# EVCI Planner Tool: A systematic approach to siting charging infrastructure in Indian cities and along freight corridors

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## Highlights

- Locating of EV chargers in India has largely been carried out in an unplanned manner, with limited consideration for balancing commercial viability, technical feasibility, and user convenience.
- Using a systematic and scientific approach that incorporates proximity to the grid—ensuring low installation costs and reliable power supply—along with considerations of impact, user convenience, and optimisation of CPO revenues can support the decarbonisation of the transport industry in India, in line with the national objective of achieving carbon neutrality by 2070.
- MPEnsystems has developed a software tool based on grid, parking, bus depots, and substation data, verified through ground-truthing surveys, for optimizing EV charger siting for private EVs and commercial freight fleets.
- Analysis of the Electric Vehicle Charging Infrastructure planner tool shows its potential to improve charger utilisation, align network expansion with demand clusters, and reduce grid stress.

## Abstract

The widespread adoption of electric vehicles depends significantly on the availability of reliable and accessible charging infrastructure. In India, the current approach to locating spaces for the installation of public charging infrastructure has largely been ad-hoc, leading to underutilisation and gaps in optimal coverage, thereby undermining its techno-commercial viability. This, in turn, contributes to range anxiety among electric vehicle users across the board (both commercial freight and personal use). To address this challenge, MP Ensystems has developed a geospatial planning tool designed to optimize the siting of electric vehicle charging stations for 4-wheelers. The tool has two versions: EVCI City Planner Tool for private passenger vehicles in cities and EVCI Freight Planner Tool for commercial freight vehicles across major expressways and national highways. Both versions of the tool incorporate parameters such as integration with existing **grid infrastructure**, **revenue potential**, **utilisation rate**, and **deployment cost**, enabling informed decision-making for policymakers, urban planners, and investors. A central focus of the tool is **data-driven co-location of charging infrastructure with existing utilities and demand hotspots to ensure maximum impact and efficiency**. The model uses grid data, parking data, site data, and substation data to co-locate charging sites with existing substations and transformers, supporting planning for diverse vehicle types, including fleets and privately owned vehicles. The tool has been deployed across multiple Indian cities and transport corridors. The results demonstrate the tool's potential to improve charger utilisation, reduce network planning costs, and align deployment with real demand clusters. However, drawbacks include the need for **expanded real-time data integration**, **more granular consumer behaviour modelling**, and **dynamic tariff consideration**. Additional features that could be incorporated include **predictive modelling for future EV adoption**, **integration with renewable energy generation forecasts**, and **automated scenario-based deployment planning** to adapt to changing technology, policy, and market conditions. EVCI chargers can be co-located with bus depots nationwide, in collaboration with depot owners, to coordinate with the grid and enable demand response and flexibility, thereby creating a new revenue stream. By adopting a systematic, science-driven approach that factors in the above-mentioned parameters, such as proximity to the grid—minimising installation costs and ensuring a stable power supply—while also addressing impact, user convenience, and optimisation of CPO revenues, India can accelerate transport sector decarbonisation, supporting the national goal of achieving carbon neutrality by 2070.

**Keywords:** EVCI optimization, Decarbonizing transport

## Introduction

The transition to electric mobility is gaining momentum across cities, driven by ambitious sustainability goals, rising EV adoption, and supportive policies, including enabling regulations notified by the electricity regulatory commissions in different states for minimizing the cost of power as well as the cost of transformers and associated equipment. However, the success of this shift depends not just on increasing the number of electric vehicles (EVs) but also on developing an efficient, accessible, and financially sustainable charging infrastructure. The ad-hoc deployment of charging stations often leads to underutilized assets, high operational costs, and adversely affects the grid in terms of increasing the demand for ancillary services as well as cost, as power at the margin during peak load hours. Without a structured and data-driven approach, stakeholders risk inefficient deployments, financial losses, and a slow pace of EV adoption.

*Table 1: Different types of chargers and their usage*

| | | | | | |
|---|---|---|---|---|---|
| Utilization Rates | Public charger usage is around 01-15%, while profitability requires higher utilization. | Installation Costs | Fast chargers (50 kW DC) cost ₹7-12 lakh; slow chargers (7 kW AC) cost ₹15,000-30,000. Additional costs include land, civil work, and electricity connections. | Land Challenges | Charging stations need ~300 sq. ft. per unit, with most existing chargers in private spaces. ROI on fast chargers takes years due to low utilization and high operational costs. |

As cities step up the pace of investments in EV charging infrastructure, they face several challenges that impact the widespread adoption of EVs—leading to low utilization rates, inefficient placement, and suboptimal revenue generation. Accordingly, the following parameters should be duly considered when making a decision in this regard.

- **For government authorities and urban planners**, identifying optimal charging locations is crucial. Traditional deployment methods are often ad hoc, leading to underutilized stations. Ensuring alignment with smart city goals requires an intelligent planning framework that considers traffic density, mobility patterns, and infrastructure availability.
- **The logistics and fleet sector,** which has immense potential for electrification, struggles with inadequate charging infrastructure, increasing downtime, and operational costs.
- **Charge Point Operators (CPOs)** face challenges due to the lack of reliable demand forecasting. Poorly utilized charging stations delay network expansion and hinder new market entrants, slowing EV infrastructure growth. EV and battery manufacturers also face hurdles in designing products aligned with real-world charging needs due to the lack of insights into infrastructure deployment and user behaviour.
- **Power providers and grid operators** must manage fluctuating electricity demand due to unpredictable charging behaviour on a large scale.
- **Financial institutions and investors** find it difficult to assess the viability of EV infrastructure projects due to unreliable demand projections and revenue models, making large-scale investments risky. Similarly, real estate developers risk underused chargers without clear demand insights, leading to wasted investment.
- **Regulatory bodies** struggle to formulate effective policies due to limited access to accurate, requisite, and reliable techno-commercial data. Without a clear picture of charger utilization and user demand, policies may not address real-world challenges.
- **EV users** face range anxiety due to inadequate charging availability, discouraging potential buyers and slowing EV adoption.

EVCI planning requires a structured methodology that extends beyond simple estimations. This paper describes an online EVCI Planner Tool developed by MP Ensystems that integrates data-driven modelling and financial analysis, providing stakeholders with actionable insights for informed decision-making on EV Charging Infrastructure EVCI) deployment. The tool can be accessed through this link[1]. The first version of the tool was developed by MP Ensystems with support from the team at Electric Mobility Initiative, Shakti Sustainable Energy Foundation (SSEF).

**Problem Statement:** The deployment of Electric Vehicle Charging Infrastructure (EVCI) in India has been largely ad-hoc, resulting in underutilised chargers, inefficient capital use, and slow EV adoption. Fragmented data, limited demand forecasting, poor grid integration, and misalignment with travel patterns hinder optimal site selection, reducing RoI and fuelling range anxiety. A structured, context-specific planning tool integrating geospatial, traffic, grid, and financial parameters is urgently needed to enable scalable, efficient deployment in urban and corridor contexts.

**Hypothesis:** A geospatial, data-driven planning tool that integrates traffic density, grid proximity, site suitability, and compatibility can significantly improve the siting of EV charging infrastructure in Indian cities and freight corridors. Such a tool can

(1) Increase charger utilization rates,
(2) Enhance financial viability for CPOs and investors,
(3) Reduce grid integration costs, and
(4) Accelerate EV adoption by mitigating range anxiety.

[1] https://evcitool.mpensystems.com/login

## Literature review

The deployment of Electric Vehicle Charging Infrastructure (EVCI) has been a critical focus globally to support the transition to electric mobility. Existing literature highlights various tools and methodologies for EVCI siting, each addressing specific aspects of infrastructure planning, such as demand forecasting, grid integration, and user accessibility. This section reviews key tools and deployment strategies and their applicability to the Indian context.

