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TECHNICAL NOTE

Interactive tool to enable electricity distribution utilities in India assess the grid impact of electric vehicles

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CONTENTS

Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

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ABSTRACT

The share of electric vehicles (EVs) in the overall transportation mix has been steadily increasing, reaching about 20 percent in 2023. This increase represents a 10 percent increase over only the past two years (Bloomberg NEF 2023). This spurt in growth, however, impacts the electric grid, necessitating well-planned upgrades and charging infrastructure to accommodate the increasing number of EVs. India's initiative, Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) – II, aims to support over 1.5 million EVs across various categories.[1] Several states have also introduced their own EV policies. To address the challenges posed by this rapid EV growth for the electric grid, a new tool called ELEVATE has been developed by the authors. It allows users to input scenarios to assess the impact of EVs on distribution transformers (DTs). The tool employs Monte Carlo simulation and linear programming techniques to create scenarios to calculate the future grid load, considering factors such as the electricity usage of different categories of users such as residential, industrial, and commercial users. ELEVATE enables distribution companies to meet the increasing load on DTs through effective planning, potentially deferring immediate upgrades and ensuring the smooth integration of EVs into the electric distribution grid.

INTRODUCTION: SETTING THE CONTEXT

This technical note introduces an online tool called ELEVATE (Saklani et al. 2022) to assess the impact of electric vehicles (EVs) on the grid. The name ELEVATE stands for "Estimate Load of Electric Vehicles and Tariff Elasticity". The technical note is structured as follows. This section describes the current EV scenario globally and in India. It also highlights the impacts of EVs on the electric grid, and the need for the developed tool. The section titled "The ELEVATE tool" summarizes the components of the tool and the simulation results. The section titled "Conclusion" summarizes the key results and suggests avenues for improving the tool and expanding its analytical capabilities.

The global context: EVs and charging

EVs have increasingly started to play a significant role in the mobility mix across the world. Recent estimates show that globally nearly 26 million passenger EVs (mostly cars, accounting for 14 percent of the global fleet), 1.5 million commercial EVs (buses, delivery trucks, and vans), and over 292 million electric two-wheelers (mopeds, scooters, and motorcycles) and three-wheelers were on the road. These numbers are projected to go up to approximately 54 million, 6 million, and 330 million, respectively, by 2025 (Bloomberg NEF n.d., 2023).

This vehicle growth impacts the electrical grid. The BloombergNEF scenarios project 14 percent and 12 percent growth in total demand for electricity by 2040 in two scenarios—Economic Transition Scenario (ETS) and Net Zero Scenario (NZS)[2]—on account of EV growth. This growth necessitates a well-planned rollout of grid upgrades and charging infrastructure, and 500 million chargers would be needed in all locations by 2050. Some of these are projected to be home chargers, but there is also a growing need for high-powered charging hubs to cater to the growing demand from commercial vehicles, particularly in the freight and shared vehicle segments.[3] The "Electric Vehicles Outlook" reports (Bloomberg NEF, 2023) advise governments to "review cost recovery mechanisms for grid upgrades and grid connections to enable more charging points, and consider if these can be included in the rate base of relevant grid operators in a given area."

The Indian context: EVs and charging

The Government of India (GoI) is providing incentives and subsidies for EV adoption in the country. Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) – II is the current policy guiding EV adoption in India. This policy was in effect from April 1, 2019, for a period of 3 years with an outlay of INR 10,000 crores (Department of Heavy Industry 2019).[4] This period has been extended by 2 years (Ministry of Heavy Industries 2021). The policy aims to support a total of 1,562,090 EVs across all categories[5] (Department of Heavy Industry 2019).

In addition to the GoI's efforts, a total of 33 governments of states and union territories, such as Gujarat, Telangana, Karnataka, Tamil Nadu, and Delhi, have also either drafted or approved state-level EV policies (Kanuri et al. 2021).

The need for charging infrastructure is also recognized by Indian policymakers. In October 2020, the Ministry of Heavy Industries (MHI) released an expression of interest to encourage investors to benefit from the INR 1,000 crores allocated for charging infrastructure under the FAME India-II scheme and permitted 2,877 EV charging stations in 68 cities across 25 states and union territories (Department of Heavy Industry 2019; IEA 2021).

Impact of EVs on the distribution grid and the need for an analytical tool

Charging of EVs can have significant impacts on the electricity system, in particular, on the distribution side of the grid. Unmanaged charging (described in the section titled "Methods"), for instance, can overload transformers, increase peak demand, necessitate transformer replacement due to continuous excursions above the threshold, degrade power quality, and require substation upgrades (Garcia-Valle and Lopes 2012; Forum of Regulators 2017; Muratori 2018; Crozier et al. 2020; Dulău and Bică 2020; Anwar et al. 2022). Deferring costly distribution transformer (DT) replacements allows those funds to be used for other grid efficiency improvements. Furthermore, in appropriate regulatory and market settings, EVs can provide grid service[6] such as frequency regulation and real-time ramping services.[7]

Key institutions in India have recognized the impacts of the projected growth of EVs on the electric grid. Forum of Regulators (2017) had commissioned a study to look at, among other things "(3) What would be the impact of EV load on the local distribution system?". The results of the simulations indicated the following:

- Slow charging has a negligible impact on the feeders considered in the study.
- A baseline 50 percent loaded commercial feeder can safely absorb up to 20 percent of additional EV load as a result of fast charging.
- Residential feeders could safely handle a ratio of 60:40 from residential and EV loads (fast charging), respectively.
- Once high loading conditions occur (beyond a threshold of 20 percent fast charging), the distribution licensees should build resilience by expanding the network.

Studies have also been conducted by the GTG-RISE initiative for a segment of the BSES Rajdhani Power Limited (BRPL) network (USAID and MoP 2020) and by Atla et al. (2019) for the BSES Yamuna Power Limited (BYPL) network. To successfully set up EV charging stations in Bengaluru City, a study was conducted to assess the capacity of the grid and the possible need for upgrade it to accommodate the growing EV load (Singh et al. 2021).

The Ministry of Power (MoP), in a memorandum (Ministry of Power 2022), has also suggested that the Power System Development Fund (PSDF) scheme—a fund meant to accommodate the financing needs of the power system—"be amended to the extent of funding towards extension of 33/11 kV and LV network and installation of distribution transformers along with necessary protection and metering system which will exclusively feed the electric vehicle charging infrastructure."

It is important for distribution companies to understand the impact of EVs on their network, which is shared with several other consumers. Although the exact technical parameters, such as cable sizing, reactive compensation, and line loss, can only be determined through detailed load flow studies, a simple planning tool can help utility planners understand fundamental aspects of the immediate impacts of different scenarios of EV growth on a DT. This understanding allows planning (e.g., deferral of investment in a higher-capacity DT) and capital investment decisions (e.g., the decision to replace a DT based on capacity overshoots by load) to be made at a granular level. In addition, the tool would enable utility planners to understand how passive utility level interventions such as the introduction of Time of Use (ToU) tariffs could be used to manage the impacts of EV charging on the grid.

Previous work on quantifying the impact of EVs on the grid

In their overview of EV behavior modeling, Li et al. (2023) mention that EV usage can be predicted using spatial, temporal, and energy consumption parameters. Using a combination of these parameters, different models of energy demand simulations and charging behavior can be used for infrastructure planning and smart charging (V2G and V2X). Our ELEVATE tool uses temporal and energy consumption parameters to estimate the load on the DT due to EVs.

