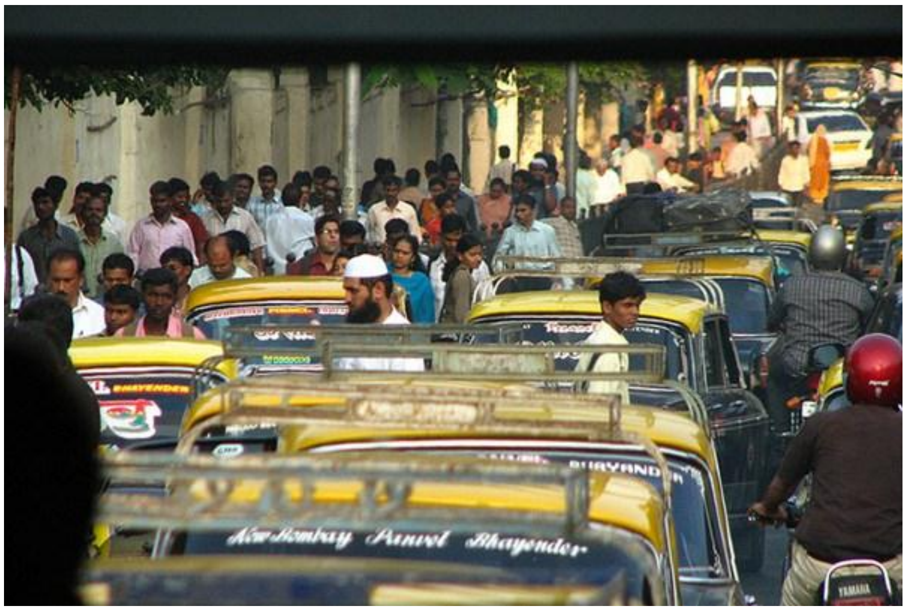
Assessing and Accelerating Electric Vehicle Deployment in India



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CLEAN ENERGY MINISTERIAL
Accelerating the Transition to Clean Energy Technologies

Electric Vehicles Initiative

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Table of Contents

Executive Summary

In 2013 India released its National Electric Mobility Mission Plan (NEMMP) 2020, the guiding document to meet the goals of the National Mission on Electric Mobility (NMEM). The plan emphasizes the importance of government-led policies and incentives, working in coordination with industry and research institutions to attain the NMEM's targets of deploying 5 to 7 million hybrid and electric vehicles in the country by 2020.

India is one of 16 member countries of the Electric Vehicles Initiative (EVI), a multi-government policy forum dedicated to accelerating the introduction and adoption of electric vehicles worldwide. EVI is one of several initiatives launched under the Clean Energy Ministerial, which is a high-level dialogue among energy ministers from the world's major economies. As part of its work, EVI is providing analytical research support to the Government of India to develop policies and plans under the NMEM. To date, this research support has focused on two activities, both of which are presented in this report:

Activity 1. Assessment of the real-world environmental and economic benefits and costs of meeting the passenger car targets of NMEM and beyond.

Activity 2. Optimal siting of public EV charging stations in the New Delhi metropolitan region.

According to the NEMMP, India aims to deploy 400,000 passenger battery electric cars (BEVs) by 2020. If this target is achieved, India can avoid importing 120 million barrels of oil and avoid 4 million tons of CO_2 emissions by 2020 based on real-world conditions of use. If these BEV adoption rates continue beyond 2020, India could save 4.8 billion barrels of oil and 270 million tons of CO_2 emissions by 2030. While BEVs are currently more expensive than conventional vehicles, they are, even today, a highly cost-effective way to reduce oil consumption in India. This is because, in India, BEVs yield better than expected real-world fuel economy and a BEV range of 100 km is sufficient for more than 99% of trips. Over time, decreasing battery costs suggest that manufacturing costs for compact and smaller BEVs will fall below costs for comparable conventional vehicles by 2030. Factoring in fuel cost savings from switching to electricity from oil, the same BEVs could become cheaper than conventional vehicles on a life cycle cost basis prior to 2030. In 2015, the consumer payback period for compact 100-km BEVs is 5.6 years, and is expected to fall as low as 1.8 years by 2020.

The uptake of electric vehicles (EVs) will depend in large part on the adequate deployment of electric vehicle supply equipment (EVSE) needed to recharge EVs. The plug-in electric vehicle infrastructure (PEVI) model -- an agent-based simulation modeling platform -- was used to explore the cost-effective siting of EVSE for passenger cars throughout the National Capital Territory (NCT) of Delhi, India. At 1% fleet penetration, or ~10,000 passenger car EVs, substantial service can be provided to EV drivers for an investment of $760,000 (Rs 460 lakh) by locating 1270 chargers, mostly low power (Level 1), throughout the NCT of Delhi with an emphasis on the more densely populated and frequented regions of the city. The amount of public charging infrastructure needed depends on the access that drivers have to EVSE at home, with more than triple the number of EVSE required to achieve the same level of service in a population of drivers without home chargers vs. with home chargers. Results also depend on the range of the EVs adopted, with approximately three times as many chargers needed to achieve the same level of service when vehicles are assumed to have 100km vs. 220km of range.

In summary, the benefits of EVs in India are greater than expected when real-world use conditions are taken into account, primarily due to the superior ability of electric powertrains to maintain high efficiency in highly transient operation. The investment needed in EVSE in the New Delhi region is also very reasonable considering the substantial role that widely available EVSE has on improving EV uptake by alleviating both vehicle range constraints and consumer range anxiety.

Acknowledgements

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Real-World Benefits and Costs of Passenger Electric Cars in India

The assessment results for Activity 1 are based on national hybrid, plug-in hybrid, and battery electric deployment targets contained in the NEMMP. The goal for battery electric cars is 400,000 vehicles sold in 2020. Activity 1 assumes that this deployment target is met. In some cases, the analysis extends beyond 2020 to assess potential outcomes that may result by 2030 given the momentum established by the uptake of electric vehicles to meet the 2020 goals.

Oil and Carbon Dioxide Savings Potential

Energy security is a key part of India's National Mission on Electric Mobility. India relies heavily on oil imports for transportation and this dependence is expected to increase over time. In 2020, oil consumption is expected to exceed production by ~225 million tons (1.6 billion barrels).[1]

Figure 1 shows both potential cumulative oil savings and carbon dioxide savings from switching to BEVs for the period from 2015-2020. Figure 2 extends oil and CO_2 savings potential to the period 2015-2030, assuming that BEV adoption rates established by the NEMMP continue to 2030. Note that these figures show disaggregate results for the four classes of cars that dominated 2011 vehicle sales in India and CO_2 savings assuming BEVs with a 100-km/charge range.

Figure 1. Cumulative oil savings (million barrels of crude oil) and CO_2 emission savings (million tons) resulting from NEMMP 2020 target deployment (400,000 passenger car BEVs sold in 2020).