**Existing studies,** such as "Demand Prediction and Placement Optimization for Electric Vehicle Charging Stations[2]," have combined Points-of-Interest mapping, traffic density, and historical charging data within a multi-view learning framework to predict site-level demand and optimize the placement of charging stations using packing-covering heuristics. Meanwhile, the study "Data-Driven Optimization of EV Charging Station Placement Using Causal Discovery[3]" employs causal discovery methods to reveal that station utilization is primarily driven by proximity to amenities, EV ownership concentration, and adjacent high-traffic corridors—informing data-driven siting recommendations that prioritize utilization. These works reinforce the importance of incorporating geospatial parameters—such as grid co-location, traffic flows, amenity access, and EV density—into any rigorous EVCI siting methodology.

A number of EV infrastructure planning tools have been developed globally to support the transition to electric mobility, each offering varying degrees of complexity, geographic specificity, and stakeholder orientation. While these tools have contributed meaningfully to infrastructure deployment, many are either optimized for developed country contexts or lack the granularity required for dynamic urban and peri-urban conditions found in emerging economies like India.

Tools such as the **EVI-X Modelling Suite[4]**, developed by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), offer a highly structured framework for simulating charging needs based on EV adoption, travel behaviour, and corridor usage. Its three-pronged architecture—network planning, site design, and financial analysis—makes it a valuable resource for utility-scale deployment planning. However, EVI-X is primarily tailored to the North American context, focusing on long-distance travel and corridor electrification, with limited application to mixed urban demand patterns and land-use constraints typically found in Indian cities.

Similarly, the **European Commission's JRC EV Charging Infrastructure Tool[5]** provides a macro-level planning mechanism aligned with EU policy mandates such as AFID and AFIR. It supports fleet-level forecasting and regulatory compliance, but its emphasis remains largely at the national and regional scales, offering limited granularity for city-level deployment or substation-level optimization.

**Localiser[6]** offers advanced geospatial analytics for site selection, commonly used in retail and urban development. Though not EV-specific, its methodology—relying on demographic and accessibility data—is valuable for understanding spatial opportunity. However, it lacks integration with electrical infrastructure and EV-specific demand forecasting, both of which are core strengths of the EVCI Planner Tool.

Within India, the BEE **EV Charging Station Locator** offers a basic GIS-enabled platform to help users find existing charger locations. However, it functions solely as a locator and does not incorporate parameters such as traffic flow, grid capacity, or other siting criteria for identifying suitable locations for new charger installations.

While global tools such as EVI-X, JRC's GIS platform, and eCharge4Drivers offer value in structured forecasting, regulatory alignment, and user adoption, respectively, they often lack contextual specificity—incorporating local data, travel behaviour, and regulatory conditions—and operational readiness, meaning the capability for direct, real-world deployment rather than purely theoretical analysis. This is where the EVCI Planner Tool and approach come in.

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[2] Gopalakrishnan, R., Biswas, A., Lightwala, A., Vasudevan, S., Dutta, P., & Tripathi, A. (2016). *Demand Prediction and Placement Optimization for Electric Vehicle Charging Stations*.

[3] Junker, J. S., Hu, R., Li, Z., & Ketter, W. (2025). *Data-Driven Optimization of EV Charging Station Placement Using Causal Discovery*.

[4] https://www.nrel.gov/transportation/evi-x#planning

[5] JRC Technical Reports (https://publications.jrc.ec.europa.eu/repository)

[6] Localiser is a berlin based software company for the automated construction of charging infrastructure for electromobility.

## The EVCI Planner Tool: A data-driven approach to context-specific EVCI deployment

The EVCI Planner Tool serves as a central resource catering to a diverse range of stakeholders actively involved in the EV ecosystem.

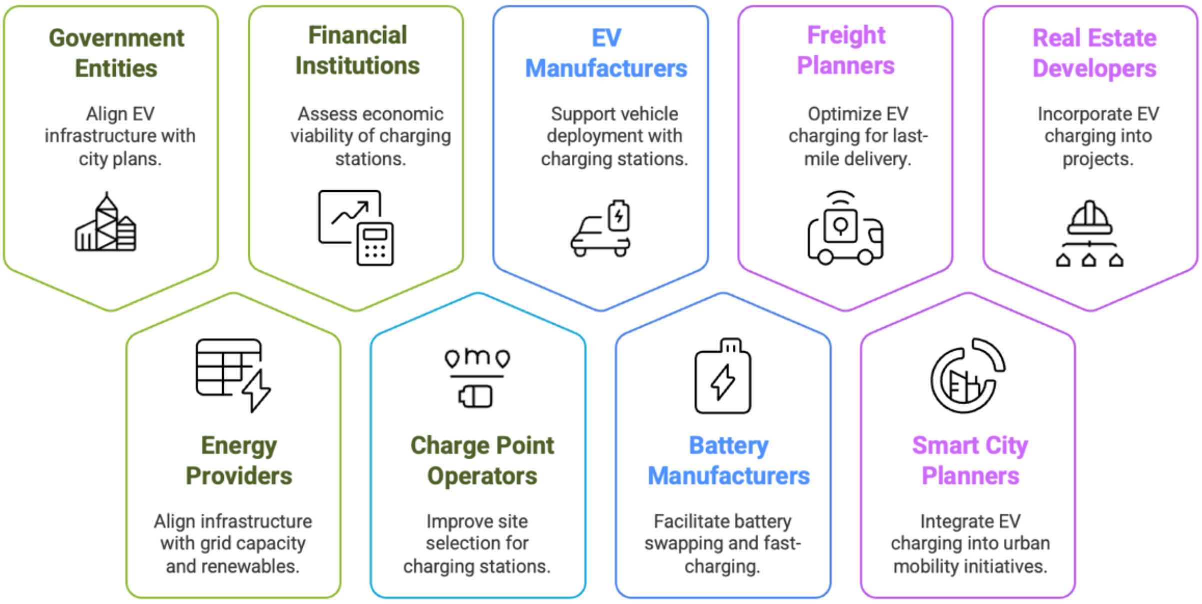


*Figure 1: Stakeholders of the EV ecosystem and how they benefit from the EVCI Planner Tool*

## Methodology: Data curation and inputs for the EVCI Planner Tool

The tool is based on integrating **multiple data layers**—such as **traffic density**, **grid data, site feasibility, and parking access**—to ensure that charging stations are strategically deployed to maximize usage, economic viability, and long-term sustainability. Additionally, leveraging **geospatial data**, **energy availability assessments,** and **traffic analysis**, the tool identifies optimal locations that enhance utilization rates, reduce investment risks for operators, and improve accessibility for EV users, and serves as a replicable model for scaling EV infrastructure in other cities.

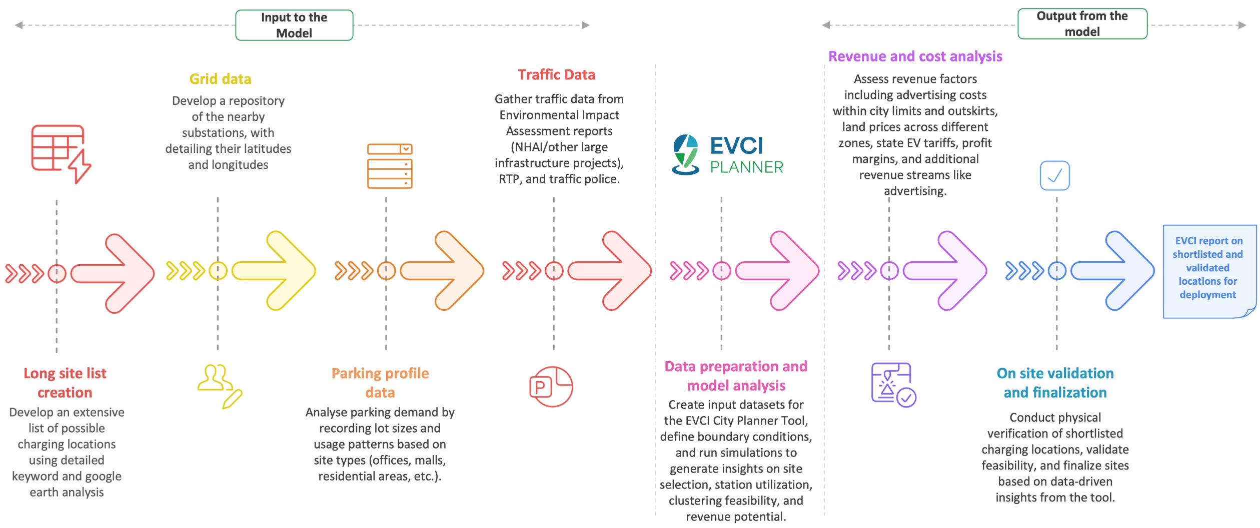


*Figure 2: The EVCI Planner Tool methodology*[7]

Accurate, context-specific inputs are critical to ensuring that the EVCI Planner Tool produces reliable site recommendations. At this stage, spatial, technical, and operational datasets are carefully sourced, processed, and validated. The following diagram provides a detailed overview of the parameters used and the functioning of the tool.

