infrastructure (HT lines and substation)**

**The a**vailability of HT lines and substations is important to ensure a reliable power supply for electric vehicle charging stations. Sites near energy infrastructure reduce the installation cost and improve the efficiency for power supply, making them a more viable option.

ix. **Vacant land apart from agricultural land and forest land**

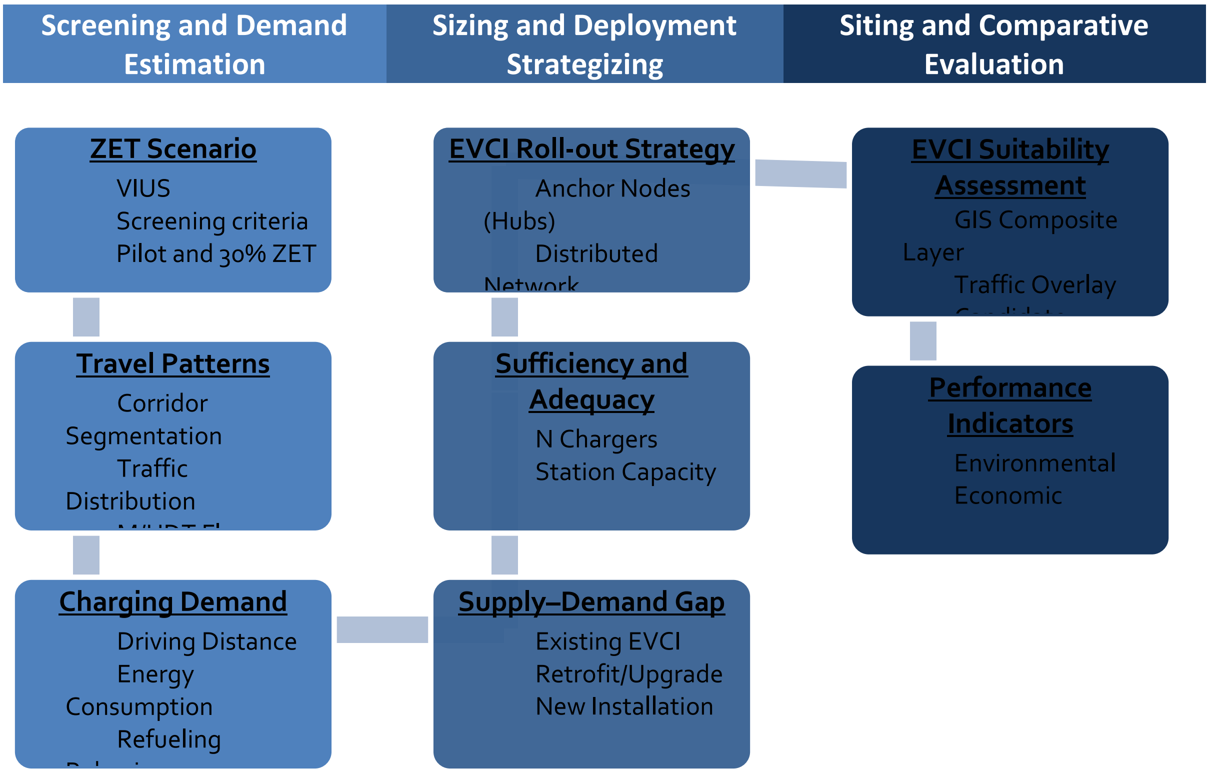
Identifying vacant land is critical for setting up electric vehicle charging infrastructure. These lands provide large-scale opportunities for setting up new charging stations without disrupting the existing infrastructure and green areas.

x. **Solar potential of land around the highway stretch**

Evaluating solar potential of land along the highway can support green development. Areas with high solar radiation can generate electricity, thus reducing dependency on the grid.

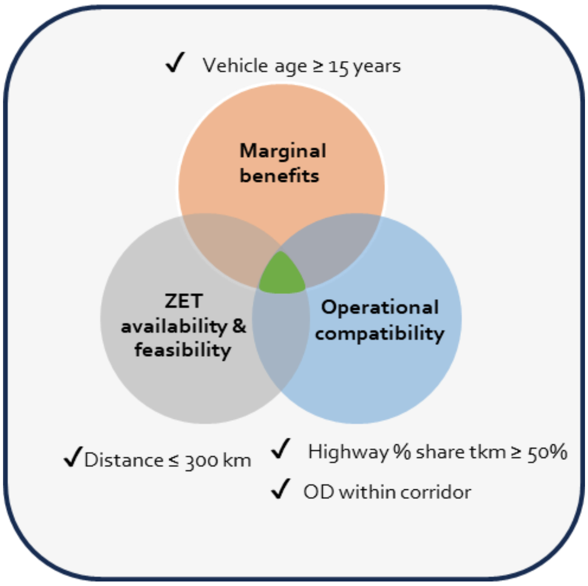
## 1.6 Methodology

*Figure A19 Screen, Size, Strategize and Site corridor EVCI build-out framework to support ZET transition*



*Source: Authors' analysis*

*Figure A20 Criteria for selecting the first 100 MHDTs most suited for ZET*



*Source: Authors' analysis*

The analytical framework in Figure 6, reproduced for clarity in Figure A19 — **Screen, Size, Strategize and Site** — lays out a structured process to guide corridor-scale EVCI development for ZET transition from prospecting ZET adoption through select scenarios to site selection and site-level specifications.