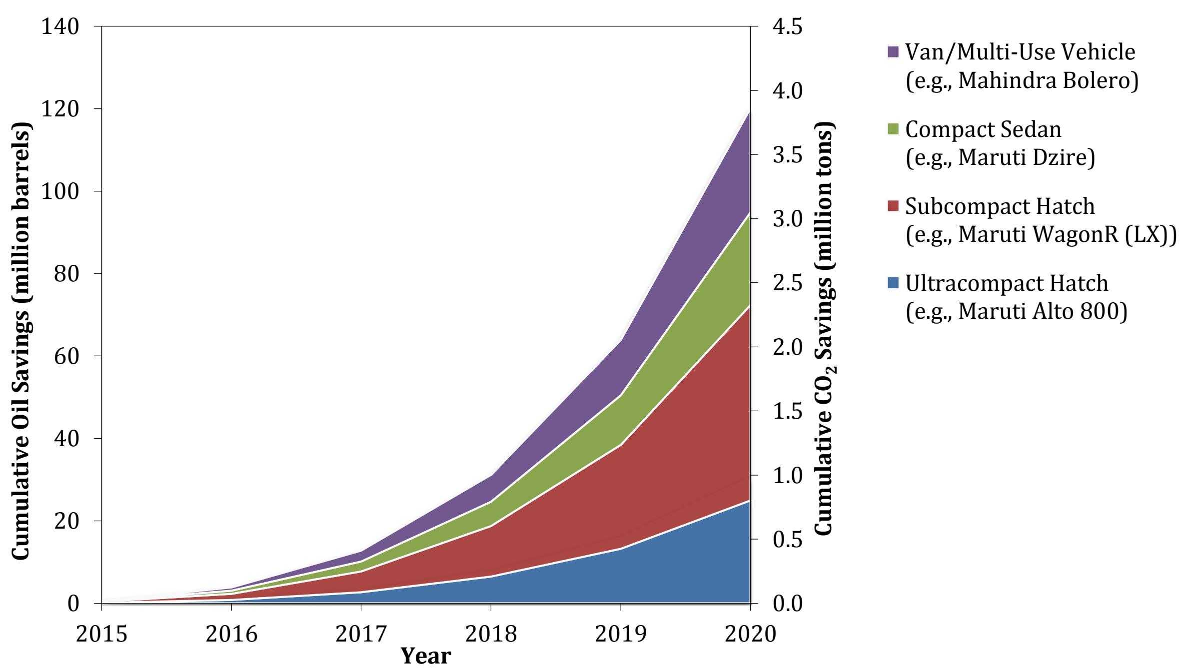
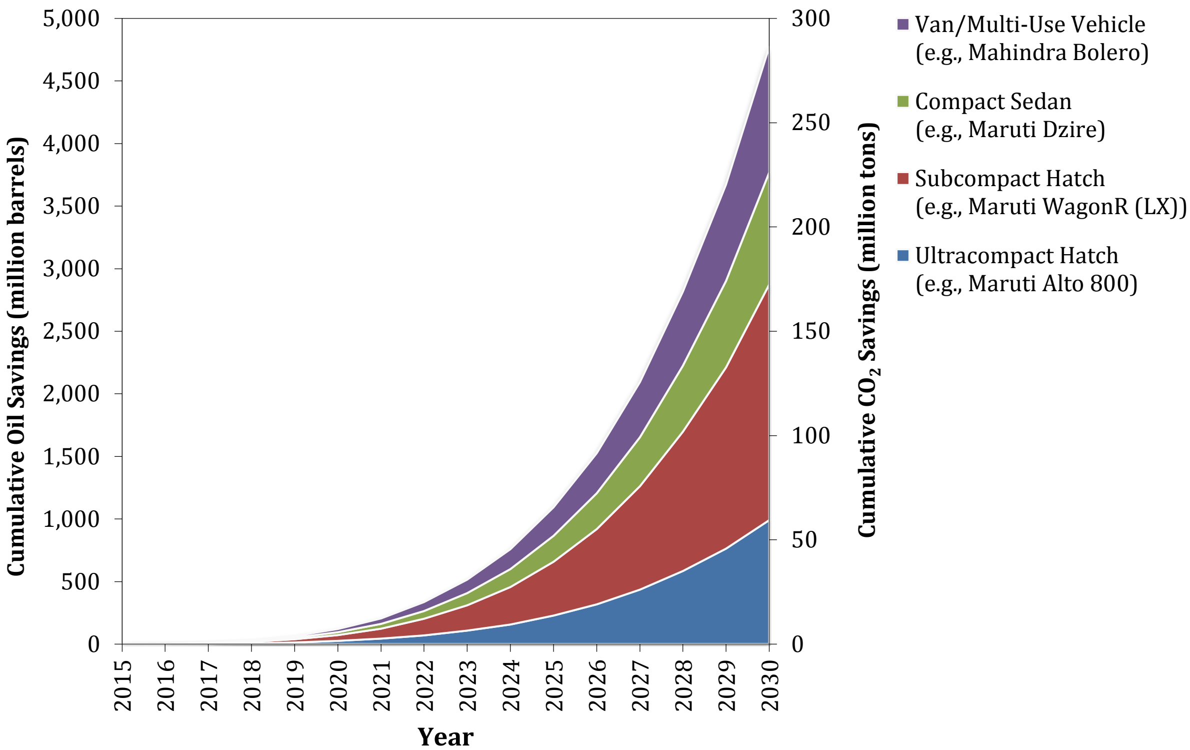


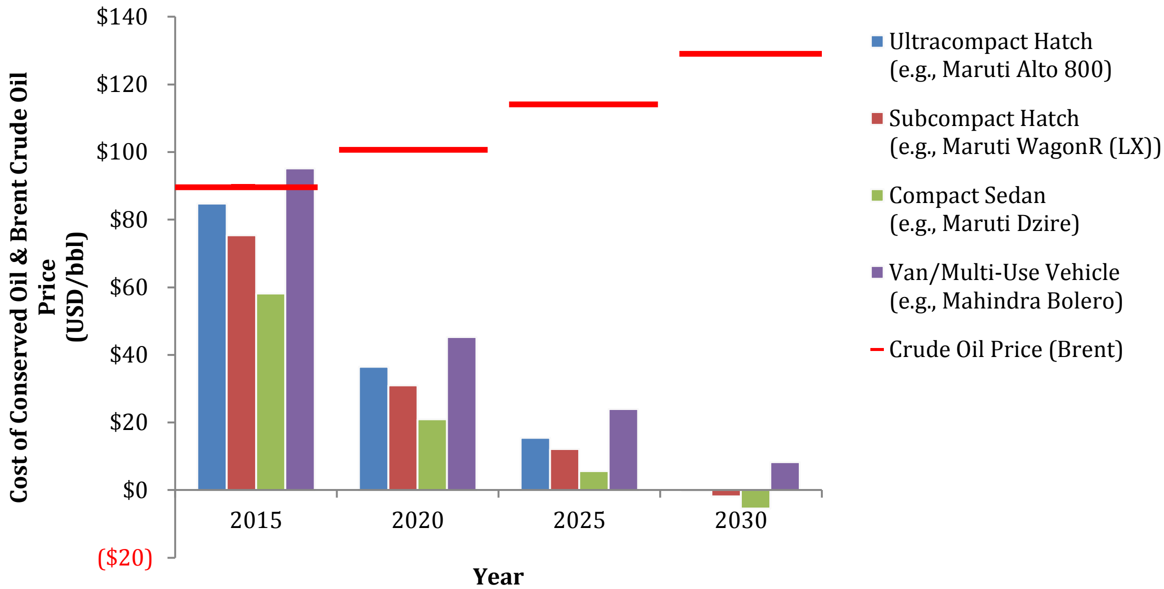
Figure 2. Cumulative oil savings (million barrels of crude oil) and CO_2 emissions savings (million tons) projected to 2030 using BEV deployment trends established by meeting the NEMMP 2020 (896,000 passenger car BEVs sold in 2030).



Cost of Conserved Oil

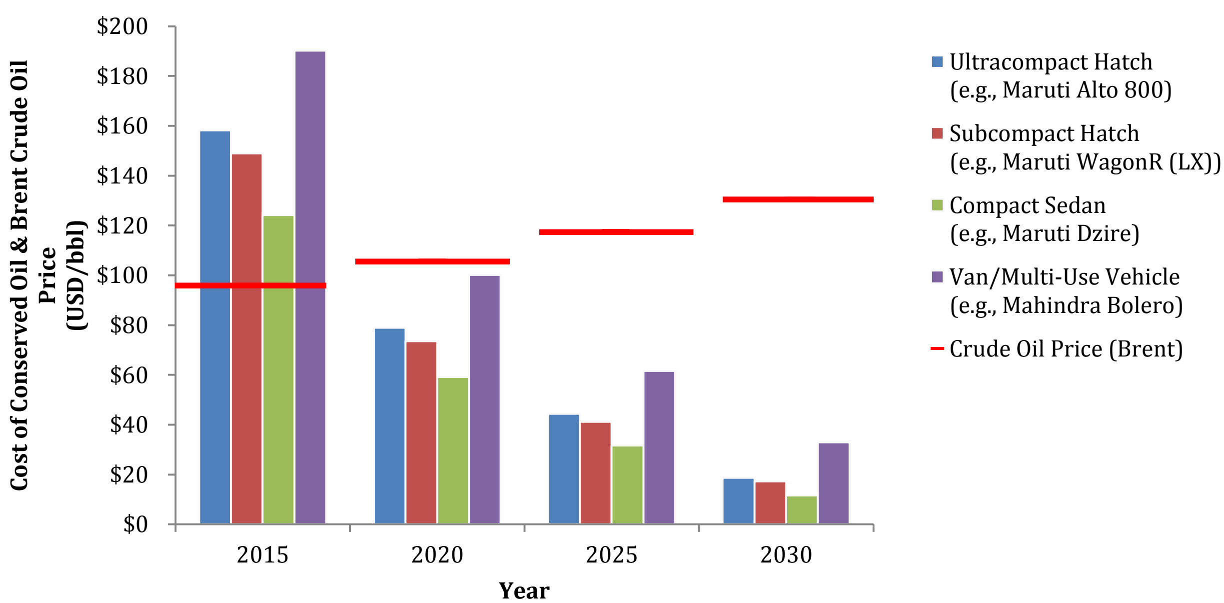
The cost of conserved oil illustrates the incremental manufacturing cost of BEVs per unit of oil saved by switching from conventional vehicles to BEVs. The analysis finds that, in 2015 and every year thereafter, the cost of conserved oil for BEVs with a range of 100 km is less than the projected oil price (see Figure 3).