There are two main methods for studying the travel patterns and charging behavior of a large population of EVs: conducting a large-scale EV trial or modeling a fleet of EVs. The latter method is preferable but requires data-intensive microsimulation efforts[8] and a charging decision algorithm. Alternatively, scaling data from EV trials could be used, but this approach is limited to the fleet compositions for which data are available; more fundamentally, it may not always be feasible to conduct such a trial. Stochastic models, on the other hand, are computationally less intensive and can also be used for future projections and scenarios, which are more useful than using historical data alone. Recent studies have used a stochastic approach[9] to examine the effect of EVs on power system demand and their ability to provide power system services such as flexibility analysis (Garcia-Valle and Lopes 2012; Daina et al. 2017; Deb et al. 2017; Nicoli et al. 2018). Deterministic approaches[10] are also commonly used, such as deriving power demands from the travel patterns of EVs and plug-in hybrid electric vehicles (PHEVs), assuming that travel patterns remain constant across the year; or using vehicle travel data to investigate the provision of vehicle-to-grid (V2G) services by PHEVs (Jiang et al. 2013; Brady and O'Mahony 2016). Sundstrom and Binding (2011) developed a semi-Markov chain model to predict trip and parking times for an EV charging service provider.

Brady and O'Mahony (2016) generated a daily travel schedule for an EV fleet using hourly intervals and the corresponding charging profiles. Their approach stands out in two ways: first, it incorporates actual EV data into the modeling process, and second, it focuses on trip-level information. Another innovative feature is the use of conditional probabilities of several variables, such as state of charge (SoC), parking time, and trip number, to determine whether an EV will run out of charge after that particular trip. van Triel and Lipman (2020) utilized simulation tools such as GridSim, SWITCH, and V2G-SIM to model the potential impacts on the grid in California by 2030 of managed and unmanaged, unidirectional and bidirectional EV charging. Their analysis incorporated assumptions regarding California's charging infrastructure, future improvements in vehicle technologies, and previous studies on mobility behavior.

Needell et al. (2023), in their recent study, modeled hourly electricity supply from PV panels and correlated it with the hourly EV demand for energy in New York City (NYC) and Dallas in the United States. The authors concluded that managed daytime charging, complemented by solar energy generation periods or overnight EV charging, mitigates the increased peak-hour electricity demand from EV charging. They also observed that this approach does not require newer technologies such as V2G charging infrastructure or networked chargers. This approach can also complement the decarbonization efforts in the transportation sector.

Remote-Areas Multi-energy systems load Profiles (RAMP) (Lombardi et al. 2019) is an open-source Python tool to understand the energy demand for appliances ranging from light-emitting diode (LED) bulbs and televisions (TVs) to EVs. It generates hourly load profiles that can be used to understand load and energy demand estimates. RAMP, however, simulates the demand for the current year and lacks options for the managed usage of appliances.

EVI-Pro Lite (Lee et al. 2021), developed by the National Renewable Energy Laboratory (NREL), helps users understand the number of chargers required to serve EV fleets in a region and the resulting load curves at the grid level. However, the online tool is hard-coded to work with US-specific data on population densities, travel behavior, and so on. In addition, users cannot visualize base loads and EV loads together in the tool.

Case studies from India have used either OpenDSS models customized on a Python interface (USAID and MoP 2020), highly rigid[11] MATLAB-Simulink models (Forum of Regulators 2017), or have explicitly not considered EV load modeling and analysis (Sharma et al. 2019). None of models are publicly available in an easy-to-use format. Open-source tools such as VencoPy (Wulff et al. 2021) , RAMP-mobility (Niu et al. 2022), and emobpy (Gaete-Morales et al. 2021) have recently emerged. All of these rely on simulating EV fleets with certain technical and behavioral characteristics. VencoPy and RAMP-mobility rely on the availability of highly granular European commute data to create load profiles, whereas emobpy also distributes this demand spatially across various charging stations.

The authors of this paper also had the opportunity to attend a closed-door demo on the IEA's tool (IEA 2023). It is an interactive Web-based tool to assess EV charging loads that allows users to understand how EVs impact electricity networks. The tool has been launched recently and is in the first phase. However, the tool differs significantly from ELEVATE: it generates daily load profiles for 5 minute time intervals and accounts for slow, fast, and ultrafast charging infrastructure[12] (ELEVATE generates daily load profiles for 15 minute intervals and currently caters only to unmanaged charging). The tool also has an option for adding up to 15 different vehicle categories at the same time. It simulates the additional grid load due to EVs. It expects users (distribution companies, in this case) to add the non-EV load for calculating the total load.

A review of the literature and the current tools highlighted a major gap. None of these tools is suitable without customization, especially in developing countries, where data on daily commutes are limited and EV fleets, though growing, are small. WRI's Electric Vehicles on the Grid Simulator (Xue and Xia 2020) was a step in this direction, although it also focused on optimizing the charging infrastructure. Building on this tool, we developed a scalable tool called ELEVATE (Saklani et al. 2022) that helps calculate total EV loads at the DT level with a few input variables related to vehicle fleet numbers, battery characteristics, average daily trip lengths, and charging behavior. One of the advantages of ELEVATE is that it utilizes data that the utility already has access to at the DT level, thus reducing the need for extensive data collection exercises. The tool does not capture inputs on whether a vehicle is connected to a charging station or is charging at home. The connected vehicle is treated as a load on the grid.

THE ELEVATE TOOL

This section provides guidance on the data and methodology used to develop the ELEVATE planning tool.

About ELEVATE

ELEVATE (Saklani et al. 2022) stands for "Estimate Load of Electric Vehicles and Tariff Elasticity." It is an online interactive and modular tool that enables distribution companies to simulate the electrical load due to increased EV electricity demand on their transformers (through scenarios) over the next five years.

The tool's primary function is to generate aggregate load curves for unmanaged charging scenarios. It also recommends capacity upgrades at the DT level based on the existing load profile and user-developed[13] growth trends and scenarios. ,[14] Thus, the tool can help analyze electricity demand and load profiles for a particular DT and provide useful information that will help energy planners and grid operators better understand patterns of electricity usage and anticipate changes in demand over time. At the DT level, the tool can also assess load profiles to determine whether capacity upgrades are necessary to ensure that sufficient power is available to meet the needs of all consumers.

Data inputs for developing the tool

During the development of the ELEVATE tool, the data collection and input followed two separate tracks. Vehicle populations and battery chemistries were collated from secondary sources and datasets. Network data were provided by the local distribution company. In our case, BRPL, (see Box 1) one of the electricity distribution companies in Delhi, provided data for three DTs. Hence, the methodology described later takes Delhi as an example but can be customized for specific states and distribution companies.

Vehicle population estimation

To calculate the vehicle population, the study's scope was limited to the South and South-West Delhi administrative area. These zones are also the BRPL's license area. We worked with BRPL under the aegis of a collaboration agreement.

From the Economic Survey of Delhi 2019-20 and registrations from the Vahan platform,[15] the study area accounts for the 30 percent of the vehicle population (Planning Department, Government of NCT of Delhi 2020). To project vehicle numbers up to 2024, a simple compound annual growth rate

(CAGR) method was used under the assumption that the current levels of per-capita car and two-wheeler ownership remain constant (see Table 1).