**Screening and demand estimation** establish two ZET scenarios: shortlisting the first 100 MHDTs most suitable for ZET piloting, and the second *scale-up* scenario *simulating* a corridor-wide scenario where 30 per cent of MHDTs transition to ZETs. Screening is based on age, operating range, and corridor orientation. For the first 100 trucks, selection is guided by three conditions. First is marginal benefit, where vehicles aged 15 years or older are prioritised, as replacing older trucks yields higher air quality and performance gains. Second is ZET availability and feasibility, defined by trip distances ≤ 250 km, ensuring that current ZET models can meet operational needs without range limitations. The third criterion is operational compatibility, assessed by ensuring that over 50 per cent of tonne-kilometres are on highways (Figure A9), and that the origin-destination (O-D) pairs lie within the identified corridor in Figure 8. Only trucks meeting all three conditions are screened as ideal pilot deployment candidates (Figure A20).

Unlike the immediate phase — more stringent for pilot feasibility — the 30 per cent ZET scale-up scenario accounts for fleet evolution over time, including retirement of older vehicles, entry of newer models, and technology maturation. Trip distances were extended up to 400 km, capturing a wider range of freight operations, including inter-state and off-corridor O-D pairs. While the highway tonne-kilometre share remained ≥ 50 per cent to retain alignment with corridor-focused planning, vehicle age filters were relaxed to include trucks with an average age of 4 years or older. This adjustment is in line with the typical holding period, which often ranges between 4 to 6 years for first owners before vehicles enter the secondary market. As such, the scale-up scenario captures vehicles that are realistically positioned for replacement or transition by 2030 — whether due to fleet turnover, compliance, or declining residual value in the used market.

The first 100 MHDTs were identified as part of an exploratory and indicative screening effort, aimed primarily at understanding vehicle-operational feasibility and identifying early adopters and industrial partners for piloting ZETs. This subset serves a normative function — helping shape stakeholder engagement, testing readiness conditions on the ground and identifying who could transition first, as well as lay the foundation for more scalable interventions such as the 30 per cent ZET scenario. Charger sizing, capacity, and deployment strategy, was carried out only for the 30 per cent ZET scenario (1,000 ZETs), which represents a forward-looking scale-up.

Travel patterns are analysed through segmentation, traffic distribution, and peak hour fractions (PHF) from historical toll transaction reports. The charging demand is derived using daily distance, energy consumption, and refuelling behaviour mapped to charging SoC (Figure A9,

Figure A10). Annexure detailed traffic flow, M/HDT composition, justifications, supplementary data sources, peak hour factor assumptions, and the proportion of MDTs and HDTs. In the 30 per cent ZET case, resulting traffic flow composition and distribution along the corridor segmented into five stretches is presented in Table A19

Three charging levels — 50 per cent, 75 per cent, and 90 per cent SoC — were used to reflect varied real-world charging behaviour, mapped directly from the VIUS responses on existing refuelling preferences — full to full, near reserve, half- tank. and more than half-tank. Refuelling at mid tank is treated as equivalent to charging up to 50 per cent SoC, a little more than mid tank corresponds to 75 per cent SoC, and full-to-full refuelling or when near reserve is used as a proxy for 90 per cent SoC. These assumptions reflect the expected behavioural carry-over from diesel to electric trucks, acknowledging that drivers may adopt similar patterns in ZETs. While this approach is more conservative than assuming 100 per cent SoC charging events, it is a realistic approximation of diesel refuelling heterogeneity, and better captures partial or opportunity charging scenarios likely to emerge in real-world operations.

**Sizing and deployment strategising —** Currently installed EVCI along the NH44 corridor was first examined to assess its compatibility for ZET charging — charger ratings, working status, connector types, and location proximity to the highway. Installed charging capacity (supply) was calculated and compared against the projected peak charging demand levels to estimate the supply gap for each corridor stretch. Based on supply deficit across different corridor stretches, EVCI sizing was conducted to estimate the number of chargers required and the aggregate site capacity.

Two EVCI deployment strategies that differ in several key aspects — such as capacity, spatial requirements, risk profile and use-case among others, are considered — *anchor node or 'hub';* and d*istributed network or 'corridor-wide'. The anchor node* strategy focuses on consolidating a large number of chargers (12–15 per site) at fewer, strategically located hubs, typically spaced every 50 km along the corridor. These hubs demand high installed capacity (3–5 MW) and could draw up to 3,000 A. The c*orridor-wide* strategy requires more sites spaced ~10-20 km apart with fewer number of chargers (2–4 chargers per site) and installed capacity less than a MW.

Anchor nodes emphasise centralised capacity for high-demand zones, while distributed networks prioritise accessibility and flexibility across broader geographic areas. This is indicative of the *scale-versus-spread* trade-off. The decision between the two eventually boils down to a combination of costs, convenience, corridor characteristics, land availability, DISCOM readiness, expected utilisation patterns, and the deployment timeline. By evaluating both strategies, the methodology offers insights on suitability, accessibility, and readiness perspectives. Table A9 enumerates the salient differences between these two strategies.

**Siting and comparative evaluation —** builds on the outputs of demand estimation and infrastructure sizing to identify suitable locations for EVCI deployment along the chosen corridor. Candidate sites are evaluated using a GIS-based composite framework that overlays spatial demand, corridor segmentation, and peak ZET charging load with existing infrastructure. This geospatial filtering ensures alignment with travel intensity, accessibility, and operational feasibility.