[7] RTP- Regional Transport Plan

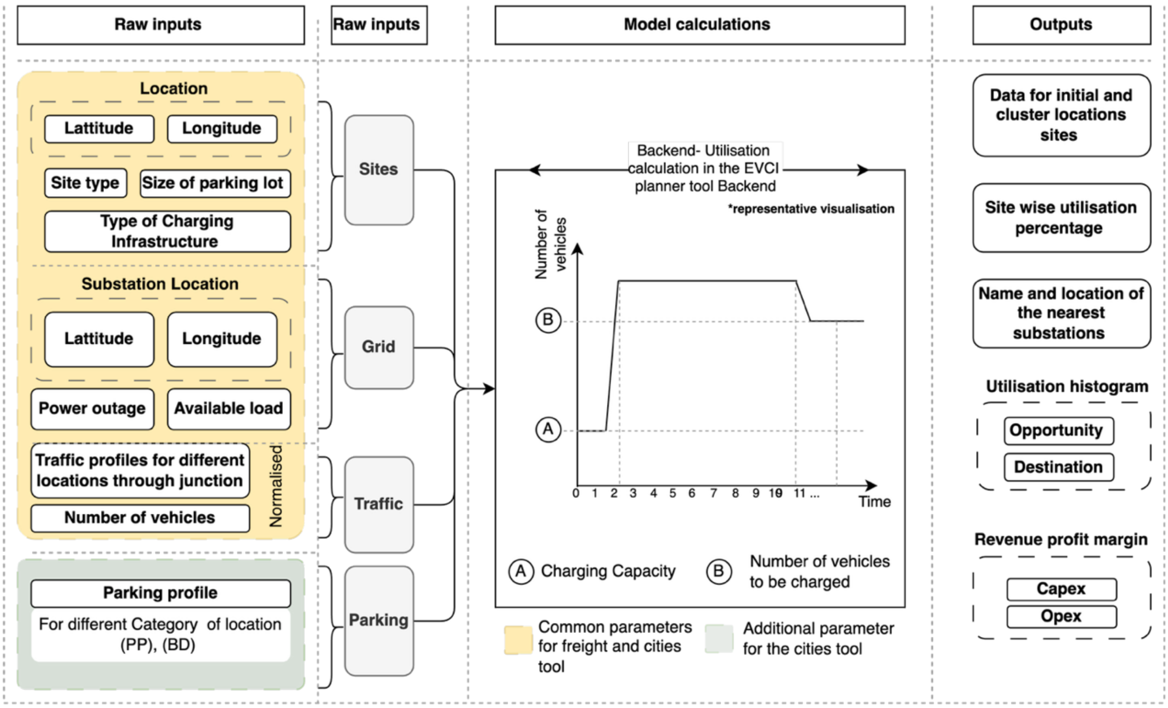


*Figure 3: The EVCI Planner tool model analysis and parameters*

**Input selection:** The tool's inputs, categorized into four key domains-

*Table 2: Categorisation of the tool inputs*

| **Grid-specific inputs**: | **Charger-specific inputs**: | **Site-specific inputs**: | **Traffic-specific inputs**: |
|---|---|---|---|
| Include transformer locations, power capacity, and grid connectivity data provided by local power authorities and secondary data collected by GIS analysis. These ensure that charging stations are co-located and analysed with substations to minimize grid upgrades and implementation costs. | Encompass charger types (fast, slow, AC, DC), power ratings (e.g., 60 kW for fast chargers, 2.2 kW for 2W chargers), capital expenditure (capex), and charging durations. These are tailored to use cases (e.g., opportunity vs. destination charging) and can also be tailored to vehicles types. | Covers potential site locations, that can be high-priority or optional based on ground-truthing surveys. Additional revenue streams (e.g., hoardings, kiosks) and land availability (~300 sq. ft. per charger) are factored in to enhance analysis of financial viability. | Includes traffic density (e.g., 9,000–45,000 vehicles/day), peak patterns (bi-peak for working days, flat for holidays), and vehicle composition (e.g., 60% 2W, 20% 4W). These are derived from traffic authority surveys and EIA reports |

The data sheet assumptions are designed to support EV charging infrastructure planning across different user groups—such as public transport, logistics fleets, and personal vehicles. The process starts with defining use cases, site types (depots, hubs, public places), and compatible chargers. These feed into the "**chargers_site_categories"**, which lays out how many chargers to install at each site, how many vehicles can be charged at once, and the setup configuration, followed by adding of technical and cost data for each charger—such as power, capex, and vehicle compatibility. For fast-changing needs, the "**chargers_opportunity_charging" data point (assumption)** is linked to the site categories, eventually deciding the number of charging bundles being deployed in the area. In case of a bus depot, the case would be of opportunity charging (not more than 2 hrs pause time), and in case of malls etc. in the Public place category it will be a case of destination charging where vehicles will be stay for longer hours that depending on the parking space available can cater to more charging stations. Meanwhile, "**battery-specific data points"** focuses on battery swap options, charge times, and efficiency, helping match energy needs to vehicle types.

An added feature is the "**clustering analysis"**, which uses substation data and expected usage to pinpoint ideal hub locations. It ensures that catchment areas don't overlap and that each site sees high utilization. This leads to more efficient infrastructure, less downtime, better energy management (especially for trucks), and greater environmental and financial benefits.

## Analytical framework for the EVCI Planner tool

The analytical framework defines the computational backbone of the EVCI Planner Tool, detailing the equations and parameters that drive its calculations. It translates spatial, technical, and operational inputs into measurable indicators used for site assessment. This section presents the mathematical structure that underpins the model's analysis and output generation.

**Input data parameters:** All the required input data is provided in MS EXCEL format. The python backend engine reads these EXCEL files into pandas data frames. The parameters listed below are inputs into the model.

*Table 3: General input parameters to the model backend*

| Category | Parameter | Description | Notation |
|---|---|---|---|
| **Charger types & data** | Number of charger types | 5 types – 2/3WS, 2/3WF, 4WS, 4WF, P4WF | $M$ |
| | Capex per charger type | Capital cost per charger type | $Kj$ |
| | Required kW per charger | Power requirement for each charger type | $Dj$ |
| | Required space per charger | Area requirement for each charger type | $Hj$ |
| | Annual maintenance per charger | Maintenance cost per year | $Qj$ |
| | Charging time per charger type | {4WS: 3/2, 4WF: 1/2} hours | $tj$ |
| | Number of evaluation slots | {4WS: 48, 4WF: 16} – calculated as 24 / $tj$ | $24/tj$ |
| | Timeslot index | Charging slot index | $hj \in \{1,2,\dots,24/tj\}$ |
| | Number of chargers per site | Number of chargers of each type at site | $Cij$ = {'4WS': #, '4WF': #} |
| **NITI Norms** | 2W | 1 Slow charger / 2 EV | – |
| | 3W | 1 Slow charger / 3 EV | – |
| | 4W | 1 Slow / 3 EV, 1 Fast / 10 EV | – |
| | Bus | 1 Fast / 10 EV | – |
| **Grid transformers** | Number of transformers | Total count of grid transformers | $Ng$ |
| | Transformer locations | Latitude, Longitude | Lat$g$, Long$g$ |
| | Total available kW | Capacity of transformer | $Gg$ |
| **Site-specific data** | Potential number of sites | Total number of candidate sites | $N$ |
| | List of sites | Coordinates of each site | (Lat$i$, Long$i$) |
| | Distance to closest transformer | Proximity to nearest grid transformer | $di$ |
| | Available kW at closest transformer | Vector of $24/tj$ slots | $G(hj)i$ |
| | Cabling cost per metre | INR/m at each site | $Wi$ |
| | Available area | Area available at each location | $Aj$ |
| | Annual cost per sqm | Annual land lease/rent cost | $Li$ |
| | Margin per sqm | Revenue margin from site area | $Bi$ |
| | Renewable kW at location | Available renewable energy | $R(hj)i$ |
| | Grid tariff margin | Margin from grid-supplied energy | $Mg$ |
| | Renewable margin | Margin from renewable-supplied energy | $Mri$ |
| **Utilisation data** | Vehicles of type $j$ (working days) | Count per slot on working days | $djworking(i,hj)$ |
| | Vehicles of type $j$ (holidays) | Count per slot on holidays | $djholiday(i,hj)$ |
| | Conversion percentage | EV conversion rate per year | $pj(year)$ |
| | % of vehicles needing charging | Per slot on working days & holidays | $qjworking(i,hj)$, $qjholiday(i,hj)$ |
| | Max conversion % | Max percentage of vehicles of type $j$ _converted over the period | $Pj = \Sigma pj(year)$ |