Figure 3. Cost of conserved oil (USD/bbl oil) for BEVs with a range of 100 km.



Because BEVs with a 200-km range have higher incremental manufacturing costs than 100-km range BEVs, the cost of conserved oil does not fall below the market price of oil until 2020, but remains below the projected oil price thereafter, as shown in Figure 4.

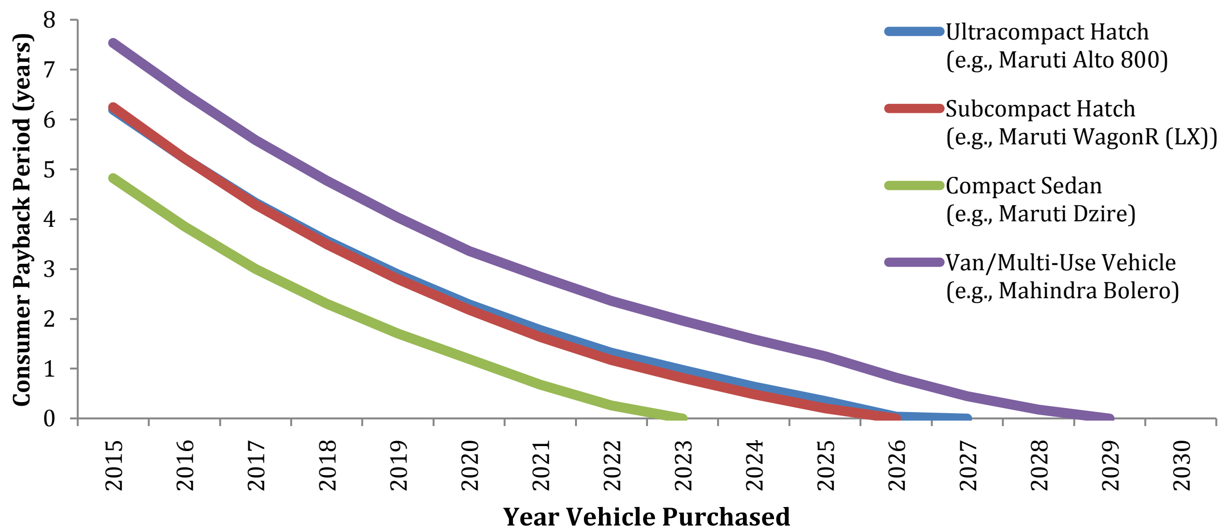
Figure 4. Cost of conserved oil (in USD/bbl oil) for BEVs with a range of 200 km.



Consumer Payback Period

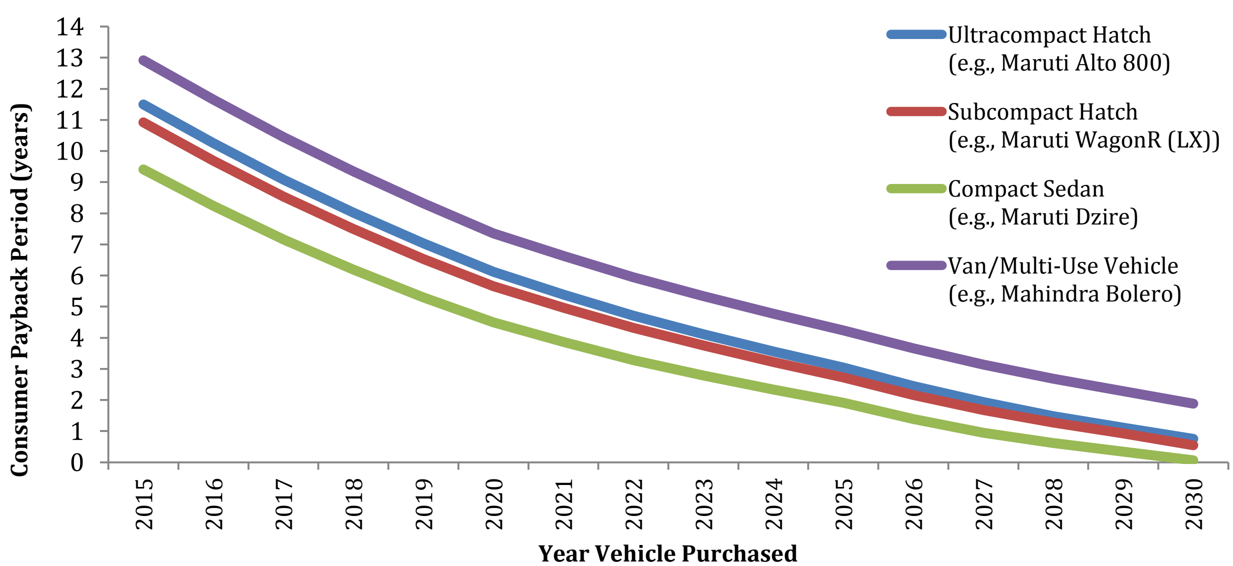
The research also analyzed the payback period for BEVs based on expected vehicle prices and fuel prices (accounting for both gasoline savings and energy prices from electricity for BEVs). Figure 5 illustrates the payback period for BEVs with a 100-km range. The payback period declines with time because of decreasing price differences between BEVs and conventional cars and increasing gasoline prices. For this analysis, the period analyzed was extended to 2030.

Figure 5. Payback period (years) for BEVs with a range of 100 km.



For BEVs with a 200-km range (Figure 6), the payback period does not reach zero in the 2015-2030 time period because price differences remain above zero for the entire period.

Figure 6. Payback period (years) for BEVs with a range of 200 km.



Methodology for Analysis

Real World Passenger Car BEV Performance in India

The research estimates the electrical consumption rates of BEVs under real world driving conditions.[2] These estimates can then be compared to conventional vehicles' performance (under the same conditions) to estimate the oil savings and electricity demands of implementing the NEMMP. This research assessed two levels of BEVs in India: 1) BEVs with 100-kilometer range and 2) BEVs with 200-kilometer range.

For comparison purposes, vehicles were sorted into eight different classes based on vehicle specifications. When compared to Indian vehicle sales data from 2011, four classes of vehicles dominated a majority (~95%) of sales. The remainder of this analysis focuses on research results from these dominating vehicle classes: (1) ultracompact hatch, (2) subcompact hatch, (3) compact sedan, and (4) multi-use vehicles (vans). The top-selling cars were converted into equivalent, but hypothetical, BEVs to isolate the benefits and costs of a pure electric powertrain over a conventional internal combustion engine (ICE) powertrain. Table 1 shows the conventional and the hypothetical BEV specifications for each vehicle class.

Table 1. Conventional Vehicle and BEV Specifications used in Real-world Simulations.

	Ultracompact Hatch	**Subcompact Hatch**	**Compact Sedan**	**Multi-Use Vehicle (MUV)**
Similar Vehicle	Maruti Alto 800	Maruti WagonR (LX)	Maruti Dzire	Mahindra Bolero
Vehicle mass (kg.)	695	825	960	1615
Engine Max. Power (kW)	35.3	47	64	46.3
Top Speed (km/h)	155	152	169	117
Final Drive Ratio	3.65	4.388	4.529	3.27
Tire Size	145/80R12	145/80R13	165/80R14	215/75R15
Drag Coefficient	0.3	0.321	0.31	0.42
Frontal Area (m^2)	1.757	1.987	2.090	2.532
Baseline electrical accessory load (W)	200	200	200	200
Hypothetical BEV Version				
Total Battery Capacity	6.90	7.95	8.62	12.74
Usable Battery Capacity	6.040	6.960	7.539	11.151
Battery Low SOC	0.075	0.075	0.075	0.075

The analysis simulated fuel consumption rates of the conventional and the EV version of each vehicle class on real-world Indian driving cycles. The real-world drive cycle data for this analysis is from New Delhi and Pune. These two cities are highly representative of most private car driving behavior across the country. Table 2 shows the results of these simulations.