The comparative evaluation examines two major dimensions — fleet-level benefits from ZET deployment and site-level investment considerations for EVCI build-out. First, the analysis quantifies the annual average emission benefits from transitioning MHDTs to ZETs. This includes estimated reductions in GHG emissions, PM, and NOx, as well as diesel savings from the fleet segments covered under the 30 per cent ZET scenario. These benefits are calculated by linking vehicle energy consumption with fuel emission factors and daily operating distances.

On the charging infrastructure side, the evaluation incorporates capital expenditure (CAPEX) estimates and location-specific feasibility of each proposed EVCI site. This involves a spatially grounded assessment of site-level requirements, examining whether the location involves retrofitting existing infrastructure, or new installations, along with the corresponding electrical and civil works. For each candidate site, inputs such as required transformer upgrades (e.g., LVDS to HVDS), primary substations, and capacity alignment with peak load estimates are considered. This spatially disaggregated costing and planning exercise enables a more granular understanding of what it takes to operationalise ZET charging on the ground.

### 1.6.1 Nodal vs. Network strategy for EVCI roll-out

*Table A9 Salient features of hub-based and corridor-wide EVCI deployment strategies*

| Attribute | Anchor Node<br>*(Concentrated Hub)* | Distributed Network<br>*(Corridor-Wide)* |
|---|---|---|
| **Site** | Centralized hubs with 10–15 chargers per site | Relatively Smaller sites with ~2–4 chargers per site |
| **Spacing** | ~ 50 km | ~ 10–20 km |
| **Minimum land requirement** | High | Lower |
| **Voltage/Ampere Ratings** | ~3000 VDC/1200 A | ~1000 VDC/500 A |
| **Capital investment per site** | High | Lower |
| **Deployment speed** | Slower due to DISCOM coordination, land and permitting requirements | Relatively faster due to modularity, smaller footprint, and easier integration |
| **Use case suitability** | High-traffic hubs, logistics parks, freight junctions | Moderate or variable traffic corridors, early-phase rollout |
| **Risk profile** | Concentrated; higher risk per site; underutilization risk if demand is overestimated | Spread-out; lower risk per site; lower risk of localized overbuild |
| **What it prioritizes** | Load-handling capacity, efficiency, and throughput | Accessibility, adaptability, and redundancy |
| **Utility readiness & LT/HT access** | High – primary substation upgrades and DISCOM alignment essential | Moderate to low – increasing the capacity and retrofitting existing EVCI could suffice in select cases |
| **Best deployed when** | Demand is concentrated, land and grid are readily available | Land scarcity, demand is dispersed; coverage is important |
| **Future proofing** | Designed to scale with future fleets needing high current and high-voltage, MW charging (MCS) system | Typically limited to CCS2 ≤ 500 kW); lower complexity |

*Source: Authors' interpretation from (K.-C. Chu, Miller, K. G., Schroeder, A., Gilde, A., & Laughlin, M. 2024; D2Z 2023; Green 2020; Ladeinfrastruktur 2022; Unterluggauer 2022; ABB 2021; Burges 2021)*
*Note: Qualitative descriptions are illustrative and not comprehensive*

### 1.6.2 Technology mapping, ZET and EVCI specifications and parametric assumptions

The ZET technology assumptions used in this analysis categorise specifications by haulage segment and tonnage class. For MDTs — defined here as >7 tonnes and ≤15 tonnes — two sub-categories are considered:short-haul and mid-haul, with assumed energy consumption of 0.75–1.0 kWh/km, battery sizes of 100–200 kWh, and daily operating distances ranging from 125 to 200 km. For HDTs (≥ 15 t) — regional and long-haul segments are considered, with energy consumption ranging from 1.75 to 2.25 kWh/km, battery capacities of 400–1000 kWh, and daily distances of 225 to 450 km. The chosen segmentation enables differentiated infrastructure strategies that align with ZET platform readiness, operational feasibility, and corridor-level charging demands. Each segment reflects a specific use-case that informs battery sizing, energy consumption, and EVCI design.

Specifications, emissions factors, corresponding diesel truck mileage (km/l) summarised in Table A10 and Table A11 align with current ZET model offerings (Fleataable 2024) and prior studies (NITI Aayog 2021, 2022; OECD-ITF 2024; Purohit and Klimont 2023; Qamar S and Jamal F 2021; TCIL 2015; Rana 2021; ISGF 2024).

*Table A10 Vehicle technology specifications and attributes*

| | **Haulage** | **Tonnage** | **Energy Consumption (kWh/km)** | **Battery Size kWh** | **Daily Distance (km)** | **Mileage (km/l)** |
|---|---|---|---|---|---|---|
| **MDT** | *Short* | <=15 t | 0.75 | 100 | 125 | 5 |
| | *Mid* | | 1 | 200 | 200 | 5 |
| **HDT** | *Regional* | > 15 t | 1.75 | 400 | 225 | 4 |
| | *Long* | | 2.25 | 1000 | 450 | 4 |
| | | | | | | |
| | | | **Typical operations** | | | |
| **MDT** | *Short* | <=15 t | Return to a home base daily; operating within urban or peri-urban areas—serving intra-city freight, and distribution loops. | | | |
| | *Mid* | | Serve inter-city or district-to-district freight with higher daily utilization. | | | |
| **HDT** | *Regional* | > 15 t | Between cities or industrial zones within a region; repeatable daily loops and predictable patterns | | | |
| | *Long* | | Inter-state freight; national corridors; long uninterrupted stretches; continuous duty cycles | | | |