Based on the inputs specified above, the tool **analyzes the potential of a given list of sites** and provides various indicators – **_site utilization**, **capex**, **opex**, gross margin, and measure of un-serviced vehicles. The analysis accounts for EVCI sites in close proximity while analyzing and provides site-wise information. The following equations, based on the above notations, are used:

Number of vehicles of type $j$, at location $i$ needing charge in slot $h_j$ in year $k$

$$n(j,i,h_j,k)_{working} = q_{j_{working}}(i,h_j) * d_{j_{working}}(i,h_j) * p_j(y_k)\left[(1-e^{-d_{j1}})(1-e^{-d_{j2}})...\right]$$

Time of use of each charger type $j$, at location $i$, in slot $h_j$ in year $k$:

$$t(j,i,h_j,k)_{working} = \begin{cases} n(j,i,h_j,k)_{working}\left(\frac{t_j}{C_{ij}}\right), & \text{if } C_{ij} > 0 \\ 0 & \text{otherwise} \end{cases}$$

Utilized time of charger type $j$ at location $i$, in slot $h_j$, in year $k$

$$U(j,i,h_j,k)_{working} = \begin{cases} t(j,i,h_j,k)_{working}, & \text{if } t(j,i,h_j,k)_{working} \le t_j \\ t_j & \text{otherwise} \end{cases}$$

Similarly, the utilization is worked out for holidays.

**Capital expenditure or Capex:**

$$\text{Capex}(i) = \sum_j (C_{ij}K_j) + W_i d_i \sum_j (C_{ij})$$

**Operating expenses or Opex:**

$$\text{Opex}E(i) = 300\sum_{h_j=1}^{24/t_j}\sum_j C_{ij}U_{working}(j,i,h_j,k)t_jD_jE_g^{(h_j)} + 65\sum_{h_j=1}^{24/t_j}\sum_j C_{ij}U_{holiday}(j,i,h_j,k)t_jD_jE_g^{(h_j)}$$

where

$$E_g = \lambda_i(h) \in [0,1]$$

$\lambda_i$ is proportion of grid power and $(1-\lambda_i)$ is proportion of renewable power

**Land opex**

$$\text{Opex}L(i) = L_iA_i + C_h(i) + C_k(i)$$

Margins:

$$\text{Margin}E(i) = 300\sum_{h_j=1}^{24/t_j}\sum_j C_{ij}U_{working}(j,i,h_j,k)t_jD_jM_g^{(h_j)} + 65\sum_{h_j=1}^{24/t_j}\sum_j C_{ij}U_{holiday}(j,i,h_j,k)t_jD_jM_g^{(h_j)}$$

**Land margin**

$$\text{Margin}L(i) = B_iA_i + M_h(i) + M_k(i)$$

Together, these inputs, parameters, and equations form the computational backbone of the EVCI Planner Tool, enabling it to translate diverse datasets into clear, quantifiable indicators for site assessment. This general backend calculation supports both versions of the tool—the **EVCI City Planner Tool** for urban passenger vehicle charging and the **EVCI Freight Planner Tool** for commercial freight corridors. By integrating spatial, technical, grid, and utilisation data into a unified analytical framework, the tool provides an objective basis for comparing potential sites and prioritising those with the highest impact potential. The following results illustrate the application of this framework in two distinct scenarios—Goa (city-level) and the Pune–Kolhapur corridor (freight-level).

## Results

The following cases illustrate the outcomes derived from using the EVCI Planner Tool in two distinct scenarios: Case 1 focuses on the application of the tool for cities, using Goa as a case study, while Case 2 addresses the tool's application for freight, with the Pune-Kolhapur corridor as the example.

**Case 1 - EVCI siting tool for cities, Goa:** The inputs for the cities part are classified into different sections and listed in the table below. In each category, user inputs are facilitated to enable the system to make automated yet practical decisions.

**The input assumptions are:**

- **Grid-specific:** Power sector authorities in Goa have provided a detailed list of grid transformers along with their latitude and longitude information. We have also been given to understand that while deciding EVCI locations, we could prima facie assume that they will be able to provide us with grid power of the required rating (voltage of supply – HT/LT). Based on the above considerations, no particular constraint from the grid perspective has been incorporated in the model. It is also assumed that the capex cost of the charger includes the cost of connecting to the closest grid transformer. A fast charger will require connection to a grid substation with a voltage level of at least 66 kV, which entails a substantial investment in the associated transformer.
- **Charger specific:** In the case of multiple chargers per location, the following configuration is assumed: 1 Fast charger for 4W rated at 60 KW, 1 Slow charger for 4W rated at 22KW, 4 Slow chargers for 2W, each rated at 2.2 KW. The capex costs per charger are assumed to be INR 1L, INR 9L & INR 0.25L, respectively. The charging times are assumed to be 0.5 hr, 1.5 hr, and 1 hr, respectively.
- **Site-specific:** A list of all potential sites, close to 120 in number, were identified. Based on extensive site visits and study, some of these were designated as high-potential, "must-have" sites, and the rest were taken to be optional. Sites were also analyzed for additional revenue potential, viz., hoardings and kiosks. Priority was accorded to high-profile sites with potential for other revenues, given the expected low penetration potential of EV in Years 1-2.
- **Traffic specific:** Based on our meetings with the traffic authorities, we learnt that their surveys showed maximum traffic observed in Goa at around 55,000 vehicles per day at the most crowded junctions, and the traffic typically peaked twice in a day. These inputs contributed to designing the following traffic curve.
    - Based on an empirical study of traffic at various possible sites, we designated each site with a traffic index ranging from 1-5, with 1 corresponding to a total of 9,000 vehicles per day and 5 corresponding to 45,000 vehicles per day.

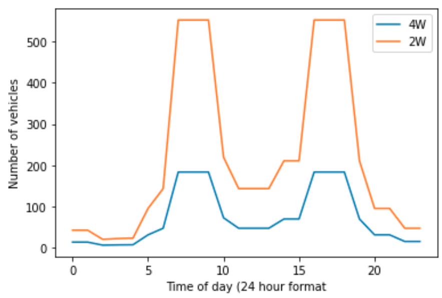


*Figure 4: Traffic data input*

- Working days vs. holidays: While the above bi-peak model is considered for working days (300 days per year), for the holidays, a 'flat-model' is assumed where the total number of vehicles is 30% of that of a corresponding working day, and the traffic is the same in every slot throughout the day.
- Based on the data provided by the Goa RTO authorities, it is assumed that 60% of the traffic at each location is contributed by 2W and 20% by 4W. Further, at any junction, it is assumed that 80% of the 4W requiring charging would prefer fast charging, while 20% would prefer slow charging.