Based on this database, CAGRs of 3, 6, –17, 7, and –2 percent were determined for the categories Cars and Jeeps, Taxis, Autorickshaws, 2-Wheelers, and Buses, respectively. These CAGRs were used to project the growth in each vehicle category up to 2023–24 (Table 2).

The vehicle projections and the Delhi EV policy were then used to understand the share of EVs in the overall vehicle growth (see Table 3). In the Delhi EV policy, targets are not specified on a yearly basis. Hence, the growth of 25 percent by 2024 was distributed among the intervening years. For the years 2020, 2021, and 2022, the actual numbers were calculated from Vahan Dashboard, Ministry of Road, Transport and Highways (MoRTH) (MoRTH n.d.).

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Table 1 | **Number of vehicles in Delhi, 2015-16 to 2018-19**

YEAR	CARS AND JEEPS	TAXIS	AUTORICKSHAWS	TWO-WHEELERS	BUSES
2015-16	2,986,579	91,073	198,137	6,104,070	34,365
2016-17	3,249,670	118,308	105,399	7,556,002	35,206
2017-18	3,246,637	118,060	113,074	7,078,428	35,285
2018-19	3,249,670	109,780	113,240	7,556,002	32,218

Source: The Vahan Database (MoRTH n.d.).

Table 2 | **Estimation of vehicles in Delhi (as opposed to new registrations)**

YEAR	CARS AND JEEPS	TAXIS	AUTORICKSHAWS	TWO-WHEELERS	BUSES
2019-20	3,342,420	116,834	93,975	8,113,027	31,533
2020-21	3,437,817	124,340	77,987	8,711,115	30,862
2021-22	3,535,937	132,330	64,719	9,353,295	30,205
2022-23	3,636,857	140,832	53,709	10,042,815	29,563
2023-24	3,740,658	149,881	44,571	10,783,167	28,934

Source: For 2019–20: registrations for Delhi state in the Vahan platform of the Ministry of Road Transport and Highways (MoRTH n.d.). For the other years: projections based on the CAGRs calculated by the authors.

Table 3 | **Projected share (%) of EVs in Delhi according to the Delhi EV Policy**

SHARE OF EVS IN NEW REGISTRATIONS	2020	2021	2022	2023	2024
	2.92	5.62	10.23	18	25

Note: EV = electric vehicle.

Source: WRI India authors.

In the above analysis, e-buses were not included, because data on future procurement were not available (they are generally procured or leased in fixed quantities). E-rickshaws (three-wheelers) are largely unregistered in Delhi. For the projections, only registered e-rickshaws were considered because we expect that provision of favorable terms under Delhi's EV policy will increase the share of registered e-rickshaws.

Based on these year-wise shares of EVs and the growth rate identified for each vehicle category, Table 4 shows projections for the number of EVs added annually for the whole of Delhi.

We have mentioned earlier that 30 percent of the total vehicle population of Delhi is in the BRPL region (study area). Based on this, Table 6 shows the derived and projected EV numbers

Table 4 | **Annual addition of EVs in Delhi**

ANNUAL EV ADDITION IN DELHI	CARS AND JEEPS	TAXIS	TWO-WHEELERS
2019–20	677	51	4,064
2020–21	4,770	375	29,904
2021–22	9,812	799	64,218
2022–23	18,166	1,530	124,114
2023–24	25,950	2,262	185,088

Note: EV = electric vehicle.

Source: WRI India authors.

Table 5 shows the cumulative annual addition of EVs in Delhi.

Table 5 | **Cumulative addition of EVs in Delhi (estimated)**

ANNUAL EV ADDITION IN DELHI	CARS AND JEEPS	TAXIS	TWO-WHEELERS
2019–20	677	51	4,064
2020–21	5,447	427	33,969
2021–22	15,259	1,226	98,187
2022–23	33,424	2,756	222,300
2023–24	59,374	5,018	407,388

Note: EV = electric vehicle.

Source: WRI India authors.

Table 6 | **Derived and projected EV numbers in the BRPL area**

CUMULATIVE NUMBER OF EVS IN THE BRPL REGION	CARS AND JEEPS	TAXIS	TWO-WHEELERS	E-RICKSHAWS
2019–20	203	15	1,217	6,996
2020–21	1,630	128	10,167	7,459
2021–22	4,567	367	29,389	7,952
2022–23	10,004	825	66,538	8,478
2023–24	17,772	1,502	121,938	9,038

Note: BRPL = BSES Rajdhani Power Limited. EV = electric vehicle.

Source: WRI India authors.

of Cars and Jeeps, Taxis, and Two-wheelers for the study area. We have also considered e-rickshaws as a separate input derived from the Delhi Economic Survey.

Battery range and capacity

Batteries used in EVs in India are of two types: lithium-ion and lead-acid. Whereas lithium-ion batteries are used in all EV categories found in the Indian market—two-wheelers, three-wheelers, and four-wheelers—lead-acid batteries are recognized as outdated and are used largely in the three-wheeler segment and to some extent in two-wheeler EVs. Li-ion batteries encompass different chemical compositions in their cells: lithium nickel manganese cobalt (NMC), lithium nickel cobalt aluminum oxide (LCA) or lithium cobalt oxide (LCO), lithium titanate oxide (LTO), and lithium phosphate (LFP). NMC, LTO, and LFP batteries vary in their costs, energy density, and charging characteristics (IIT Madras and WRI India 2019). NMC batteries are the most common Li-ion batteries used in Indian EVs, because of their low cost and moderate energy density. More details on the battery chemistry, range, and capacity can be found in the Kumar–Jhunjhunwala report (IIT Madras and WRI India 2019).

From the EV charging load modeling perspective, data on batteries' average energy capacity (kilowatt-hours; kWh) and the average efficiency (kWh/100 km) are useful. Table 7 displays the average energy capacity and vehicle efficiency for the different types of batteries commonly used in India. We collated data from the websites of multiple vehicle manufacturers and calculated average energy capacity and energy efficiency values. It is assumed that up to 2024, slow charging will continue to dominate, with a relatively lower penetration of fast charging.

Table 7 | **Battery data considered**

VEHICLE CATEGORY	BATTERY CHEMISTRY TYPE	AVERAGE ENERGY CAPACITY (KWH)	AVERAGE VEHICLE ENERGY EFFICIENCY (VF) (KWH/100 KM)
2W-PV/2W-CV	Lead-acid 48 V	0.96	1.92
	Lead-acid 64 V	1.54	1.92
	Lead-acid 72 V	3.24	2.47
	Li-ion 48 V	1.27	2.06
	Li-ion 60 V	2.31	2.82
	Li-ion 72 V	2.60	2.32
3W PV	Lead-acid 48 V	5.05	4.92
	Li-ion 48 V	5.53	5.01
3W CV	Lead-acid 48 V	5.04	5.04
	Lead-acid 60 V	6.90	11.23
	Li-ion 48 V	6.24	6.48
4W PV/CV	Li-ion 54 V	13	10.35
	Li-ion 72 V	21.35	10.90
	Li-ion 350 V	37.97	10.48
Bus	Li-ion 24 V	186	124

Note: 2W = two-wheeler. 3W = three-wheeler. 4W = four-wheeler. CV = commercial vehicle. PV = passenger vehicle.