*Source: Authors' analysis and interpretation; primary VIUS survey descriptive*

*Table A11 Fleet-wide emissions factors*

| | Bharat VI norms | | |
|---|---|---|---|
| **Fuel** | **$CO_2$** | **PM** | **NOx** |
| Diesel | 2.5 | 4.5 | 60 |
| *Units* | *kg/l* | *mg/km* | *mg/km* |
| Electricity | 0.65 | | |
| *Units* | kg/kWh | | |

*Source: GHG (Gajjar and Sheikh 2015; DPIIT, GIZ, and TERI 2022); Bharat Stage Norms (ARAI 2021); CEA average grid emission factors (CEA 2024)*

*Note: $CO_2$ reference is 2.6 kg/l (DPIIT, GIZ, and TERI 2022) after incorporating ~5% improvement (Deo 2021) results in 2.5 kg/l*

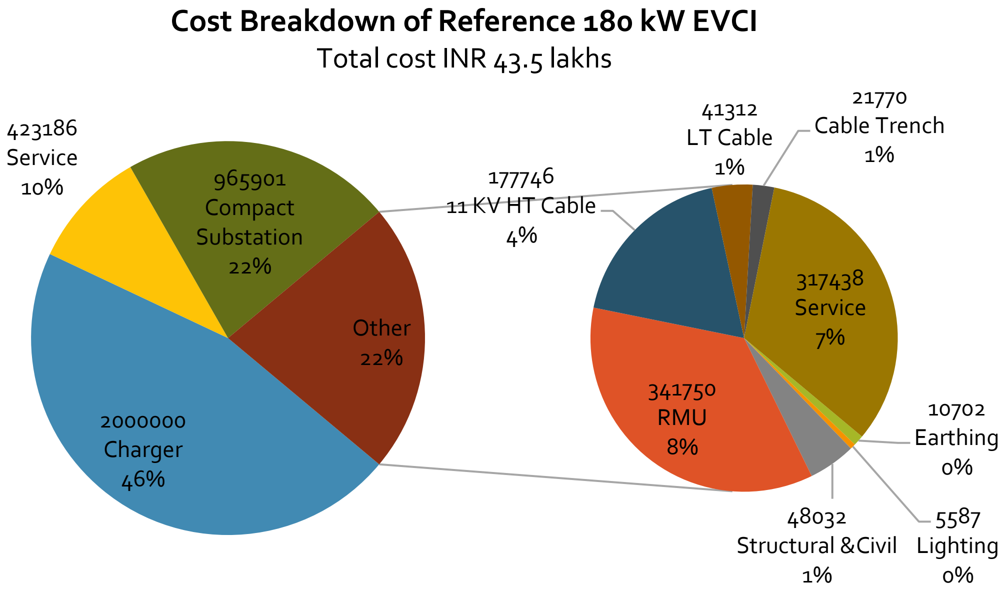
Table A12 Charging technology and EVCI build-out nominal specifications

| | **Anchor Node or “Hub”** | **Distributed Network or “Corridor-Wide”** |
|---|---|---|
| Installed capacity | 4–6 MVA | 1–1.5 MVA |
| Number of chargers per site | 15-20 | 2–4 |
| Charger rating | 240–350 kW | 240–350 kW |
| Average corridor spacing | 40–50 km | 10–20 kW |
| Minimum land required | 1600–2100 m$^2$ | 200–450 m$^2$ |
| Grid interfacing | Local reinforcement and substation level | Local reinforcement |

*Source: Authors’ analysis*

## 1.7 EVCI and behind-the-meter grid upgrade costs

*Figure A21 Cost breakdown of reference 180 kW charger*



*Source: Authors analysis based on information provided by (EoDB 2023)*

*Table A13 EVCI cost benchmarks, subsidies and effective cost*

| | | *INR lakhs* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N Chargers | Outlay | | Per charger | | | per kW | | |
| | **Target** | **BEE*** | **Subsidy** | **Effective** | **BEE*** | **Subsidy** | **Effective** | **BEE*** | **Subsidy** |
| 50 kW | 530 | 7036 | 4804 | 4.2 | 13.3 | 9.1 | 0.08 | 0.27 | 0.18 |
| 100 kW | 60 | 1594 | 974 | 10.3 | 26.6 | 16.2 | 0.10 | 0.27 | 0.16 |

*Note: *BEE cost benchmarks*

*Table A14 EVCI cost breakdown*

| | *INR Lakhs* | | |
|---|---|---|---|
| | **Total** | **Charger** | **Onsite/Upstream** |
| 50 kW | 13.3 | 7.3 | 6.0 |
| 100 kW | 26.6 | 11.7 | 14.8 |

Sources: (BEE 2024; CoEZET 2024; EoDB 2023; MHI 2024; SSEF 2021; Tata n.d.)