Table 2. Fuel economy of conventional (km/L) and BEV vehicles (km/L-equivalent) using Indian drive cycles.

	Ultracompact Hatch			**Subcompact Hatch**			**Compact Sedan**			**Multi-Use Vehicle/Van**		
	Conv.	BEV 100-km	BEV 200-km	Conv.	BEV 100-km	BEV 200-km	Conv.	BEV 100-km	BEV 200-km	Conv.	BEV 100-km	BEV 200-km
New Delhi	24.36	89.15	87.29	21.05	77.30	75.64	17.25	71.36	69.70	18.00	48.29	47.13
Pune	25.16	83.52	81.43	21.82	72.20	70.32	18.18	64.84	63.06	16.43	43.24	41.94

Costs of Passenger Car BEVs

The manufacturing costs of BEVs and conventional cars were calculated using vehicle component cost information and methods developed by the U.S. National Research Council.[3] The results in Tables 3 and 4 reflect the following assumptions: (1) the cost of manufacturing conventional vehicles will increase over time because of the requirement to achieve higher fuel efficiency and (2) the auto components supply chain is globalized, and therefore manufacturing costs shown are not adjusted for Indian production.

Table 3. Difference in manufacturing cost between 100-km range BEVs and conventional cars (USD/vehicle).

	Ultracompact Hatch	Subcompact Hatch	Compact Sedan	Multi-Use Vehicle/Van
2015	$2,841	$2,919	$2,725	$4,598
2020	$1,552	$1,525	$1,246	$2,775
2025	$806	$733	$408	$1,802
2030	-$24	-$137	-$502	$778
2035	-$204	-$341	-$728	$472
2040	-$366	-$525	-$931	$199
2045	-$490	-$665	-$1,085	-$4
2050	-$598	-$787	-$1,220	-$178

Table 4. Difference in manufacturing cost between 200-km range BEVs and conventional cars (USD/vehicle).

	Ultracompact Hatch	Subcompact Hatch	Compact Sedan	Multi-Use Vehicle/Van
2015	$5,299	$5,762	$5,817	$9,182
2020	$3,356	$3,612	$3,516	$6,141
2025	$2,314	$2,478	$2,306	$4,619
2030	$1,219	$1,301	$1,063	$3,104
2035	$860	$890	$614	$2,468
2040	$535	$518	$207	$1,894
2045	$283	$230	-$108	$1,457
2050	$58	-$26	-$388	$1,070

Charging Infrastructure Analysis for the National Capital Territory of Delhi

Public charging infrastructure is a critical component in accelerating the adoption of EVs. Installation of infrastructure for EV charging is typically less expensive than for petroleum fueling, but still requires significant capital investment. It is therefore important to conduct comprehensive planning analysis prior to the rollout of electric vehicle supply equipment (EVSE) in order to ensure that charging stations are optimally sited, providing the best returns on investment while maintaining high service levels. The focus on cost-effective EVSE deployment is especially important for a developing country like India.

Approach

One of the principal challenges that planners face in developing guidelines for regional EVSE deployment is how to site EVSE in a cost-effective manner. Cost effectiveness will depend on the answers to the following questions:

- Where do EV drivers live?
- Where do they drive?
- How long do they spend at their destinations?
- If drivers have a choice of EVSE based on location (home or away) and on power (Level 1, 2 or 3), which will they choose?
- How do drivers impact each other's access to EVSE?
- How do drivers adapt when they need a charge but no station is available?
- How will a given deployment of EVSE improve the experience of drivers? Can we quantify the improvement?

The Schatz Energy Research Center in the United States, in collaboration with the U.S. Department of Energy's Lawrence Berkeley National Laboratory, has developed the Plug-in Electric Vehicle Infrastructure (PEVI) model, a detailed simulation model to assist in the optimal siting of EVSE in any metropolitan region. PEVI is capable of simultaneously addressing all of the above considerations, using an approach called "agent-based modeling," which provides a flexible and powerful framework for evaluating the impact of infrastructure on EV drivers' experiences.

The PEVI model includes a representation of the National Capital Territory (NCT) of Delhi, split into 53 travel analysis zones (TAZs), and its road network. Chargers of the following types can be placed in any TAZ:[a]

- Level 1: low power chargers up to 1.5kW (in Delhi, service voltage is 230V, so any charger on a circuit with a capacity up to 6.5 amps is considered Level 1)
- Level 2: medium power chargers up to 20kW
- DC Fast: direct current fast chargers ranging from 30-100kW
- Battery Swapping Stations: stations where vehicle batteries can be replaced with pre-charged batteries.

[a] See Table 6 for the specific EVSE assumptions used in this analysis.

Individual EV drivers are simulated as they conduct their travels and interact with the EVSE network. Drivers begin a day with a vehicle, an itinerary of trips, and a set of behavioral rules, which include the following:

- Drivers attempt all of their daily trips.
- They include a factor of safety in their range estimations (10%).
- They may or may not have a home in the region and a charger at home.
- They seek a charger if they need it and sometimes if they don't (according to a random process based on observed usage of public EVSE in the United States by plug-in hybrid electric vehicle drivers).
- They consider neighboring and en-route zones in their list of candidate charging sites, but only if desperate for charge (within one hour of departure without sufficient range).
- They choose the charging option that minimizes their cost, a calculation that places a monetary value on their time.

The itineraries that drivers follow are based on two critical sources of data: 1) results from the most recent travel demand model commissioned by the NCT of Delhi and implemented by RITES Ltd., and 2) results from the most recent household travel survey with 45,000 respondents. A stochastic, non-parametric resampling technique was used to blend these two data sources into dozens of unique sets of itineraries, which were used in the context of Monte Carlo simulation to include a suitable amount of variability in the analysis. In addition, data from The EV Project, a large-scale demonstration project in the United States, were used in the development of probability distributions that characterize aspects of driver behavior as well as for model calibration.

During a model run, drivers attempt to execute their travel itineraries by following their behavioral rule set. The experience of every driver is traceable in full detail, charging events can be tracked temporally and spatially, any inconvenience experienced by drivers can be logged, and the model run can be summarized across a variety of metrics.

Optimizing EVSE

The PEVI model provides a quantitative basis for evaluating the efficacy of a given deployment of EVSE throughout the region. An optimization algorithm is employed to determine the set of chargers that provide the biggest benefit to EV drivers for a given amount of public investment. The objective of the optimization is to minimize the total delay experienced by drivers given a cost constraint. Small banks of chargers are sited, one-by-one, throughout the NCT of Delhi. Each siting involves an evaluation of every potential location and charger level, selecting the alternative that provides the largest reduction in driver delay per unit cost. The siting process stops when the return on investment has been sufficiently diminished.

For more information on the PEVI model, the optimization process, and key model assumptions, see the section below titled "Methodological Approach and Key Model Assumptions."