Source: Table A-1 in Appendix A lists the sources considered for vehicle energy density and efficiency calculations and the average values calculated by the authors.

Network data

The tariff orders issued by the Delhi Electricity Regulatory Commission (DERC) for financial year (FY) 2019–20 and FY2020–21 were analyzed to understand the network load. The authors also included the revised petition submitted to DERC to factor in the impacts of COVID-19. For the development of ELEVATE, the authors projected the electricity consumption and connected load across Residential, Commercial, Agricultural, Other, and Industrial categories based on the previous loading from FY2013–14 to FY2018–19 because these form an important component of the DT-level load estimation (Table 8). The CAGRs used for this projection are 5.72, 2.74, and 0.32 percent for Domestic, Non-domestic/Commercial, and Industrial categories, respectively, in the BRPL license area.

Electricity sales were calculated from the tariff orders and then projected up to 2024–25. "Charging Stations for EV" was projected as a separate category because the estimates for e-vehicles will be included in it.

Table 8 | **Category-wise sales (MU) in the BRPL license area**

CATEGORY/ SUB-CATEGORY (MILLION UNITS)	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21 (PRE-COVID-19)	2020-21 (POST-COVID-19)	2021-22	2022-23	2023-24	2024-25
Domestic	5,348	5,788	5,975	6,516	6,924	7,214	7,623	8,136	7,884	8,335	8,812	9,316	9,849
Non-domestic/ Commercial	2,765	2,827	2,941	3,028	3,141	3,161	3,251	3,335	2,074	2,131	2,189	2,249	2,311
Industrial	526	507	502	499	500	529	535	529	394	395	397	398	399

Note: BRPL = BSES Rajdhani Power Limited. MU = million units.

Source: WRI India authors.

Box 1 | **Collaboration with BRPL**

One of the three distribution companies in Delhi, BSES Rajdhani Power Limited (BRPL), agreed to work with the authors as the tool was being developed. The key objectives of this collaboration were as follows:

1. Understand the stochastic charging load for both managed and unmanaged charging due to the addition of electric vehicles (EVs) to the grid in the BRPL area.
2. Develop a summary of distribution-transformer-wise loads and capacities.
3. Suggest at a broader level immediate, medium, and long-term measures that BRPL could implement to streamline load management.

Based on this analysis, BRPL could take decisions on network augmentation, power procurement strategies, renewable energy penetration strategies, and EV charging management strategies.

Source: WRI India authors.

The current iteration of ELEVATE focuses on unmanaged charging, which typically refers to the charging of EVs without any control or coordination between the vehicles and the grid operators. In an unmanaged charging scenario, EV owners can plug in their vehicles for charging at any time and any location, without considering the availability of power on the grid or the cost of electricity (i.e., a single tariff prevails for EV charging). This can lead to challenges for grid operators, because spikes in electricity demand can overload the grid. A Monte Carlo simulation that incorporates uncertainty and randomness in its modeling was used to estimate the charging pattern and load on the grid.

Figure 1 summarizes the methodology used to calculate the total load. The total charge is calculated using the number of vehicles and charging frequencies.

The calculation of the per-minute charge is based on the normal distribution, which is a probability distribution that is commonly used to model continuous random variables. In this case, the normal distribution is employed to estimate the charge for each minute, using the mean of the charging start time and the standard deviation of the charging start time.

The normal distribution, also known as the Gaussian distribution, is characterized by its bell-shaped curve. It is completely defined by two parameters: the mean (μ) and standard deviation (σ). The mean represents the center of the distribution, around which the data points tend to cluster. The standard deviation determines the spread or dispersion of the data points around the mean.

For any one vehicle, the flow of charge delivered at any time is based on the starting SoC, the charging start time, the power rating of the charger, and the battery's C-rate. ELEVATE inputs these values for the vehicle category type of interest, and the variable n represents the number of vehicles in each category. A normal distribution is used to generate a random value for each vehicle. In the context of calculating the per-minute charge, the normal distribution is used to generate random values that represent the charge for each specific minute. The mean of the distribution is determined by the charging start time, which provides a reference point for the distribution. The standard deviation of the distribution, on the other hand, quantifies the variability or uncertainty in the charging start time

By utilizing the normal distribution, we can obtain a range of charge values for each minute, considering the characteristics of the charging start time. This statistical approach allows the charges to be calculated in a manner that reflects the inherent randomness and variability of the charging process.

The average distance traveled by a vehicle category and its standard deviation, along with the time range of 1,440 minutes (24 hours × 60 minutes), gives the distance traveled. To calculate the charging duration in minutes, the following formula was used:

If (SoCe -SoCs)<0

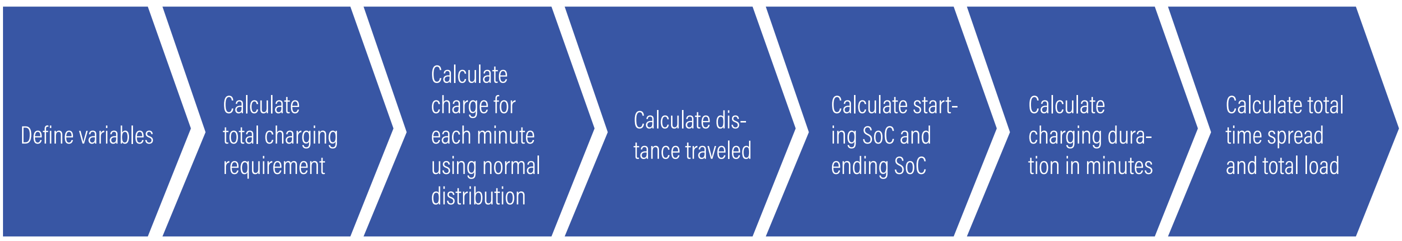
then 0,

else (SoCe -SoCs) Battery Capacity/(Charging Power*Charging Efficiency))*

where SoCe is the SoC ending time, when the vehicle is disconnected from the charger. SoCs is the SoC starting time, when the vehicle is plugged in for charging. The above formula calculates the charging duration by using the difference in the SoCs when the vehicle is plugged in for charging and disconnected from charging. It also uses the charging efficiency and battery capacity to calculate the charging duration.

The module then uses the steps shown in Figure 1 to calculate the load for each block of the timeline based on the charging power and the number of vehicles charging during that block. It then aggregates the loads across all the blocks of the timeline to obtain the total load for the day. Finally, it

Figure 1 | **Flowchart for calculating the load for a vehicle category**



Note: SoC = state of charge.
Source: WRI India authors.

calculates the annual energy consumption and the maximum demand for the simulation based on the total load for the day. At the city scale, in the unmanaged charging module, the tool is designed to throw up aggregate load curves, while at the DT level, it is designed to offer insights into the need for capacity upgrades. The analysis considers slow charging. Slow chargers are Level 1 chargers, which are similar to those used with residential outlets.

System architecture

ELEVATE is a Python-based modular tool (Figure 2). It was developed in Python as an offline version and uses an API (application programming interface) to run on a browser. The online version allows users to enter inputs using an easy-to-navigate user interface.