*Table A15 PM E-DRIVE highway EVCI benchmark, subsidy and effective costs*

| **PM-EDRIVE** | *INR Lakhs* | | |
|---|---|---|---|
| | **Effective** | **BEE*** | **Subsidy** |
| Per 240 kW charger | 22.5 | 63.7 | 41.2 |
| per kW | 0.09 | 0.27 | 0.17 |

*Sources: (BEE 2024; CoEZET 2024; EoDB 2023; MHI 2024; SSEF 2021; Tata n.d.)*

### 1.7.1 Low/High Voltage Distribution System (LV/HVDS)

*Table A16 Secondary DISCOM upgradation reference cost in INR lakhs*

| **Particulars** | **LVDS System** | **HVDS System** |
|---|---|---|
| No. of DTs | 1 | 8 |
| Capacity of DTs, KVA, each | 100 | 12.5 |
| Capacity of DTs, KVA, aggregate | 100 | 100 |
| Length of HT line, kms | 0.5, single line | 3.0, (two lines) |
| Length of LT line, kms | 3.5, (two lines) | 0.8, (eight lines) |
| Cost of Total System | 21 | 30.02 (bare)/33.62 (ABC) |
| Items | LVDS System | HVDS System |
| No. of DTs | 1 | 8 |
| Capacity of DTs, KVA, each | 250 | 2x50+6x25 |
| Capacity of DTs, KVA, aggregate | 250 | 250 |
| Length of HT line, kms | 0.5 single line | 3.0 (two lines) |
| Length of LT line, kms | 3.5 (two lines) | 0.8 (eight lines) |
| Cost of System | 17.5 | 27.1 (bare)/30.7 (ABC) |
| *Distribution Transformer* | | |
| **Rating (KVA)** | **Cost/Unit** | |
| 12.5 | 1.35 | |
| 25 | 1.57 | |
| 50 | 2.15 | |
| 63 | 2.5 | |
| 100 | 3 | |
| 250 | 6.5 | |
| *Cabling* | | |
| | Cost/km | |
| 11 kV OH line (with Bare conductor) | 4.5 | (3-phase, 3-wire) |
| LT OH line (with Bare conductor) | 3.5 | (3-phase, 4-wire) |
| LT OH line (with ABC conductor) | 8 | (3-phase, 4-wire) |
| *LV to HVDS* | | |
| Reactive Power, kVA | 250 | |
| Power factor (p.f) | 0.9 | |
| Diversity Factor | 0.8 | |
| Real Power, kW | 180 | kVA × p.f × Diversity Factor |
| Upgradation cost | 12.5 | |
| New Installation cost | 31 | |
| | **Upgrade** | **New Installation** |
| per kW | 0.05 | 0.124 |
| per MW | 50 | 124 |

*Source: (CEA 2023, n.d.; EoDB 2023)*

*Note: OH-Overhead; ABC-Aerial Bunched Cable; estimates are conservative and not exhaustive; per kW new HVDS or LV to HVDS excludes transmission and primary distribution level cabling and HT to LT substation including transformer. An HVDS brings 11 kV line nearest to the load centre using smaller size distribution transformer instead of using 11 kV/415 V stepdown DT at convenient location and laying 11 kV lines. In the absence of actual data on site specifications and detailed installation site plans, the kVA levels were scaled. This must be strictly interpreted for costing alone and not based on actual operations.*

Table A17 EVCI, onsite and behind-the-meter installation costs in INR lakhs

| *Front -of-the meter* | **Actual** | **Charger** | **Upstream** | **Subsidy** | **Effective** |
|---|---|---|---|---|---|
| Reference 180 kW | 45 | 25 | 20 | 15 | 30 |
| Cost Per kW | 0.2658 | 0.0886 | 0.1752 | 0.143 | 0.122 |
| *Behind the meter* | *Low Voltage-LV & High Voltage (HV) Distribution System (DS)* | | | | |
| LVDS to HVDS 180 kW Upgrade | | | | | 12.5 |
| HVDS 180 kW New Installation | | | | | 31 |
| LV to HVDS Per kW Upgrade | | | | | 0.05 |
| HVDS Per kW New Installation | | | | | 0.124 |
| | | | | | |
| *33 kV substation electrical<br>*PSCC poles, 1 x 5 MVA power transformer and three 11 kV feeders with 11 kV/ 2 MVAr capacitor bank* | | | | | 120–165 |
| *33 kV substation electrical + civil works | | | | | 270–310 |
| *Fixed line charge 4 MVA—10 MVA | | | | | 4.66 |
| *Fixed line charge 3 MVA—4 MVA | | | | | 3.99 |
| *Fixed line charge 1 MVA—3 MVA | | | | | 2.72 |
| &Fixed line charge 0.2 MVA—1 MVA | | | | | 2.25 |

Source: Authors analysis of data compiled from (CoEZET 2024; EoDB 2023; MHI 2024; NCRPB 2023; Tata n.d.; SSEF 2021; CEA n.d.) and DISCOM cost data books (refer Table A23 )
Note: PSCC- Prestressed Cement Concrete.
* Required for the anchor node strategy, cost depending on capacity;
& applicable for network strategy

Table A18 PV and BESS installation costs in INR lakhs

| | **Cost** | **Source** |
|---|---|---|
| 1 MWh BESS | 150–165* | (SET 2023; TERI 2021) |
| 1 MW Utility scale PV<br>*PV modules, inverter, EPC, BoS, rack and mount, other soft* | 400-600 | (AmpusSolar 2025; IRENA 2024) |

Note: 165 lakhs per MWh of BESS and 500 lakhs per MW PV assumed.

## 1.8 Charging demand and supply gap

In order to account for PHF variations across the corridor, PHFs of 2.5 per cent, 5 per cent, 7.5 per cent, 10 per cent, 15 per cent, 20 per cent, and 25 per cent were considered. Table A19 summarises the resulting traffic distribution and peak ZET flow based on the toll transaction reports and metadata, and the Delhi-Jaipur ZET assessment by the PSA’s office for the chosen PHF levels.