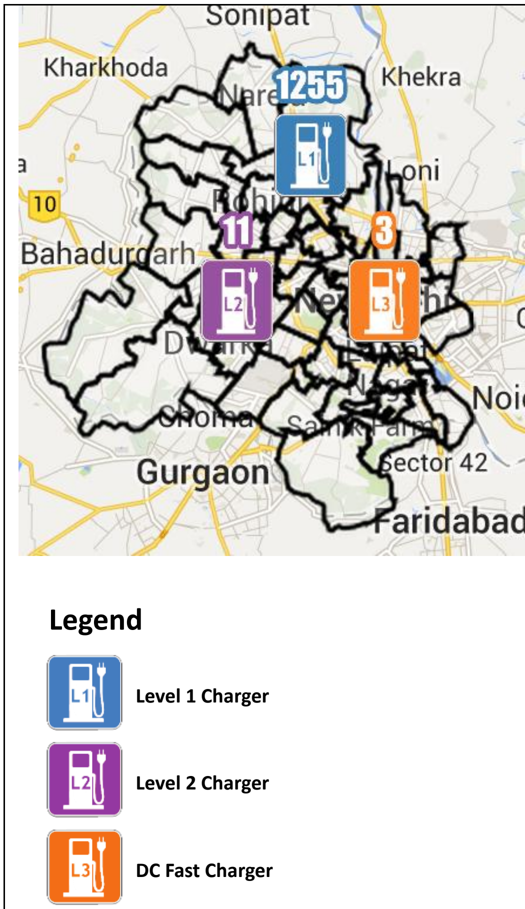
Base Scenario and Results

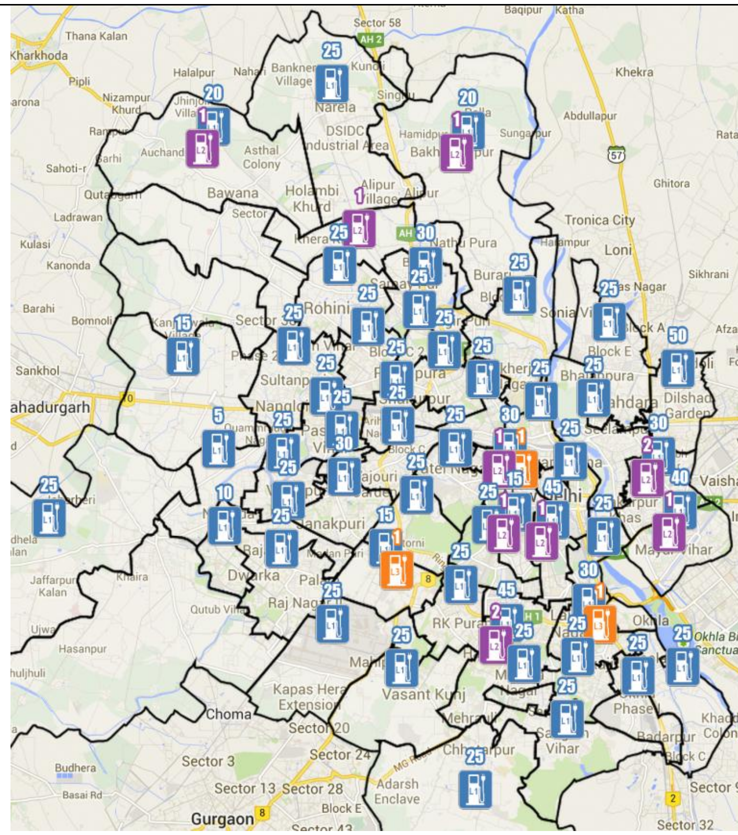
Figure 7 presents the outcome of the optimization process for a base scenario when Level 1, Level 2, and DC Fast chargers are considered, 1% EV penetration (~10,000 vehicles) is assumed, and only 50% of drivers are given access to a private home charger. The spatial distribution of chargers roughly parallels the level of traffic intensity and density of places of employment in the metropolitan region of Delhi, with the highest concentration of chargers occurring near the city center and the lowest concentrations occurring in the outlying regions.

In this scenario, Level 1 chargers dominate the infrastructure portfolio, with 1255 chargers sited, compared to 11 Level 2 and 3 DC Fast chargers. In addition, Level 1 chargers are invariably the first type of EVSE to be sited during the optimization process. This result is due to both the low cost of Level 1 EVSE and the abundance of EV drivers for whom Level 1 is sufficient to accomplish their daily travel. Of the DC Fast chargers sited, one was located in the city center and two were along the highways associated with traffic bound to/from Gurgaon and Faridabad reflecting that commuters from outside the NCT of Delhi tend to have higher daily vehicle kilometers driven and longer individual trips requiring faster charging services to avoid delay.

In terms of infrastructure investment,[b] the bulk of the cost for this solution lies with Level 1 charging, requiring $630K (Rs 328 lakh[c]), compared to $55K (Rs 33 lakh) for Level 2 chargers and $75K (Rs 45 lakh) for DC Fast chargers. Figure 8 compares the results from the base scenario for three penetration levels in terms of the number of chargers, the power capacity of those chargers, and the associated investment required. In Figure 9, the level of investment for the three penetrations is recast in terms of investment required per electric vehicle driver in the metropolitan region. The marginal investment required to support additional drivers decreases with penetration primarily because the EVSE are used more frequently by a greater number of drivers, providing more overall service per charger.

[b] See Table 6 for assumptions on the installed cost of EVSE.
[c] One lakh is equal to one hundred thousand (100,000). "Rs 328 lakh" is equivalent to 32.8 million rupees.





Explore an interactive map of these results at: http://www.schatzlab.org/projects/policyanalysis/pev/delhi/charger-map.html

Figure 7: Optimal EVSE for base scenario at 1% fleet penetration or ~10,000 EV drivers. The siting of chargers occurred only at the scale of the travel analysis zone (bold black lines). Chargers were not sited in any specific location within a zone.

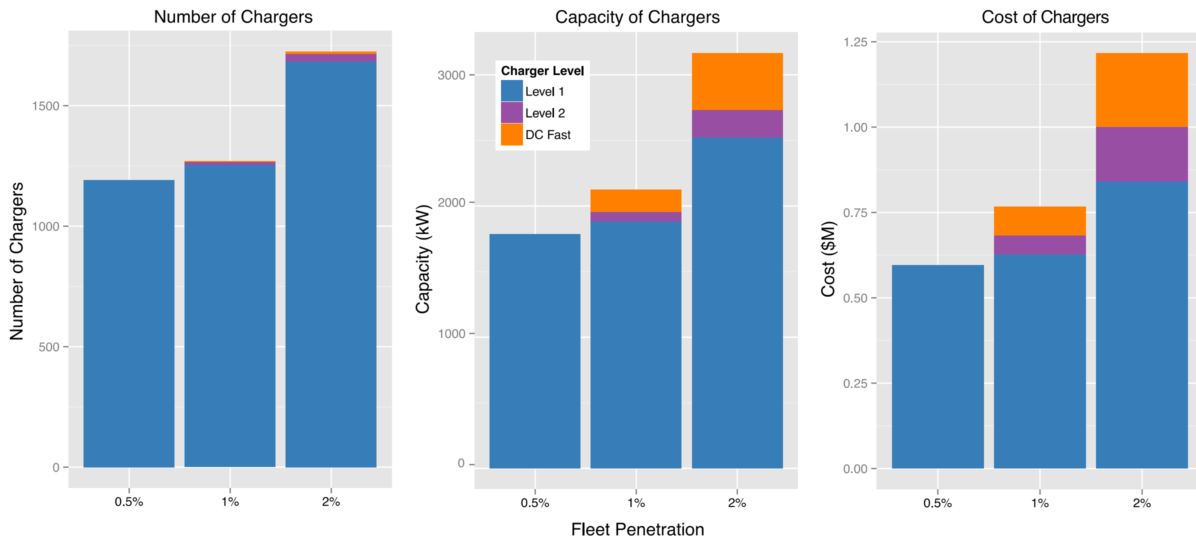


Figure 8: Number, capacity, and cost of chargers sited for three fleet penetration scenarios and three charging levels.

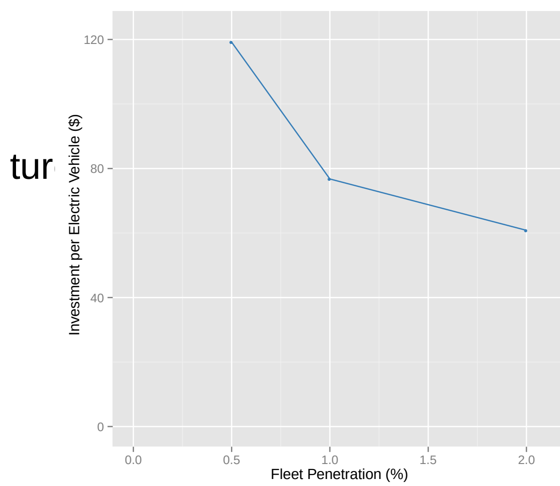


Figure 9: Total public investment in EVSE per electric vehicle driver for the base scenario and three fleet penetrations.

For all penetration levels, both delays and the occurrence of stranding events are substantially reduced from the scenario where no EVSE has been installed (Figure 10). Without EVSE the average driver experiences as much as 1.75 hours of delay every day and a 1 in 3 chance of becoming stranded.[d] With EVSE, the average delay and incidence of stranding events effectively vanishes for 0.5% and 1% penetrations and is substantially minimized for 2%.