The user interface of the application allows users to input values for variables such as the consumer category load, categories of vehicle, and the cost of procurement. If the user does not know the category load split, the application allows the user to input the consumer category load as a percentage of the total load.

The application runs the simulation to project the loads on the utilities with the base load and EVs or with only the base load. This allows power distribution companies to understand the future demand and plan the expansion accordingly.

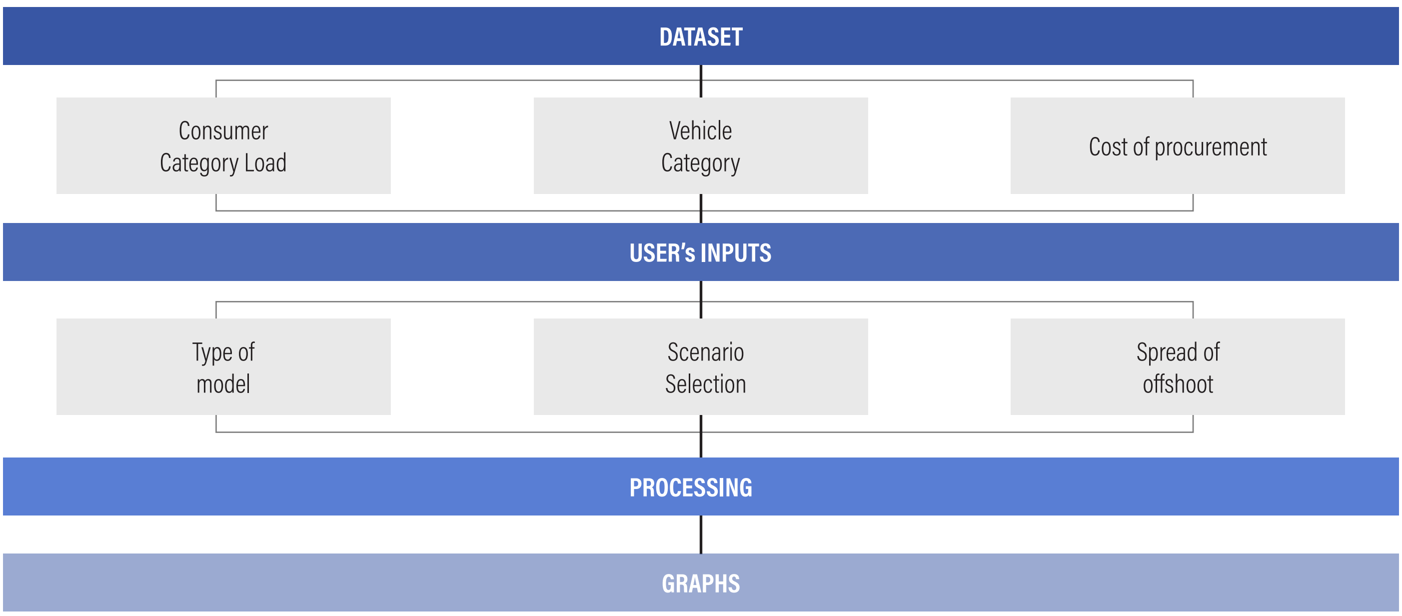
Once the data have been uploaded and criteria have been selected by the user, the application runs the simulations in the background to project the load on the grid. The results are then displayed as graphs, which show the loads on the grid and the threshold limits.

Data inputs for running the tool

DT load

Users need to start by entering data in a standard format in an Excel sheet that can be downloaded from the tool's opening page. The tool also provides a pre-filled set of data points to enable users to test the tool. The inputs for the Excel sheet are explained in Table 9.

Figure 2 | **The system architecture**



Source: WRI India authors.

Table 9 | **Description of inputs**

INPUT	EXPLANATION
Capacity	This is the capacity of the transformer, denoted in kilovolt-amperes (kVA). The capacity of transformers to carry an electrical load is determined by their kVA nameplate ratings, which are specified based on their rated output voltage and current.
CT (current transformer) ratio	The CT ratio, which is the ratio of the primary current to the secondary current of a current transformer. The CT ratio is a critical parameter for measuring and protecting high-voltage power systems. CTs ensure safe and accurate measurement of primary currents, protecting equipment from damage due to faults.
Meter Number	A unique identifier of the distribution transformer.
ACTIVE_B_PH	This refers to the active power in Phase B of a three-phase system (see Box 2).
ACTIVE_Y_PH	This refers to the active power in Phase Y (which is sometimes called Phase C) of a three-phase system.
ACTIVE_R_PH	This refers to the active power in Phase R (which is sometimes called Phase A) of a three-phase system.
REACTIVE_B_PH	This refers to the reactive power in Phase B of a three-phase system (see Box 2)..
REACTIVE_Y_PH	This refers to the reactive power in Phase Y (which is sometimes called Phase C) of a three-phase system.
REACTIVE_R_PH	This refers to the reactive power in Phase R (which is sometimes called Phase A) of a three-phase system.
VBV	Phase-to-ground voltage of the Blue phase.
VYV	Phase-to-ground voltage of the Yellow phase.
VRV	Phase-to-ground voltage of the Red phase.

Source: WRI India authors.

Box 2 | **Active power and reactive power**

Active power, also known as real power, is the component of power that performs useful work in an electrical circuit. It represents the actual power consumed by the load. Active power is typically measured in watts (W) or kilowatts (kW) and is denoted by the symbol “P”. These values are important for analyzing the power distribution, load balancing, and monitoring the performance of specific phases in a three-phase system. In a single-phase system, the power component works similarly to how the components work in a three-phase system, just within a single phase.

Reactive power is the component of power in an alternating current (AC) circuit that is responsible for the exchange of energy between inductive and capacitive elements. Unlike active power, which is the power that performs useful work, reactive power does not perform any actual work but is necessary for the operation of certain electrical devices. Reactive power is measured in units called volt-amperes reactive (VAR) or kilovolt-amperes reactive (kVAR). It is denoted by the symbol “Q” and is represented as a vector quantity in electrical calculations. Together, active power and reactive power make up the total power in an electrical circuit.

Source: WRI India authors.