*Table A19 30 per cent ZET: ADT distribution and peak hour flows*

| | | | **Peak Hour Fraction (PHF)** | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Stretch** | *Share* | **ADT** | 2.50% | 5% | 10% | 15% | 20% | 25% |
| | | | *Peak hour ZET flows* | | | | | |
| Delhi<>Badarpur | *7%* | 72 | 2 | 4 | 8 | 11 | 15 | 19 |
| Badarpur<>Gadpuri | *15%* | 145 | 4 | 8 | 15 | 22 | 30 | 38 |
| Gadpuri<>Karman | *26%* | 259 | 7 | 13 | 26 | 39 | 52 | 67 |
| Karman<>Mahuvan | *35%* | 352 | 9 | 18 | 36 | 53 | 71 | 90 |
| Mahuvan<>Agra | *17%* | 171 | 5 | 9 | 18 | 26 | 35 | 44 |
| **Total ZETs** | | 1000 | 27 | 52 | 103 | 151 | 203 | 254 |
| **Average ZETs** | | 200 | 5 | 10 | 21 | 30 | 41 | 51 |
| **Maximum ZETs** | | | 9 | 18 | 36 | 53 | 71 | 90 |

Source: *Authors' analysis of National Highways Authority of India monthly toll transaction reports (MoRTH 2024a, 2024b)*

Note: Percentage share of traffic flow distribution and composition based on historical toll transaction reports

*Table A20 30% ZET: Average daily charging demand in kWh*

| **Stretch** | **ADT** | **MDT.Short** | **MDT.Mid** | **HDT.Regl** | **HDT.Long** | *Col Sum* |
|---|---|---|---|---|---|---|
| Delhi<>Badarpur | 72 | 537 | 2923 | 2333 | 20890 | *26683* |
| Badarpur<>Gadpuri | 145 | 1077 | 5860 | 4678 | 41880 | *53495* |
| Gadpuri<>Karman | 259 | 1920 | 10454 | 8345 | 74708 | *95428* |
| Karman<>Mahuvan | 352 | 2616 | 14241 | 11369 | 101775 | *130001* |
| Mahuvan<>Agra | 171 | 1272 | 6922 | 5526 | 49466 | *63185* |
| *Row Sum* | *1000* | *7422* | *40401* | *32251* | *288718* | |
| **Corridor Demand** | | | | | | **368792** |

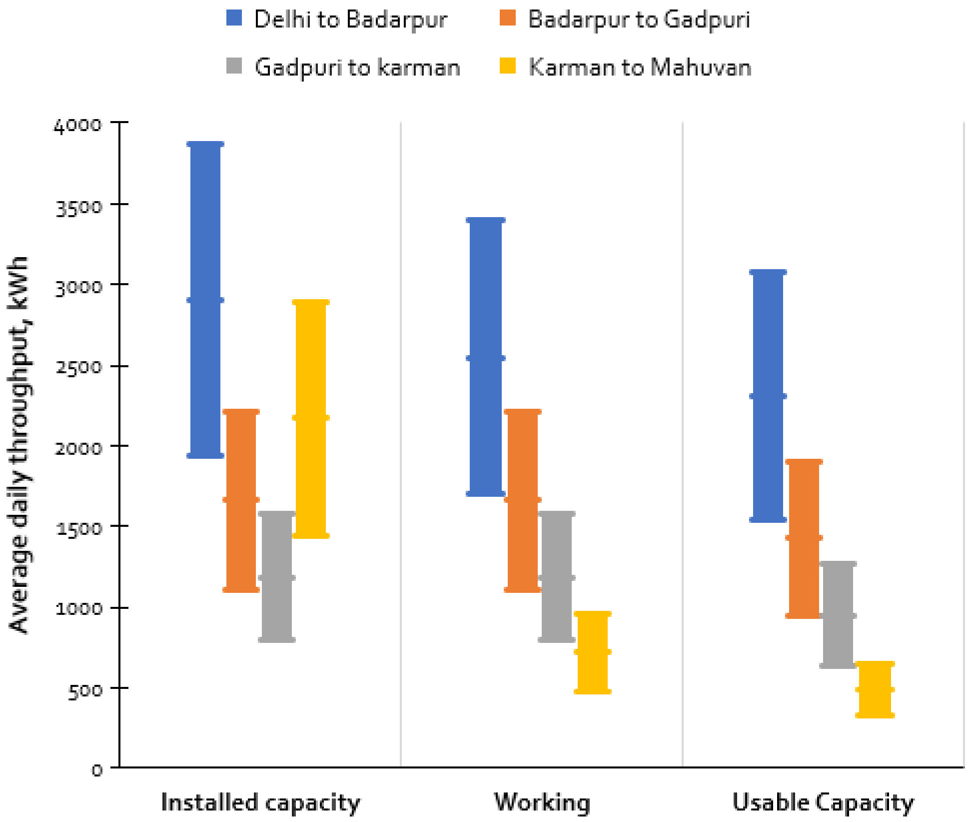
*Source: Authors’ analysis*

*Table A21 30% ZET: Peak hour demand in MWh*

| | Peak Hour Fraction (PHF) | | | | | |
|---|---|---|---|---|---|---|
| **Stretch** | 2.50% | 5% | 10% | 15% | 20% | 25% |
| | *Peak hour Charging Demand* | | | | | |
| Delhi<>Badarpur | 0.7 | 1.3 | 2.7 | 4.0 | 5.3 | 6.7 |
| Badarpur<>Gadpuri | 1.3 | 2.7 | 5.3 | 8.0 | 10.7 | 13.4 |
| Gadpuri<>Karman | 2.4 | 4.8 | 9.5 | 14.3 | 19.1 | 23.9 |
| Karman<>Mahuvan | 3.3 | 6.5 | 13.0 | 19.5 | 26.0 | 32.5 |
| Mahuvan<>Agra | 1.6 | 3.2 | 6.3 | 9.5 | 12.6 | 15.8 |
| **Corridor Total** | 9.2 | 18.4 | 36.9 | 55.3 | 73.8 | 92.2 |