[d] Note that the PEVI model considers a long delay (ranging from 0.5-2 hours, depending on the driver) a stranding and a penalty of 4-6 hours is added to the driver's delay to simulate the inconvenience of temporarily abandoning the EV or getting a tow.

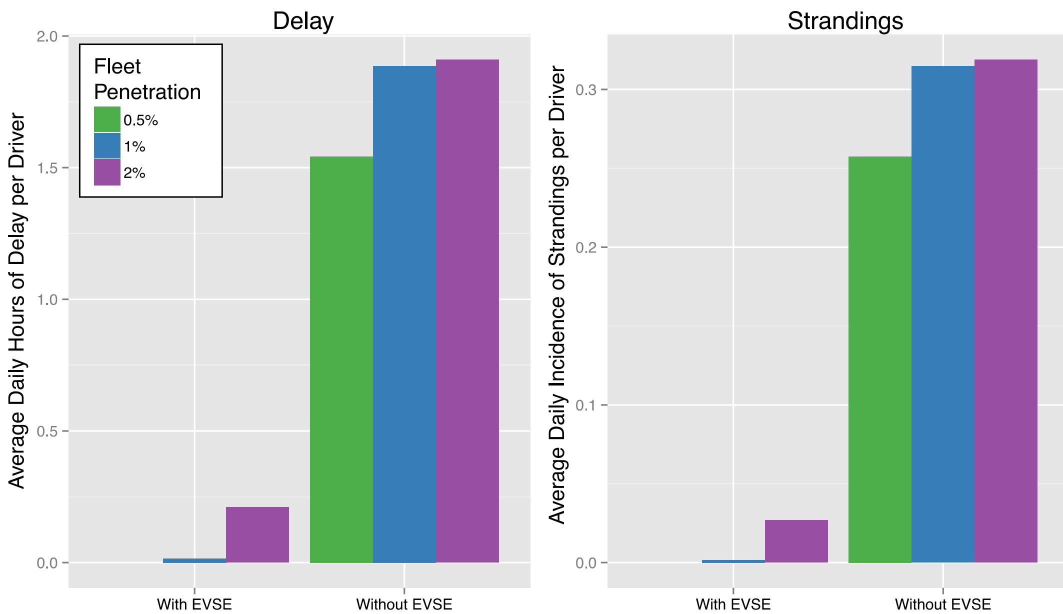


Figure 10: Average occurrence of delay and strandings for three fleet penetration scenarios in simulation runs with and without the optimal EVSE infrastructure from the base scenario.

Finally, it is useful to examine the direct impact that public EVSE has on driver delay when expressed in monetary terms. Using the median wage of Delhi residents, the total daily delay experienced by drivers was monetized and projected over a 10-year time horizon to match the typical life span of the installed EVSE. As EVSE infrastructure is added to the region, the present value of driver delay decreases with decreasing returns on investment as delay approaches zero (Figure 11). With no EVSE, the value of the 10-year delay is approximately \$75M (Rs 454 crore)[e] at 1% fleet penetration. After \$750K (Rs 4.5 crore) in infrastructure investment, the value of the delay is reduced by approximately \$73M (Rs 442 crore).

While these results suggest that a substantial service can be provided to EV drivers for a relatively small amount of public investment, it is important to note that the PEVI model does not simulate the impact of driver delay and stranding events on the *uptake* of EVs. Range anxiety is a very important factor influencing the decisions of prospective EV owners. Public EVSE should therefore be deployed in advance of the arrival of EVs in order to minimize the potential spoilage effects of negative driving experiences.

[e] One crore is equal to ten million (10,000,000). "Rs 230 crore" is equivalent to 2.3 billion rupees.

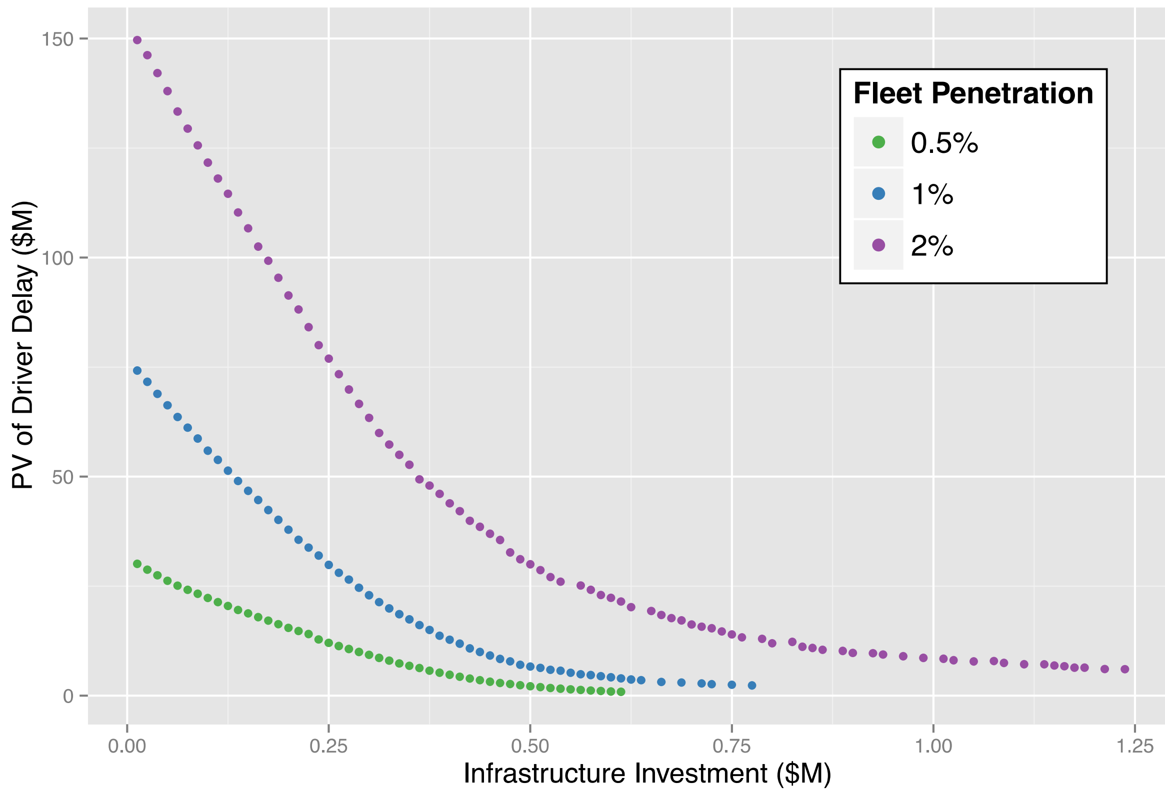


Figure 11: Present value (PV) of driver delay versus the cost of the infrastructure that optimally reduces that delay for three fleet penetration scenarios.

Impact of Battery Swapping

The base scenario optimization was repeated while including battery swapping as a decision variable. Due to the high cost of battery swapping stations and the suitability of lower charging levels, the optimization algorithm never sited swapping stations. The results were therefore identical to the base scenario results presented above.

Impact of Access to Residential Charging

Access to residential EV charging is a critical model assumption that is difficult to forecast accurately. Much of the Delhi population lives in multi-unit dwellings. The willingness and ability of homeowners and residential building managers to install EVSE in parking spaces could vary substantially, presenting a potential barrier to adoption of EVs. Public entities could mitigate this barrier by either subsidizing the cost of installing residential chargers in multi-unit dwellings or by installing adequate public charging infrastructure close enough to multi-unit dwellings to compensate for any residential sector shortfall.

The optimization process was repeated while varying the percentage of drivers who have access to a personal charger at home. In each scenario, the level of charging service provided systemwide is kept constant. The solutions therefore represent the minimum-cost infrastructure required to achieve an equivalent level of service, allowing a normalized basis for comparison. The solutions are not directly comparable to the baseline results presented above, which achieve a lower level of service (as show in Figure 10).