*Table 4: EV charging requirement assumptions across the sites*

| | Cumulative % of EVs at a location requiring charging | | |
|---|---|---|---|
| Vehicle type | Year 1 | Year 2 | Year 3 |
| 2W | 2% | 5% | 10% |
| 4W | 2% | 5% | 10% |

The output from the tool is presented in the following figures:

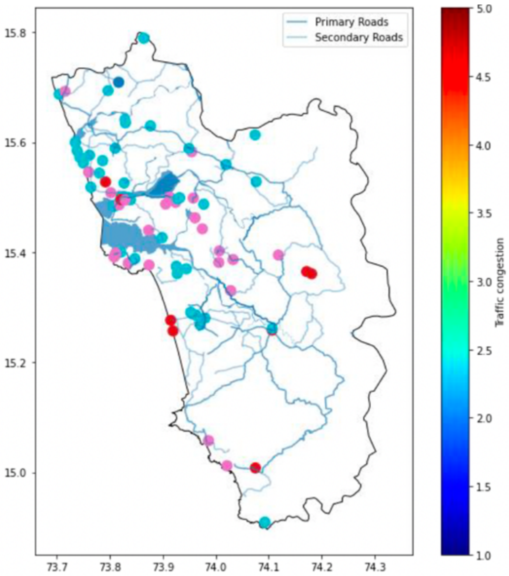

*Figure 5: Traffic congestion analysis and site distribution*

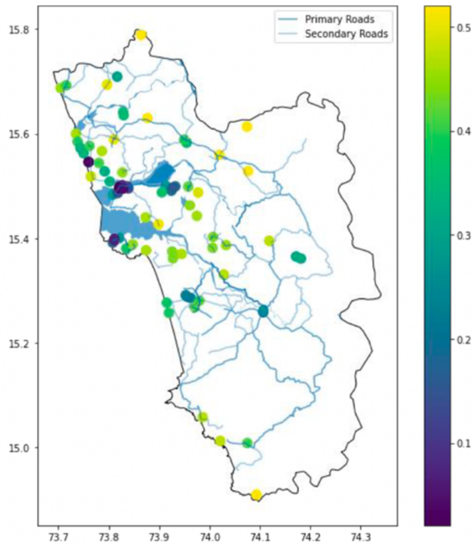

*Figure 6: Charging locations utilisation*

The traffic congestion analysis, as illustrated in **Figure 5**, provides a comprehensive overview of the road network conditions along the corridor, with congestion levels rated on a scale from 1 to 5. Derived from detailed on-site assessments, the map reveals a wide distribution of primary and secondary roads, most of which exhibit minimal to moderate congestion. The absence of severe bottlenecks across the network underscores the corridor's capacity to support additional vehicular activity, making it conducive for EV charging infrastructure deployment. This analysis formed a critical input into the broader planning framework, informing both the traffic count estimates and the prioritization of road segments for charging infrastructure siting. Building on this analysis, **Figure 6** presents the identified sites color-coded by their projected utilization, offering a visual representation of demand potential. The majority of shortlisted locations demonstrate promising utilization, validating their selection for initial deployment. Only a small number of sites show a utilization factor below 10%, highlighting areas that may require targeted demand stimulation or phased

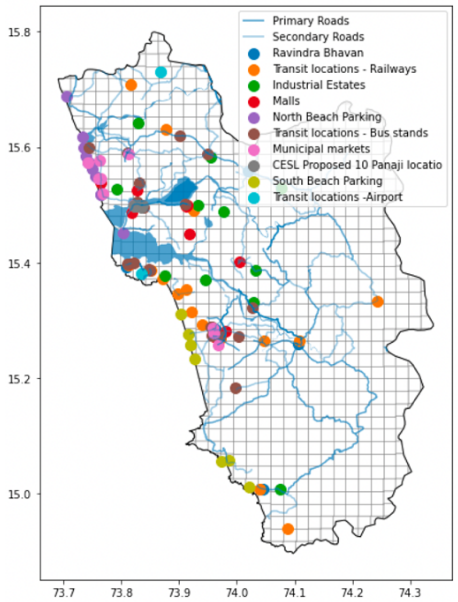

*Figure 7:Initial longlist of sites*

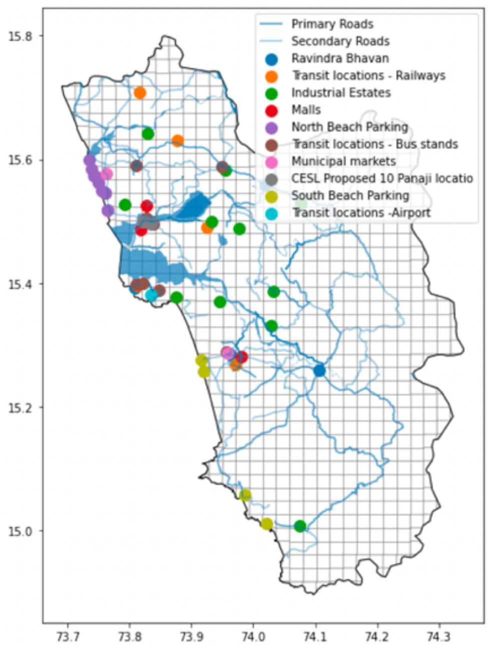

*Figure 8: Shortlisted sites*

development. Together, these maps underscore the importance of integrating traffic dynamics with demand forecasting to optimize the siting of EV charging infrastructure.

**Figure 7** presents the initial landscape of potential charging sites, identified prior to the application of the EVCI Planner Tool and clustering analysis. These sites were selected using broad, high-level criteria, primarily based on their general location along the corridor and perceived relevance to traffic flow and infrastructure presence. At this stage, no optimization or detailed filtering had been applied, making this a preliminary dataset that served as a starting point for deeper analysis. As a continuation of the analysis, **Figure** showcases the refined outcome after running the tool with defined input parameters. The tool incorporated key variables such as traffic density, proximity to existing infrastructure, substation access, and spatial distribution efficiency. Through clustering analysis, it grouped sites by their relative potential for optimal EVCI deployment, effectively identifying areas where investment would yield the highest returns in terms of utilization and operational viability. This transition from raw selection to targeted optimization demonstrates the value of systematic planning in enabling smarter, more impactful infrastructure rollouts.

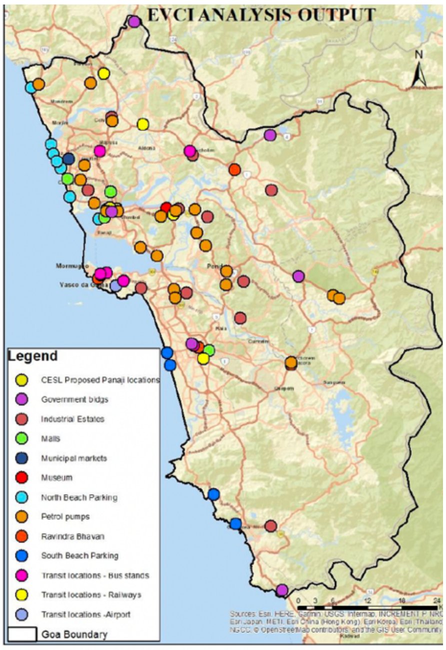


*Figure 9: The final EVCI output locations*

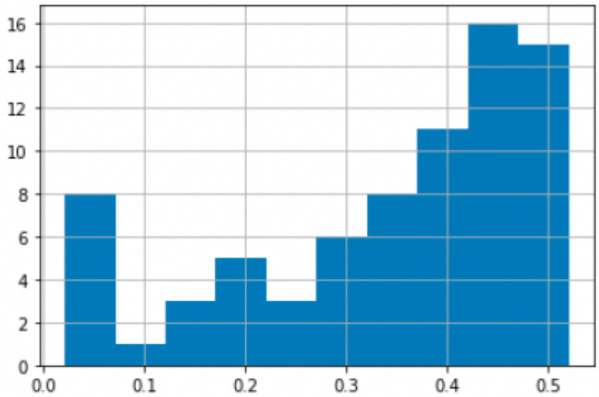


*Figure 10: Utilisation histogram*

Figures 9 and 10 present two key outputs from the EVCI Planner Tool:

- **Figure 9** is the final EVCI analysis map, showing the spatial distribution of charging sites selected for phased implementation across the study area. This map reflects the results after integrating all critical parameters—vehicle flow, land suitability, power infrastructure proximity, and category-wise demand segmentation, etc. The selected sites are located to maximize both accessibility and coverage, ensuring that the charging infrastructure meets the current and projected needs of diverse user segments, including private vehicles, commercial fleets, and shared mobility services.
- **Figure 10** presents the **utilization histogram**, which provides a quantitative distribution of expected utilisation levels across the proposed sites. Most sites fall within a moderate to high utilization range, indicating strong alignment with demand centers and optimal siting. Only a small number of sites show lower utilization, which may correspond to areas where long-term strategic presence can be prioritized over short-term returns—such as emerging zones or coverage areas meant to support equitable access.