*Source: Authors' analysis*

*Figure A22 Existing EVCI on NH44 stretch-wise: Minimum, Average and Maximum daily throughput in kWh*



Source: Authors' analysis

Note:

**Charger and operations assumptions:**

- Charger efficiency: 95%
- Uptime: 90%
- Annual hours: 8,760
- Nominal (low) utilization: 1
- Maximum (high) utilization: 20%
- **Charger Classification:**
    - *Installed:* Includes all existing EVCI rated at least 60 kW
    - *Working:* Excludes any chargers that are currently non-functional
    - *Usable:* Subset of working chargers rated at least 120 kW
- **Box Plot Details (for supply gap assessment):**
    - Lower and upper bounds of each box represent low and high utilization, respectively
    - Mean marker indicates the average of the lower and upper bounds
- **Additional Notes:**
    - The Mahuvan–Agra stretch is not shown as no EVCI rated ≥60 kW is currently installed
    - A 240 kW charger has an average daily energy output ranging from 520–1,040 kWh
    - For supply-demand gap assessment, lower (LB) and upper (UB) bounds reflect the minimum and maximum values across *installed*, *working*, and *usable* categories

## 1.9 PV potential across the corridor

*Table A22 Estimated PV potential at select candidate sites along the corridor*

| Stretch | Candidate Sites | Lat | Long | Unit Output kWh | Area Per Charger $m^2$ | Area PV $m^2$ | PV kWh |
|---|---|---|---|---|---|---|---|
| Gadpuri <>Karman | N1 | 28.240 | 77.290 | 7.4 | 105 | 63 | 466.2 |
| | N2 | 28.164 | 77.321 | 7.4 | 105 | 63 | 466.2 |
| | N3 | 28.098 | 77.335 | 7.4 | 105 | 63 | 466.2 |
| | N4 | 27.893 | 77.379 | 7.5 | 105 | 63 | 472.5 |
| Karman <>Mahuvan | N5 | 27.792 | 77.433 | 7.6 | 105 | 63 | 478.8 |
| | N6 | 27.661 | 77.538 | 7.6 | 105 | 63 | 478.8 |
| | N7 | 27.512 | 77.650 | 7.7 | 105 | 63 | 485.1 |
| | N8 | 27.379 | 77.691 | 7.8 | 105 | 63 | 491.4 |
| Mahuvan <>Agra | N9 | 27.238 | 77.839 | 7.9 | 105 | 63 | 497.7 |
| | N10 | 27.222 | 77.912 | 7.8 | 105 | 63 | 491.4 |
| | N11 | 27.216 | 77.950 | 7.8 | 105 | 63 | 491.4 |
| | N12 | 27.197 | 77.985 | 7.9 | 105 | 63 | 497.7 |
| Gadpuri <>Karman | H1 | 28.127 | 77.330 | 7.4 | 105 | 63 | 466.2 |
| | H2 | 27.906 | 77.369 | 7.5 | 105 | 63 | 472.5 |
| Karman <>Mahuvan | H3 | 27.542 | 77.645 | 7.7 | 105 | 63 | 485.1 |
| | H4 | 27.440 | 77.693 | 7.8 | 105 | 63 | 491.4 |
| Mahuvan <>Agra | H5 | 27.210 | 77.966 | 7.8 | 105 | 63 | 491.4 |
| *Average** | | | | *7.65* | *105* | *63* | *482* |
| *Total* | | | | *91.8* | *1260* | *756* | *5783* |

*Source: ISRO Solar calculator (ISRO n.d)*

*Note*

*N/H prefix denote network/hub strategy candidate site*

*PV efficiency 20%; Unit Output refers to kWh generated per $m^2$ of PV panel per day; Minimum area per charger including parking based on MoHUA minimum spacing requirements for EVCI on highways; fraction of charger area with PV installation is assumed 60%; PV kWh- Daily photovoltaic (PV) energy generated for the selected PV area (in kWh).*

** Since there is not much variability , average values are used (7.65 kWh per $m^2$ per day; 482 kWh per charger area per day ) for estimating potential of PV to offset the grid emissions due to charging irrespective of node or network site*

## 1.10 Secondary sources for data augmentation and imputation

*Table A23 Consolidated list of data for parameterization, data augmentation and triangulation*

| Data description | Source(s) |
|---|---|
| Monthly average tolling transaction count and revenue | (MoRTH 2024a) |
| Top selling model and manufacturer | (MoRTH 2024c) |
| Passenger and commercial vehicle activity in NCR | (CSIR-CRRI 2018) |
| EV infrastructure status quo and ecosystem synthesis | (NITI Aayog 2023a) |
| EV charging infrastructure guidelines and standards | (BEE 2024) |
| EV charging infrastructure costs benchmark and estimates | (NCRPB 2023; Tata n.d.; MHI 2024; EoDB 2023) |
| Emissions regulations and Bharath Stage Norms | (ARAI 2021) |
| Vehicle stock by fuel type, norms, category, class, and make | (MoRTH 2024c) |
| Overall sectoral trends and aggregate statistics | (NITI Aayog 2024a) |
| Exemplar charging hub functionalities and specifications | (GoI 2023) |
| Mobility Plans—Comprehensive, Regional and Sub-Regional - NCR | (MoHUA 2021) |
| Toll plaza meta data | (MoRTH 2024b) |
| Wayside Amenities (WSA) | (MoRTH 2023) |
| Fuel economy norms | (BEE 2022) |
| Logistics performance indices, trends and ease | (MoCI 2023) |
| Upstream grid connection & electricity supply—DISCOM cost data books | (UHBVNL 2023; UPERC 2022; TSSPDCL 2023) |
| Electricity grid emissions CO2 baseline—CEA | (CEA 2024) |
| Electricity distribution network planning criteria | (CEA 2023) |