In Figure 12, the need for public chargers decreases as the proportion of drivers with home chargers increases. However, even when the fraction of chargers at home is 100%, there is still a need for EVSE infrastructure. This is because the ranges of EVs simulated in the model (100km, 160km, and 220km) are insufficient to cover the entire range of travel patterns inherent in the travel demand forecasts and travel surveys used by the PEVI model. In addition, it is instructive to note that when 0% of drivers have access to home charging, only approximately 1,500 public chargers are needed to achieve the service level for 10,000 drivers. Taken together, these results suggest that a goal of 100% coverage of personal home EVSE is neither adequate alone to support EV drivers, nor is it a cost-effective means of providing that support.

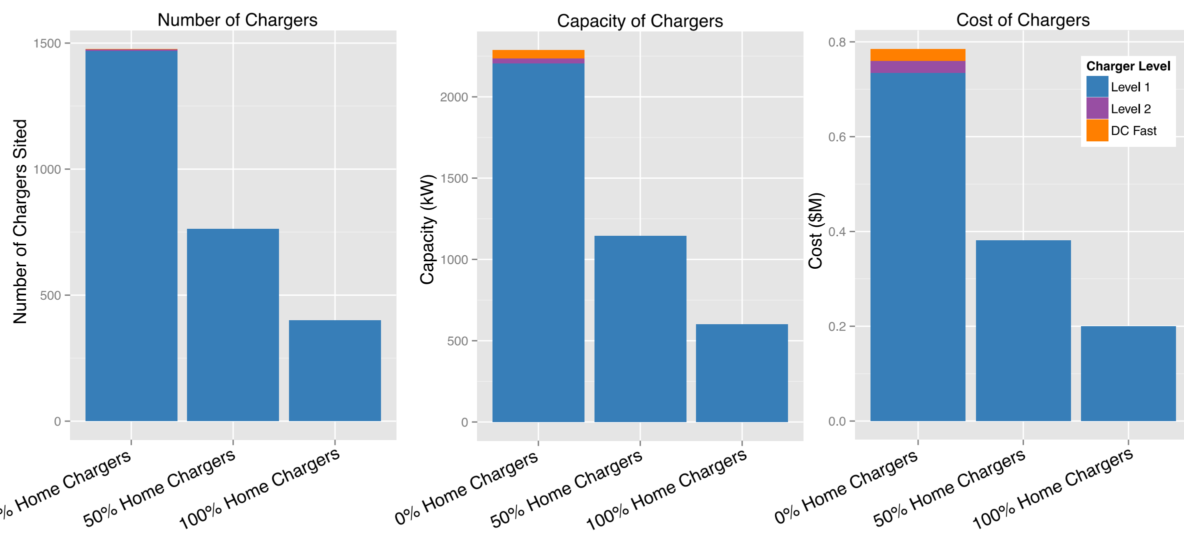


Figure 12: The number, capacity, and cost of public chargers needed for varying levels of access to chargers at home to maintain the same level of service. Increasing the number of residential chargers decreases -- but does not eliminate -- the need for public chargers.

Impact of Vehicle Class

Market trends in EV adoption are also uncertain and difficult to forecast. The optimization process was therefore repeated under different assumptions about the class of vehicles on the road. The base scenario assumes that there is an even split between vehicles of low, medium, and high capacity. Here "capacity" refers to both the power of the electric motor and the effective range of the vehicle (19, 50, and 80kW of propulsion power and 100, 160, and 220km of range, respectively). Two additional scenarios were conducted assuming that all vehicles are either of low or high capacity.

As shown in Figure 13, the change in vehicle class has a substantial impact on the overall number of chargers sited. As before, to make an equitable comparison between scenarios, the level of systemwide charging service is kept constant for all scenarios. By all metrics (number, capacity, and cost), a fleet of low capacity EVs requires roughly three times as much charging infrastructure as a fleet of high capacity EVs.

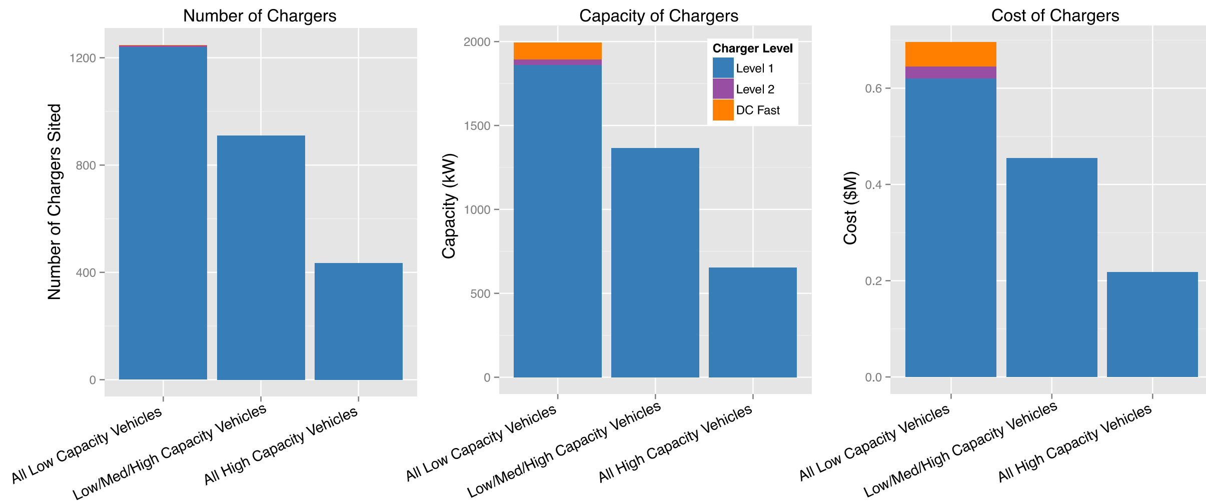


Figure 13: The number, capacity, and cost of chargers sited for three vehicle class scenarios all representing the infrastructure required to maintain the same level of service systemwide. Increasing the range capacity of the vehicle fleet leads to a reduction in need for charging infrastructure.

Impact of the Value of Drivers' Time

Because range anxiety is a documented barrier to EV uptake, an additional optimization was performed after tripling the value placed on drivers' time. The extra value is used as a proxy for the value that policymakers may place on encouraging adoption through exceptional service and fuel availability to EV drivers. When the value placed on driver's time was tripled, the number of chargers sited by the optimization process was predictably higher (Figure 14). In particular, Level 2 and DC Fast chargers more than doubled, increasing the total infrastructure cost by over $0.25M (Rs 150 lakh).

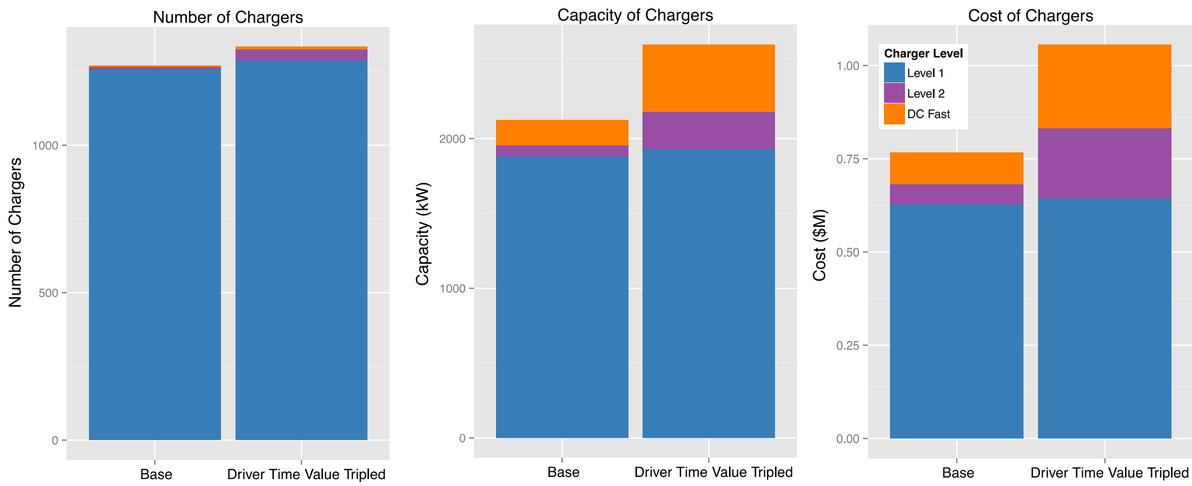


Figure 14: The number, capacity, and cost of chargers sited in the base scenario and with triple-valued drivers' time. Increasing the value of drivers' time places a greater emphasis on fast-charging infrastructure.