Categories of consumer

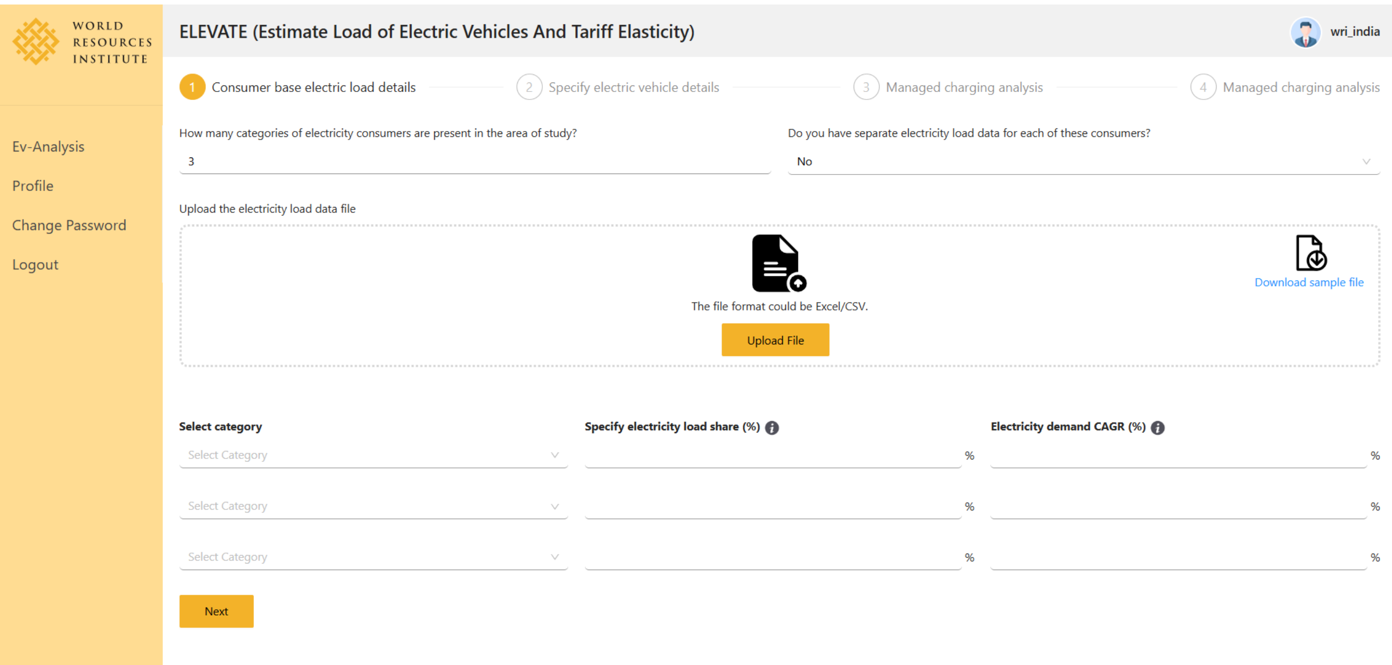
ELEVATE (Table B-1, Appendix B) starts by requesting for the base electric load details of consumers. Consumers are divided into different categories, such as Industrial, Agricultural, Residential, and Commercial, based on the purpose of their energy consumption. The tool takes a combined load data file as input and requests the users to divide the total load into a load share percentage.

In Figure 3, we have added the consumer category as 2, the load of the categories, and the expected CAGR in the selected category. The CAGR allows us to analyze the expected growth of energy demand within the different consumer categories.

Information on EVs

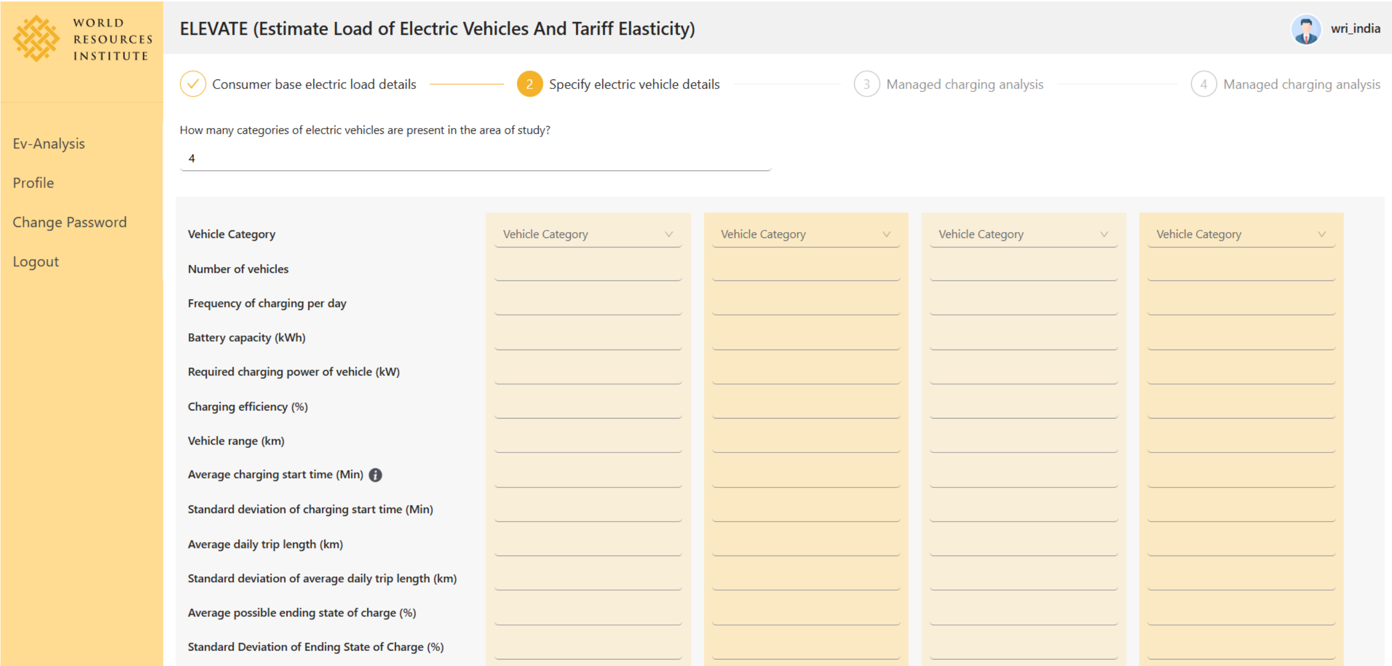
In the next step, ELEVATE requests users to enter information on the EVs that are anticipated to contribute to the DT's load. Figure 4 indicates that details regarding the vehicle categories, such as cars, buses, and two-wheelers, are sought. The user provides inputs such as the number of vehicles in the category, daily charging frequency of a vehicle, battery capacity, and range of the vehicle in kilometers. The user is also requested to enter the average charging time and the CAGR in the EV category. ELEVATE uses this input to calculate the EV load on the DT.

Figure 3 | **Screenshot of ELEVATE: Adding consumer base data**



Source: WRI India authors.

Figure 4 | **Screenshot of ELEVATE: Information on electric vehicles**



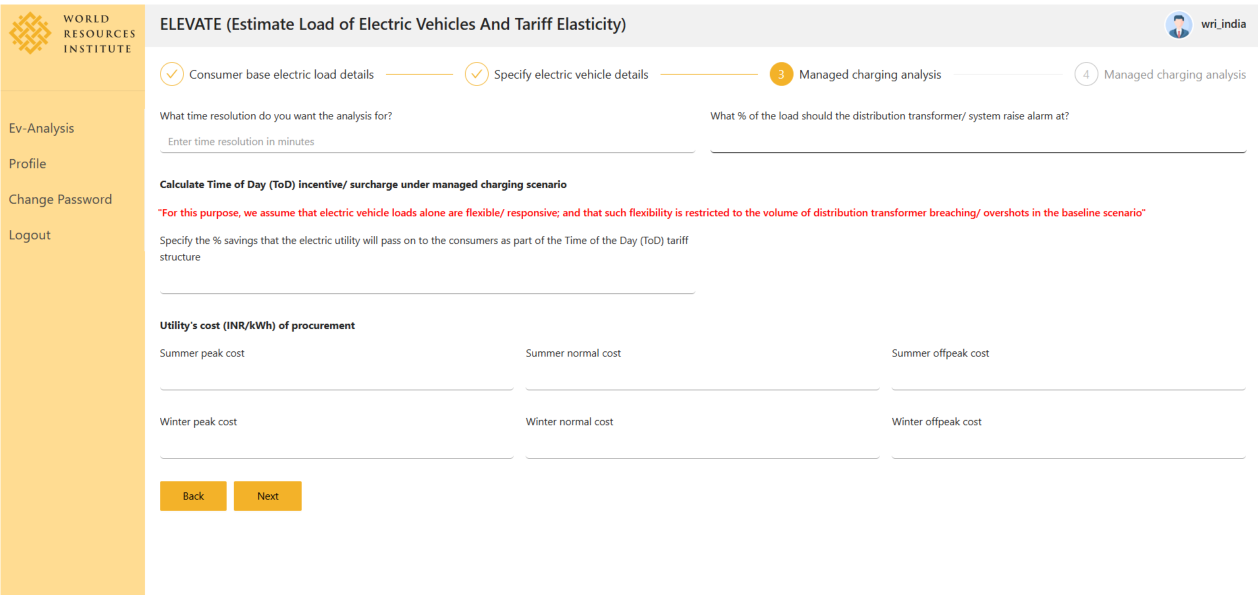
Source: WRI India authors.