### 1.11 PV potential and net GHG scenario parameterization

*Table A24 Parameters inputs and scenario definitions for emissions and PV sizing in EVCI planning*

| Parameter | Units | | L(ow) | M(edium) | H(igh) |
|---|---|---|---|---|---|
| | | | | | |
| **Constants** | | | | | |
| Diesel Emission Factor | kg $CO_2$/litre | 2.75 | - | - | - |
| Grid Emission Factor | kg $CO_2$/kWh | 0.75 | - | - | - |
| PV Generation Rate | kWh/$m^2$/day | 7.65 | - | - | - |
| Hub Site Area | $m^2$ per site | 1850 | - | - | - |
| Network Site Area | $m^2$ per site | 325 | - | - | - |
| Hub: Network PV Area Ratio | | 1.25 | - | - | - |
| PV Area Availability | % of site area | 40% | - | - | - |
| | | | | | |
| **Scenario Settings** | | | | | |
| Annual Distance | km | | 75000 | 100000 | 125000 |
| Diesel Mileage | km/l | | 2 | 3 | 4 |
| Energy Consumption | kWh/km | | 0.75 | 1.25 | 1.75 |
| PV Utilization | % | | 15% | 20% | 25% |
| Total Hub PV Area | $m^2$ | 3700 | | - | |
| Total Network PV Area | $m^2$ | 975 | | - | |
| | | | | | |
| **EVCI** | | | | | |
| Number of Hubs | N | 5 | | - | |
| Number of Network Sites | N | 12 | | - | |
| | | | | | |
| **PV Generated** | | | | | |
| Hub Annual | kWh/year | | 3700 × 7.65 × 365 × PV Utilization | | |
| Network Annual | kWh/year | | 1560 × 7.65 × 365 × PV Utilization | | |
| | | | | | |

*Source: Table A11 Table A13– Table A18, Table A23*

*Table A25 Summary statistics of energy demand, diesel consumption and emissions across sites*

| | Max | Mean | Median | Min | SD |
|---|---|---|---|---|---|
| | | | | | |
| **Annual Energy Demand (kWh)** | 218750 | 125000 | 125000 | 56250 | 49789 |
| **Diesel Consumption (liters)** | 62500 | 36111 | 33333 | 18750 | 13164 |
| **Diesel Emissions (kg $CO_2$)** | 171875 | 99306 | 91667 | 51563 | 36200 |
| **Grid Emissions (kg $CO_2$)** | 164063 | 93750 | 93750 | 42188 | 37342 |
| | | | | | |

*Source: Authors' analysis*

*Table A26: PV-BESS sizing and CAPEX estimates across hub and network sites for different utilisation levels*

| | **PV Utilization rate 0.15** | | **PV Utilization rate 0.2** | | **PV Utilization rate 0.25** | |
|---|---|---|---|---|---|---|
| **Power and Energy** | **Hub** | **Network** | **Hub** | **Network** | **Hub** | **Network** |
| | | | | | | |
| PV Utilization | 0.15 | 0.15 | 0.2 | 0.2 | 0.25 | 0.25 |
| PV_Area_per_Site | 740 | 81.25 | 740 | 81.25 | 740 | 81.25 |
| Num_Sites | 5 | 12 | 5 | 12 | 5 | 12 |
| PV_Area | 3700 | 975 | 3700 | 975 | 3700 | 975 |
| Annual_PV_Generation_kWh | 1273725 | 335643 | 1698300 | 447525 | 2122875 | 559406 |
| PV_capacity_kW | 456.2 | 120.2 | 608.2 | 160.3 | 760.3 | 200.3 |
| BESS_capacity_kWh | 456.2 | 120.2 | 608.2 | 160.3 | 760.3 | 200.3 |
| | | | | | | |
| | | | | | | |
| **CAPEX** | **Hub** | **Network** | **Hub** | **Network** | **Hub** | **Network** |
| **4-hour BESS backup** | | | | | | |
| PV Utilization | 0.15 | 0.15 | 0.20 | 0.20 | 0.25 | 0.25 |
| PV | 228.08 | 60.10 | 304.11 | 80.14 | 380.14 | 100.17 |
| BESS | 301.07 | 79.34 | 401.42 | 105.78 | 501.78 | 132.23 |
| BESS | 75.27 | 19.83 | 100.36 | 26.45 | 125.45 | 33.06 |
| PV+BESS | 529.15 | 139.44 | 705.53 | 185.92 | 881.92 | 232.40 |
| **1-hour BESS backup** | | | | | | |
| PV+BESS | 303.3 | 79.9 | 404.5 | 106.6 | 505.6 | 133.2 |
| | | | | | | |

*Source: Authors' analysis*