Methodological Approach and Key Model Assumptions

Building any agent-based model consists of the following key steps:

1. Create a virtual environment.
2. Create virtual agents with a set of rules describing how to interact with the environment and with each other.
3. Place the agents in the environment and let the system evolve according to the rules.
4. Observe what happens.

In the case of PEVI, the environment is the Delhi regional road network, including any configuration of EVSE infrastructure of interest. The agents are the EV drivers. Drivers interact with the environment according to the following rules:

- Every driver is given a vehicle with configurable properties such as battery capacity and fuel economy.
- Each driver follows a unique daily itinerary, i.e., a table of times and destinations defining when and where he or she will attempt to travel.
- If drivers need energy to complete their next trip (or, in some cases, to complete the remaining trips in their itinerary) then they attempt to charge.
- Drivers are also permitted to charge on some occasions where they do not necessarily need a charge. These events are generated using data on driver charging behavior.
- Drivers choose which EVSE to use based on minimizing their cost. This decision includes the fee for using the charger and, if the driver must make an unplanned stop or is delayed, the value of the driver's time (Rs. 28/hour or $3.80/hour).
- Some drivers have a charger at home and elect to charge at the end of the day according to a random process.

The model simulates two days of driving, and any delays or changes to driver itineraries are tracked. At the end of a model run, the experience of individual drivers can be examined or the entire run can be summarized by a variety of metrics.

PEVI is a stochastic model, meaning that a variety of processes and decisions within the model are based on probability distribution functions. The primary purpose of including stochastic processes in PEVI is to avoid reaching conclusions that are overly customized to suit one particular scenario. Instead, the model is run many times with the same set of initial conditions and the average benefit of a given EVSE infrastructure is calculated.

The utility of such a model is intimately linked to the quality of the data used to drive simulations. As described below, it was possible to procure the best available region-specific data, allowing the analysis to be based on travel patterns specific to Delhi.

NCT of Delhi

The region of application of the EVSE siting analysis was the NCT of Delhi, India. The metropolitan area covers 1400 square kilometers containing over 2300 kilometers of paved road surfaces. In 2008, 52% of households owned a motorized vehicle and 19% owned a car. Residents traveled approximately 22 million kilometers per day in cars and taxis, about 19% of total daily travel.[4]

Several general-purpose transportation planning studies have been commissioned by the NCT of Delhi. With the generous support of the Government of India and staff at RITES Ltd, the research team was able to acquire projections to 2021 of travel intensities throughout the Delhi metropolitan area. In addition, results were procured from the most recent household travel survey, containing over 45,000 responses by Delhi residents.

These data products were primarily used to develop a set of travel itineraries that define the daily driving patterns of individuals. The itineraries were constructed using a non-parametric resampling technique, which simultaneously preserves the projected 2021 geographic travel patterns of Delhi and the temporal patterns of the survey respondents (particularly time of travel and dwell duration between trips).

EV Fleet Composition

As EVs come to market in India, there will be a variety of form factors with a variety of battery capacities and fuel consumption rates. The relative market share of these various options will be vitally important from the perspective of deploying EVSE infrastructure. This analysis did not involve a detailed forecast of EV market evolution, but the model did assume three vehicle classes: low, medium, and high, referring both to the power capacity of the electric motor and to the range of the vehicles (Table 5).

Table 5: The three vehicle classes included simultaneously in PEVI model simulations.

Vehicle Class	Effective Battery Capacity (kWh)	Electric Consumption Rate (Wh/km)	Range (km)	Market Penetration in Base Scenario
Low	6.5	66	98	33.3%
Medium	14.3	88	163	33.3%
High	20.9	94	222	33.3%

Cost of Installing and Using EVSE

The cost of public chargers is highly site specific. Many factors contribute to the expense, such as equipment costs, permitting fees, and construction costs. For the PEVI model it was necessary to assume an average installed cost for each level of charging. Based on detailed cost estimates for a number of EV chargers in Northern California, the research team estimated the cost of installing these stations in Delhi, using international cost modifiers from construction industry survey data.[5] Table 6 presents the cost assumptions.

In practice, the cost of installing the first Level 2 charger in a given location can be substantially higher (as much as four times higher) than the cost of subsequent chargers at the same location, assuming that any conduit or electric service upgrades are sized for future expansion. Because the PEVI model is designed to site EVSE at the scale of an entire neighborhood, the savings from installing multiple chargers in one location are ignored and the cost of installing the first charger in a location is used.

The PEVI model also requires the retail price of energy for charging at each type of EVSE. The pricing data presented in Table 6 reflect a combination of cost-recovery economic analysis and, in the case of DC fast charging and battery swapping, an assumption about the willingness of EV drivers to pay for transportation fuel given that an electricity price of Rs 19/kWh ($0.32/kWh) is equivalent to the going price of petrol of Rs 72/L ($4.53/gal) when fueling a conventional vehicle.

Table 6: Characteristics of EVSE assumed in the PEVI model.

Level	Capacity (kW)	Time to deliver 100km of Range	Installed Cost in Rs. ($)	Price in Rs/kWh ($/kWh)
1	1.5	5.8 hr	0.3 lakh (500)	12 (0.20)
2	6.6	1.3 hr	3 lakh (5,000)	20.4 (0.34)
DC Fast	50	11 min	15 lakh (25,000)	33 (0.55)
Battery Swap Station	400 (effective)	1.3 min	240 lakh (400,000)	60 (1.00)

Using PEVI to Site EVSE

The PEVI model provides a quantitative basis for evaluating the efficacy of a given deployment of EVSE throughout the region. An optimization algorithm is used to determine the set of chargers that provide the biggest benefit to EV drivers for the least amount of public investment.

The objective of the optimization is to minimize the total delay experienced by drivers. To make the delay experienced by drivers comparable to the cost of the EVSE necessary to mitigate the delay, each hour of driver delay is converted to a monetary value. Driver time is valued at Rs 228 /hour ($3.80/hour), and the delay is converted into a monetary value and projected over a 10-year time horizon to make the total cost of driver delay roughly comparable to the cost of the infrastructure needed to reduce that delay.

To optimize EVSE deployment for a given penetration of EV drivers, the simulation model is run for every combination of charger level and charger location. The charger level and location selected is the one that decreases the aggregate driver delay the most per dollar spent on infrastructure. With that charger in place, the process repeats and every combination of level and location is again evaluated. When the addition of more chargers fails to decrease the total delay experienced by drivers, the process ends.

This process results in a set of charger locations and charger levels that provides the highest benefit to drivers at the least cost. In addition, the order in which chargers are added is tracked, which provides useful insight into which locations should be prioritized for EVSE deployment in the near term. Because PEVI is stochastic, the entire process is repeated a number of times (at least five) and the various distributions of chargers are averaged together to form a final set of deployment guidelines.

Conclusion

India is among a growing number of countries seeking to address future energy requirements through sustainable transportation options. It has identified electric vehicles, in particular, as one of the most promising pathways to increased energy security and reduced emissions of greenhouse gases and other pollutants. As vehicle ownership in India is set to rise substantially, an opportunity exists to diversify the transportation fuel mix to the benefit of the broader economy. Not only does vehicle electrification improve local air quality and reduce carbon dioxide emissions in support of national sustainability goals, it also helps mitigate the effects of volatile global oil prices. Just as important, EVs have the potential to unlock innovation and create new advanced industries that spur job growth and enhance economic prosperity. The results of this analysis demonstrate that if India meets the targets established by the National Electric Mobility Mission Plan it has the potential to realize such benefits.

Of course, the market success of electric vehicles is far from assured – in India or any other country. Early incentives offered by national and local governments to accelerate EV adoption are undoubtedly important, but cannot continue indefinitely. Future EV policies and investments therefore need to be smarter and grounded in data-driven analysis. Well-designed policies can be achieved by leveraging insights collected from transportation data, real-world observations, and stakeholder feedback. Consideration of the optimal location and level of charging infrastructure in urban areas, as presented in this report, is an example of proactive planning that can help guide investment and increase EV readiness. Going forward, future assessments of the challenges and opportunities of fully integrating EVs into power systems will be particularly valuable to policymakers, businesses, and consumers. By working together along with a diverse group of stakeholders and partners around the world, India and the other members of the Electric Vehicles Initiative will continue to seek the best policies and practices to attain their shared vision of electric mobility.

End Notes

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