In continuation of the analysis, **the table below** provides a phase-wise breakdown of Electric Vehicle Charging Infrastructure (EVCI) deployment across different **talukas** in Goa over a three-year period.

*Table 5: Phase-wise implementation of sites and visualisation of sites, taluka-wise*

| Taluka | Year 1 | Year 2 | Year 3 |
|---|---|---|---|
| | No. of sites | No. of sites | No. of sites |
| Bardez | 3 | 5 | 7 |
| Bicholim | 1 | 1 | 1 |
| Canacona | 1 | 1 | 2 |
| Dharbandora | 1 | 0 | 0 |
| Mormugao | 3 | 1 | 3 |

| | | | |
|---|---|---|---|
| Pernem | 1 | 0 | 2 |
| Ponda | 1 | 1 | 2 |
| Quepem | 1 | 0 | 0 |
| Salcete | 3 | 5 | 2 |
| Sanguem | 1 | 0 | 0 |
| Sattari | 1 | 1 | 0 |
| Tiswadi | 8 | 5 | 1 |
| Total | 25 | 20 | 20 |

The table shows how the number of charging sites is planned to expand in a staggered manner, starting with 25 sites in **Year 1**, followed by a total of 20 sites each in **Year 2** and **Year 3**.

**The key findings from the analysis can be categorised and summarised as under:**

- **Charging needs:** In Goa, the demand for EV charging is driven by a combination of personal 2-wheeler and 4-wheeler ownership, shared mobility fleets, and light commercial vehicles (LCVs) involved in last-mile delivery and tourism. The demand is spread across the region, requiring siting strategies that focus on accessibility, public visibility, and integration with existing parking infrastructure.
- **Vehicle type and ownership patterns:** The majority of vehicles in Goa are privately owned 2-wheelers and 4-wheelers, with an increasing adoption of 2 and 4-wheeler EVs. Residential and institutional vehicle owners contribute significantly to demand, particularly for slow and moderate chargers (3.3–7.5 kW). These chargers are most needed in public spaces such as municipal parking lots, tourist centres, and residential neighbourhoods. Public-private partnerships (PPP) prove to be more viable in areas where demand is driven by mixed-use environments, particularly in urban areas like Panaji and Margao.
- **Utilization and financial viability:** Public charger utilization in Goa is projected to exceed 20% in high-footfall zones, making these areas ripe for cost recovery through blended models, including advertising and parking fees. These models enhance the financial viability of the charging infrastructure, particularly in areas with mixed demand.
- **Grid integration and substation co-location:** By co-locating chargers with substations, Goa has reduced both the capital expenditure (CAPEX) and implementation timelines. This approach simplifies the integration of charging infrastructure into the existing grid, facilitating a smoother rollout.
- **Localized constraints and contextual planning:** In Goa, localized challenges such as narrow roads, land-use conflicts, and the presence of heritage zones have required alternative strategies. These include the installation of wall-mounted chargers and the establishment of EV-only parking streets. Site-specific planning has been crucial to overcome these barriers, ensuring the effective deployment of charging infrastructure while respecting local conditions.

**Case 2 - The Pune-Kolhapur corridor:** The Pune-Kolhapur corridor, a vital segment of National Highway 48 (NH-48), is undergoing significant infrastructural enhancements aimed at improving connectivity, reducing travel time, and fostering economic growth. With a growing emphasis on sustainable mobility, the corridor presents a significant opportunity for electric freight vehicle (EFV) adoption through the strategic placement of charging infrastructure. The EVCI Freight Planner Tool was used to identify optimal charging locations based on a combination of quantitative and qualitative spatial factors. These assessments focused on factors such as power availability, EV traffic density, proximity of locations to substations, land accessibility, and type near highways.

**Figure 11** presents a snapshot of the tool UI mapping the locations analysed. **Figures 12** and **13** illustrate the unfiltered site utilization analysis (Opportunity charging) and in cases with more locations a more refined, targeted clustering approach is followed. **Figure 12** showing the initial utilization histogram, presents a wide distribution of site performance, with many sites falling within the mid-range (10–15% utilization), while also capturing extremes of very low and high utilization. This provides an overall picture of the varied performance levels across the network. Here **Figure 13** presents the clustering histogram, which applies a threshold (e.g., utilization ≤10%) to focus on underperforming sites.

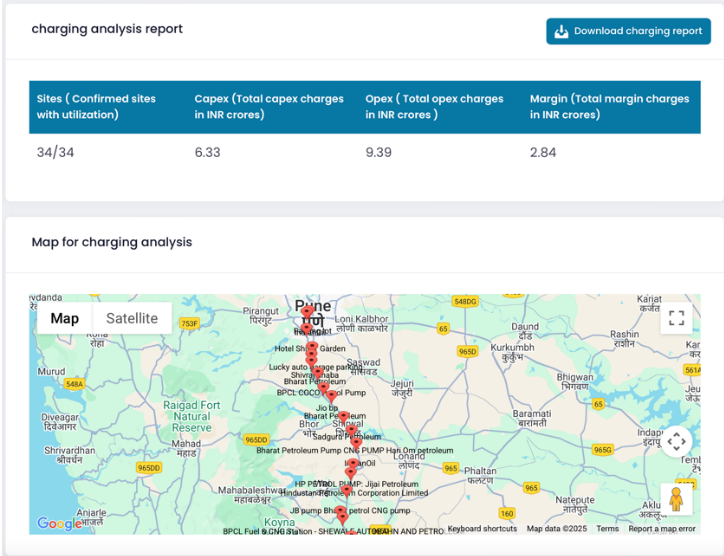


*Figure 5: Output results from the EVCI planner tool - a snapshot*

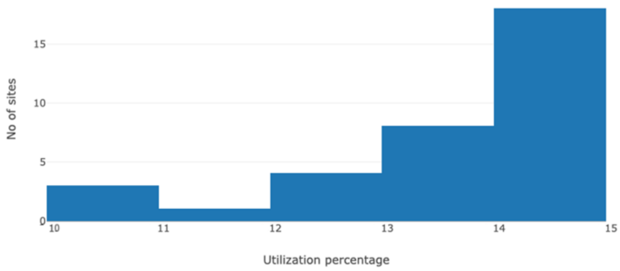


*Figure 12: Initial utilisation histogram*

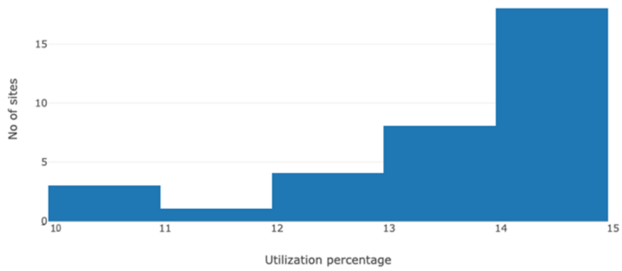


*Figure 13: Clustering histogram*

This thresholding in most cases significantly reduces the number of sites under consideration, isolating a smaller group—specifically sites in the 0–10% utilization range—highlighting them as candidates for consolidation or a physical site validation and verification. In cases where the graphs and number of sites remain the same, such as this case, the sites as fewer in number and no sites with 0 to 10% range, the clustering remains the same, meaning all 34 sites are equally important for the consideration of installation of charging infrastructure.