Information on temporal resolution and electricity procurement cost

The tool then requests information (Figure 5) on the temporal resolution at which users want to understand the load on the DT and the threshold load at which the system should flag that an upgrade is necessary. The norms for this are usually set by the local regulator.

In this iteration of ELEVATE, we encourage distribution companies to randomly fill values because this is a trial version of a Time of Day (ToD) tariff system that we intend to design and implement. Currently, it has no bearing on the functioning of the unmanaged charging module.

Figure 5 | **Screenshot of ELEVATE: Information on data for charging hours**



Source: WRI India authors.

Results

To gain a deeper understanding of the tool, one can explore various inputs and scenarios that help assess the effects of different loads on the grid and the impact of EV loads. These inputs and simulations provide valuable insights into how the grid is influenced by different types of loads, especially EV loads.

In the absence of DT-wise EV charging information,[16] for the purpose of this technical note, the authors have considered 1,000 two-wheeler vehicles charging in a normally distributed manner with a mean at 3 PM to examine the performance of the DT in each case. This is similar to conducting a stress test on the DT.

The simulations (Figure 6) show that the load shape of this particular DT indicates a problem with afternoon charging. Breaches commence in the second year of the simulations. Table 10 shows the maximum load and the number of occurrences of the excursion.

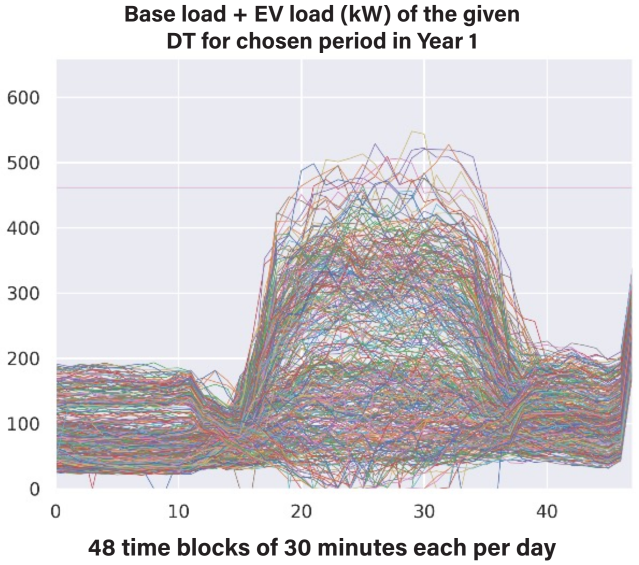
Table 10 | **Excursions and their frequencies**

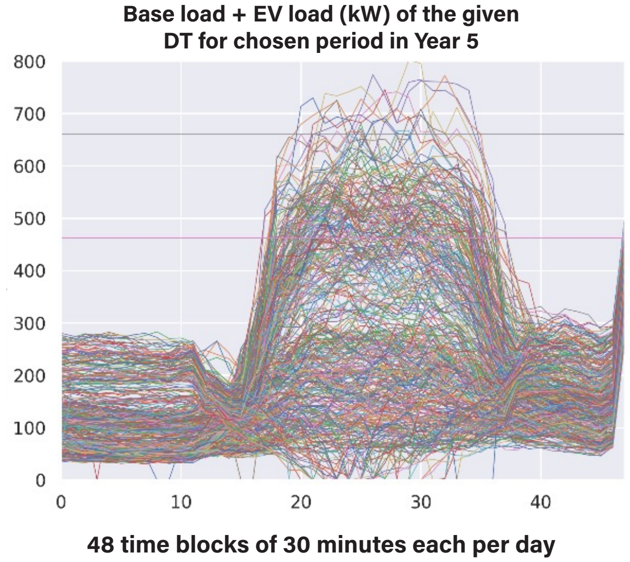
	MAX. LOAD EXCURSION BEYOND THE TRIGGER FOR PLANNING (KW)	NUMBER OF SUCH EXCURSIONS IN A YEAR (30-MINUTE BLOCKS)	MAX. LOAD EXCURSION BEYOND 100% OF THE DT INSTALLED CAPACITY (KW)	NUMBER OF SUCH EXCURSIONS IN A YEAR (30 MINUTES BLOCK)
Year 1	85.88	77	0	0
Year 2	140.66	194	8.66	2
Year 3	200.93	450	68.93	32
Year 4	267.22	880	135.22	112
Year 5	340.15	1420	208.15	258

Note: kW = kilowatt.

Source: Simulations from ELEVATE.

Figure 6 | **Base load and EV load after (a) one year and after (b) five years**





Note: DT = distribution transformer. kW = kilowatt.

Source: Simulations from ELEVATE.

The above results (Figure 6) show the daily load profile, sampled at 30-minute intervals, for an entire year. The data, which are available on the DT, enable effective grid management.

CONCLUSION

ELEVATE allows users (distribution companies and utilities) to create scenarios to calculate the future load on their DTs with and without EVs.

Testing

ELEVATE was initially developed as an offline version that users could run by installing it on their local computers. During user interaction and testing, we realized that an online server-based tool was preferable because users were wary of downloading executable files. Moreover, some programming knowledge was needed to install the tool on a computer. ELEVATE was converted to an online server-based tool, enabling faster processing and eliminating reliance on the user's system configuration. A user interface was created, and APIs were used to run the different modules and display the results.

ELEVATE was tested to check for issues that might arise during code processing and algorithm execution. It has undergone testing at different stages such as integration testing, code reviews, and dynamic testing with the user-defined dataset.

After an internal demo with WRI colleagues to understand users' perspectives and improve on them, the team had requested various user groups to test the tool with simulated datasets. The feedback from the user testing was also incorporated into ELEVATE.

Limitations

In this technical note, we do not address questions regarding the spatial distribution of EVs; these questions will be addressed in the next step of the tool's development. The tool asks the utilities themselves to estimate the number of EVs that will affect each of their transformers. Utilities can create different scenarios (see Box 3) by inputting different numbers of EVs. The model was developed based on a "representative" charging behavior, which may underestimate the variability of charging patterns across consumers. The EV charging tool is currently unable to handle multiple charging events for a single vehicle or a single charging event spread over multiple days for a vehicle category. To overcome this constraint, the model considers multiple charging events for a single vehicle as charging events for different vehicles. (for example, a user's car charging at 3 PM and again at 8 PM will be counted as charging events for two separate vehicles, but the load is considered on the DT). Currently, ELEVATE does not account for residual battery charge when a vehicle begins to charge and assumes that vehicles are charged only when the battery charge is exhausted. Finally, ELEVATE currently creates scenarios for charging only; that is, it does not include vehicle-to-grid options.