The key findings from the analysis include:

- **Charging demand characteristics:** The Pune–Kolhapur corridor, a vital regional artery in Maharashtra, supports a diverse mix of traffic. Demand is driven by intercity private vehicle travel, increasing commercial logistics (particularly LCVs), shared mobility fleets, and tourism-related transport. Charging demand is concentrated at key nodal points—such as toll booths, rest stops, food plazas, petrol pumps—necessitating a hub-and-spoke deployment strategy along the corridor.
- **Vehicle types and ownership patterns:** The corridor sees substantial use by privately owned 4-wheelers, especially for intercity and commuter travel. Growing numbers of LCVs can be expected around Kolhapur's agri-markets and Pune's peri-urban logistics zones. Fleet operators and delivery aggregators can emerge as significant user groups, particularly near the MIDC zones and transport nagars.
- **Charger specifications and siting strategy:** A mix of moderate (7.5–15 kW) and fast (30–60 kW) chargers is recommended. Moderate chargers can be sited near eateries and rural service stations to support longer pause times, while fast chargers can be prioritized at logistics hubs, petrol pumps to serve time-sensitive freight and passenger vehicles.
- **Utilization and business viability**: High utilization rates are anticipated at locations like petrol pumps, which serve as rest stops as well as refueling stations. Public-private partnerships (PPPs), combined with revenue from food courts, parking, and advertising, can significantly improve financial viability.
- **Grid and infrastructure integration:** The presence of substations along NH-48 offers a strategic advantage for grid-connected fast charging infrastructure. Upfront engagement with DISCOMs and energy planners is critical to ensure grid readiness and load management.
- **Land and operational considerations:** Varying land-use profiles along the corridor—including agricultural belts, industrial zones, and highway commercial strips—demand a data-driven approach. Containerized or

modular charging units and wall-mounted chargers in constrained sites are effective solutions. Seasonal tourism and monsoon-related disruptions also necessitate resilient, weather-proof infrastructure with remote monitoring capabilities.

This analysis emphasizes the importance of refining deployment strategies to ensure efficient resource utilization while addressing local challenges like land use, infrastructure integration, and accessibility.

## Additional features, validation, and quantitative evaluation of the EVCI Planner Tool

The following processes can be done after the EVCI Planner Tool is run to verify and strengthen its recommendations. These steps are not an internal part of the tool's analysis or outputs but are complementary actions that can help ensure successful deployment.

A **multi-step validation process** can be carried out to check that the tool's inputs and predicted outcomes align with on-ground realities. This can begin with **ground-truthing surveys** to verify land availability, accessibility, and infrastructure feasibility through physical site visits. In Goa, for example, around 120 sites were assessed, with high-potential locations prioritised. **Stakeholder consultations** can follow, engaging traffic authorities, grid operators, and regional transport offices (RTOs) to refine datasets—such as vehicle composition data from Goa's RTO. **Historical data calibration** can be done to cross-check traffic and utilization assumptions against existing charger usage trends, typically 1–15% for public chargers. Finally, **pilot testing** can be conducted in areas such as Goa and the Pune–Kolhapur corridor, comparing predicted utilization with ground survey data to fine-tune the model.

*Table 6: Validation process options*

| Validation process step | Activities | Example application |
|---|---|---|
| **Ground-Truthing Surveys** | Physically verify land, access, and infrastructure feasibility | 120 sites assessed in Goa |
| **Stakeholder Consultations** | Engage authorities for accurate datasets | Goa RTO provided vehicle composition data |
| **Historical Data Calibration** | Cross-check assumptions with usage trends | Public charger utilization: 1–15% |
| **Pilot Testing** | Compare predicted vs. actual utilization in pilot areas | Goa and Pune–Kolhapur corridor |

Once the tool's outputs are available, **quantitative evaluation** can be done to prioritise sites and assess network-wide implications. The tool provides **expected charger utilization** for each site, which can be used for utilization-based ranking. This can be followed by confirming that high-utilization sites align with key parameters such as traffic density, grid proximity, and site suitability. The tool can also produce an **overall CAPEX and OPEX distribution** for the complete site list, which can help planners understand total investment and operational requirements. Stakeholder engagement with municipal bodies, CPOs, fleet managers, and local businesses can be done to refine rankings and align them with operational realities.

*Table 7: Evaluation process options*

| Evaluation stage | Activities | Example metrics |
|---|---|---|
| **Baseline establishment** | Collect pre-deployment data on traffic, grid capacity, and charger utilization | Goa & Pune–Kolhapur baseline: 1–15% utilization |
| **Tool output analysis** | Generate recommendations, utilization histograms, and phased deployment plans | Predicted utilization %, ROI, grid impact, coverage |
| **Post-deployment monitoring** | Track real-time utilization, revenue, and grid load | IoT-enabled chargers, remote monitoring |
| **Comparative analysis** | Compare predicted vs. actual metrics using statistical methods | Utilization predictions |
| **Sensitivity analysis** | Test robustness by varying inputs | Traffic density , CAPEX |
| **Stakeholder feedback** | Gather post-deployment operational insights | CPO & EV user surveys |

By applying these additional processes, the tool's outputs can be reinforced with empirical data, stakeholder feedback, and post-deployment learnings, enabling more reliable, scalable, and financially viable charging network deployment.

## Model robustness and potential for cross-context application

By aligning infrastructure planning with real-world mobility, ownership patterns, and grid feasibility, the EVCI Planner Tool accelerates EV adoption and directly supports transport decarbonisation.

**Some of the key contributions to decarbonisation are:**

- **Optimized charger placement:** Ensures high utilization and commercial viability, encouraging faster EV uptake and reducing ICE vehicle dependency.
- **Context-specific planning:** Accounts for local travel behaviour and vehicle types, ensuring infrastructure supports actual zero-emission use cases.
- **Grid integration:** Prioritizes charger locations near substations, reducing emissions from inefficient infrastructure deployment and enabling renewable integration.
- **Support for solar-storage systems:** Especially in freight corridors, promotes decentralized, clean energy solutions where the grid is weak or unreliable.
- **Scalable and modular:** Adapts to diverse geographies and user needs, from ULBs to CPOs, ensuring broad impact across transport segments.
- **Policy and regulatory alignment:** Assists stakeholders in planning infrastructure aligned with EV mandates and climate goals.
- **Stakeholder-centric design:** Improves buy-in for EV infrastructure, speeding implementation and amplifying emissions reduction potential.

The EVCI Planner Tool standardizes the site selection process, ensuring consistent evaluation across different cities. By considering parking patterns and traffic flow, it identifies sites with high utilization potential, enhancing revenue opportunities for charging operators and improving financial feasibility. Higher return on investment (RoI) encourages investment, expanding the charging network, and accelerating EV adoption.

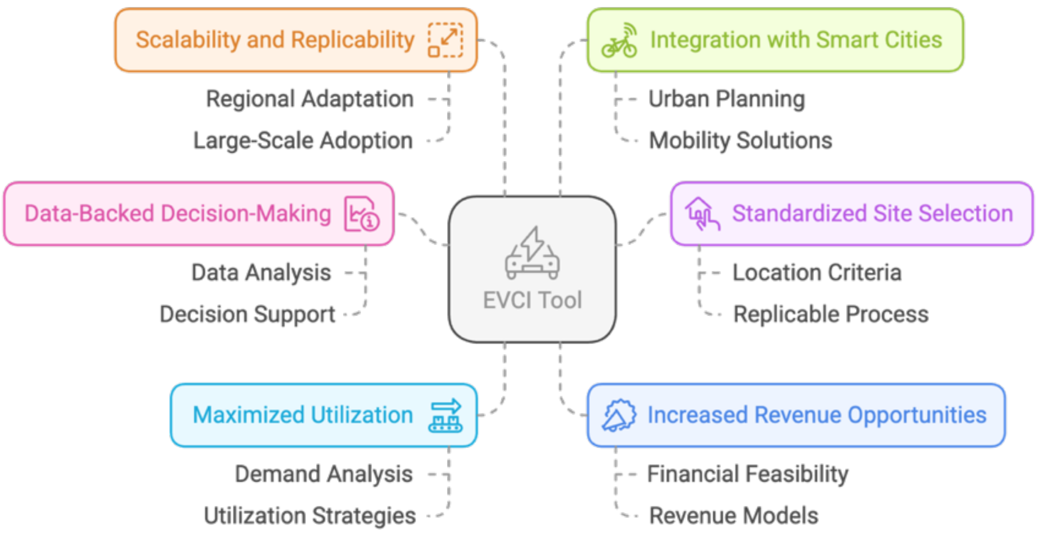


*Figure 6: The EVCI Planner Tool advantages*

The tool's step-by-step process enables systematic data gathering, making it scalable for deployment across diverse regions. It aligns with smart city objectives and urban planning initiatives, allowing integration into the town and country planning department (TCPD) processes. By identifying optimal locations in a phased manner, it supports sustainable urban development and ensures cities are prepared for increasing EV demand. Beyond individual city projects, the EVCI Planner Tool offers strategic scalability and adaptability. As EV adoption grows, a replicable and data-driven approach to charging station deployment becomes essential for sustainable urban development.

## Limitations and challenges of the model

While the EVCI Planner Tool offers a robust and data-driven framework for optimizing electric vehicle charging infrastructure siting in Indian contexts, certain limitations and challenges must be acknowledged. These are important to understand both for interpreting the results and for informing future improvements or adaptations of the tool.

One of the primary limitations lies in **data availability and quality**. The model relies heavily on accurate and up-to-date datasets such as substation locations, traffic volumes, land use classifications, and parking availability. In many Indian cities, such data is fragmented, outdated, or non-digitized, requiring extensive data collection, ground-truthing, or stakeholder validation. The absence of granular EV usage data also poses challenges in forecasting demand with high confidence, especially in early-stage adoption markets.

There is a **need to train key stakeholders,** including public agencies, city officials, urban planners, grid operators, charging station operators, community representatives, EV driver groups, land and business owners, transportation authorities, and shared mobility providers, in using the EVCI Planner Tool. Workshops along these lines were conducted by MP Ensystems in multiple cities. Large-scale training and availability of online training material are required, along with creating a publicly accessible database of knowledge on the topic.

Another challenge is the **heterogeneity of urban form and regulatory structures** across different regions in India. Planning regulations, land ownership patterns, utility coordination protocols, and mobility behaviors vary significantly, making it difficult to apply a uniform modeling logic across all geographies. While the tool has demonstrated adaptability in both city-scale and corridor-scale applications, its effectiveness is partly dependent on local area regulation and DISCOM engagement for implementation and validation.

The model also assumes a certain level of **grid readiness and substation upgrade potential**. In reality, transformer capacity constraints, feeder availability, and load balancing issues can introduce implementation delays or cost escalations—factors that are not fully embedded in the simulation logic. Similarly, revenue estimation based on auxiliary sources (such as advertising or parking) may vary with real estate market dynamics and local policy restrictions.

With regard to generalizability, while the tool is designed for scalability across Indian cities and intercity freight corridors, **applying it to non-Indian contexts** would require significant recalibration. Factors such as EV penetration rates, mobility patterns, regulatory frameworks, and grid infrastructure differ substantially in other geographies. The model's structure, however, is modular—allowing for customization of input parameters and backend calculations, which opens the possibility for adaptation in other emerging economies with similar urban and energy system characteristics.

Lastly, the model currently focuses on infrastructure planning rather than **behavioral uptake modeling**. While it identifies optimal locations from an infrastructure standpoint, it does not yet integrate dynamic user adoption behavior, socio-economic profiles, or changes in travel demand due to modal shifts—factors that could influence long-term viability.

In summary, while the EVCI Planner Tool provides a strong foundation for systematic and scalable EV infrastructure planning in India, its deployment must be complemented by continuous data updates, local stakeholder collaboration, and iterative model refinement to ensure relevance, accuracy, and impact.

## Acknowledgements

We sincerely thank all stakeholders, industry experts, and partners who contributed their insights and support to this study. All mistakes are our own.

## Disclosure of use of AI

No AI Used

## References

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**Reviewer Comments**

**Review 1:**

**Comments for the Authors**

The submitted paper presents a highly relevant and practical contribution to the field of EV infrastructure planning in India through the development and application of the EVCI Planner Tool.
A structured, data-driven, and scalable siting methodology is important against the ad-hoc ways of siting and installing EV chargers, as they remain unutilized, which is inefficient. The paper has demonstrated the tool that incorporates geospatial analysis, traffic patterns, grid infrastructure data, and cost-revenue considerations to support smarter planning decisions. The case studies in Goa and along the Pune–Kolhapur corridor, demonstrating the tool's utility in improving infrastructure utilization, reducing investment risk, and supporting coordinated rollout strategies is interesting.

Additionally, it would be valuable to understand how the tool plans to stay current with evolving traffic patterns, EV adoption rates, and infrastructure changes. Future development could include mechanisms for periodic data updates and the integration of AI or machine learning models to improve prediction accuracy, site prioritization, and user demand forecasting.

**Reply from the authors:**

Thank you for this insightful observation. We fully agree that the dynamic nature of urban systems—such as evolving traffic patterns, shifting EV adoption rates, and ongoing infrastructure developments—necessitates a flexible and adaptive tool framework.

In the current version of the EVCI tool, **data is collected and input by the user**, which enables adaptability to evolving urban patterns, datasets, and planning contexts. Moving forward, the integration of real-time data streams (where available) can be explored, along with the establishment of protocols for automated data refresh cycles to update hardwired assumptions.

Additionally, there is potential to develop alternative tool configurations: one that generates context-specific outputs based on detailed user-provided inputs, and another that offers generalized outputs with minimal inputs—relying instead on predefined assumptions. These configurations can be selected via an initial user-defined preference, allowing the tool to cater to varying levels of user expertise and data availability.

Looking ahead, we are actively assessing the incorporation of AI and machine learning algorithms to enhance the tool's predictive capabilities. This includes efforts in demand forecasting, dynamic site prioritization, and scenario-based planning. These enhancements will enable the tool to evolve into a more robust decision-support system capable of responding to real-world complexities in a timely manner.

**Review 2:**

**Comments for the authors**

This paper introduces a timely and much-needed tool to support the intelligent planning of EV charging infrastructure across Indian cities and freight corridors. The tool demonstrates promising applications across contexts and serves multiple stakeholders. The Goa and Pune–Kolhapur corridor examples add credibility.

Strengths:
- Strong relevance to India's EV transition.
- Dual urban and freight application is a plus.
- Visuals and outputs are professionally presented.
- Integration of grid data, traffic, and site characteristics is forward-looking.

Areas for Improvement:
- Reframe the document as a research paper rather than a product explainer.
- Include a structured literature review to position your tool in context.
- Expand on methodology rigor: how were inputs selected, weighted, and validated?
- Provide quantitative validation or evaluation of tool performance. – We have validated the Goa part and section on evaluating the tool performance
- Add reflections on limitations, challenges, and generalizability of the model.
- Make tone more neutral and analytical.

**Reply from the authors**

Thank you for your thoughtful and constructive feedback. We greatly appreciate your recognition of the tool's relevance to India's EV transition, its dual applicability across urban and freight contexts, and the clarity and quality of its outputs.

We acknowledge the areas identified for improvement and offer the following responses and planned revisions:

1. **Reframing as a research paper:** We agree with the recommendation to shift the narrative from a product-oriented description to a more academic presentation. The revised version incorporates a clear **problem statement, hypothesis, and structured results** and discussion sections to align with research paper standards.
2. **Structured literature review:** A detailed literature review section is added to **evaluate key determinants** for optimal EVCI siting, as well as review existing EVCI siting tools and methodologies, such as those developed by NREL, and other institutions and organizations.
3. **Methodological rigor (Input selection):** We have enhanced the methodology section to clearly document the criteria for input selection and the analytical framework of the EVCI planner tool.
4. **Quantitative validation of tool performance:** We have added a section for additional features validation and quantitative evaluation post the running of the tool, which can be done additionally.
5. **Discussion on limitations and generalizability:** A dedicated section is included to critically reflect on the model's assumptions, limitations (data dependency, resolution, interoperability), and its potential generalizability across different geographic and policy contexts.
6. **Tone and language revisions:** We have revised the tone of the document to be more neutral, analytical, and aligned with academic discourse, while maintaining accessibility for policy and planning audiences.