The way forward

To overcome the above limitations, ELEVATE can be extended to consider the various SoCs across different vehicle categories and account for different state-level EV policies. This will ensure more accurate EV estimations by preventing both overcounting and undercounting. Future versions of ELEVATE can include options for multiple charging events for the same vehicle, fast and ultrafast chargers for the same vehicle, and a managed charging module. In the next iteration, the tool will include buses for load planning, including range buffer functionality. Integration of the tool with RE as a type of energy (solar, wind, thermal) use, particularly solar energy, and daytime charging can allow EVs to run on 100 percent green energy, thus contributing to the decarbonization of the transportation sector. Lastly, the tool needs to be enhanced with the development of a ToD module, which will help utilities take advantage of the power of tariff mechanisms for effective load management of EVs.

Box 3 | **Customizing ELEVATE**

The ELEVATE tool enables users to develop scenarios to evaluate the impact of electric vehicles on the electrical grid. Although the tool itself is not geographically restricted, the input data must be localized to the specific utility of interest. For instance, data on the number of vehicles may be supplemented with proxies such as user surveys, considering that vehicles may be purchased in one region but charged in another. Additionally, charging behaviors might differ, with some users charging their vehicles at their workplace rather than at home. The average daily travel distance can also vary significantly between individuals, necessitating carefully designed user interviews to ensure representativeness in order to capture this variability.

Source: WRI India authors.

APPENDIX A. LIST OF SOURCES CONSIDERED FOR VEHICLE ENERGY DENSITY AND EFFICIENCY CALCULATIONS

Table A1 | **Sources for vehicle energy density and efficiency calculations**

VEHICLE CATE GORY	TYPE OF BATTERY	BATTERY VOLTAGE (V)	BATTERY CAPACITY (AH)	ENERGY CAPACITY (KWH)	BATTERY RANGE (R) (KM)	VEHICLE ENERGY EFFI-CIENCY (KWH/100 KM)	CURRENT RATING ON CHAR-GER (A)	C-RATE	RATED POWER OF MOTOR (W)	DEPTH OF DIS-CHARGE (%)
	Lithium-ion (Okinawa, n.d.-a)	72		3.3	139	2.374			1,000	
	Lithium-ion (Okinawa, n.d.-c)	72	29	2	88	2.273			1,000	
	Lithium-ion (Okinawa, n.d.-f)	60		1.74	84	2.071			800	
	Lithium-ion (Okinawa, n.d.-b)	48		1.25	60	2.083			250	
	Lithium-ion (Okinawa, n.d.-e)	48		1.34	60	2.233			250	
	Lead-acid (VRLA [valve regulated lead-acid battery]) (Okinawa, n.d.-d)	72	45	3.24	170	2.47			1,000	
	Lead-acid (VRLA) (Okinawa, n.d.-d)	64	24	1.536	80	1.92			800	
	Lead-acid (VRLA) (Okinawa, n.d.-d)	60	24	1.44	90				250	
	Lead-acid (RetroEV, n.d.)	48	20	0.96	50	1.92			250	
	Lithium-ion (Etech Motors, n.d.)	51.2	30	1.536					250	
	Lead-acid (Autocar, n.d.)	48	20	0.96	50	1.92			250	

VEHICLE CATE GORY	TYPE OF BATTERY	BATTERY VOLTAGE (V)	BATTERY CAPACITY (AH)	ENERGY CAPACITY (KWH)	BATTERY RANGE (R) (KM)	VEHICLE ENERGY EFFI-CIENCY (KWH/100 KM)	CURRENT RATING ON CHAR-GER (A)	C-RATE	RATED POWER OF MOTOR (W)	DEPTH OF DIS-CHARGE (%)
	Lithium-ion (BikeDekho, n.d.)	48	28	1.344	65	2.07			250	
	Lithium-ion (Indiamart, n.d.-c)	48	28	1.344			6		250	
	Lithium-ion (Bikes4Sale, n.d.)	72	26		80				1,800	
	Lithium-ion (Car&Bike, n.d.)	51.2	30	1.536	80				550/1,200	
	Lithium-ion (Indiamart, n.d.-b)	48	28 × 2		100				600/1,300	
	Lead-acid (RetroEV, n.d.)	48	28	1.344	50	2.69			250	
	Lithium-ion (Ather Electric, n.d.-b)			2.9	85–116		5		3,300	
	Lithium-ion (Ather Electric, n.d.-a)	51.1		2.7	55–75					
2W-PV and CV (2-wheeler passenger vehicle and commercial vehicle)	Lead-acid (Ampere Electric, n.d.-b)	48	20	0.96	45–50	1.92	2.7	0.135	250	100
	Lithium-ion (Ampere Electric, n.d.-b)	48	24	1.152	55– 60	1.92	6	0.25	250	100
	Lithium-ion (Ampere Electric, n.d.-a)	60	30	2.5	50–70	3.57	7.5		1,200	
Motorcycle	Lithium-ion (Revolt Motors, n.d.)	72		3.24			15			
Motorcycle	Lithium-ion (Revolt Motors, n.d.)	60		2.7			15			
	Lithium-ion (Lohia Auto, n.d.-c)	48	20	0.96	60	1.6	6		250	

VEHICLE CATE GORY	TYPE OF BATTERY	BATTERY VOLTAGE (V)	BATTERY CAPACITY (AH)	ENERGY CAPACITY (KWH)	BATTERY RANGE (R) (KM)	VEHICLE ENERGY EFFI-CIENCY (KWH/100 KM)	CURRENT RATING ON CHAR-GER (A)	C-RATE	RATED POWER OF MOTOR (W)	DEPTH OF DIS-CHARGE (%)
	Lithium-ion (TVS motors, n.d.)			2.25	75				4,400	
3W-PV (3-wheeler passenger vehicle)	Lithium-ion	48		7.37	130	5.67	57			
	Lithium-ion (Mahindra Last Mile Mobility, n.d.-b)	48		3.69	85	4.34	57			
	Lead-acid (Mahindra Last Mile Mobility, n.d.-b)	48	100	3.69	80–100	3.69	40			
	Lead-acid (Indiamart, n.d.-d)	48	130		80		45			
	Lead-acid (Lohia Auto, n.d.-a)	48	100/120	5.76			15			
	Lead-acid (Buses Dekho, n.d.)	48	80/100	4.8	70–100	4.8			1,410	
	Lead-acid (Saera Auto 2022)	48	130	6.24			15		1,200	
	Lead-acid	48	100	4.8	100	4.8			1,000	
	Lead-acid (Carz4Sale, n.d.)	48	120	5.76	60–90	6.4			1,520	
	Lithium-ion (Indiamart, n.d.-a)	51.2	75	3.84						
	Lead-acid (Carz4Sale, n.d.)	48	120	5.76						
3W-CV (3-wheeler commercial vehicle)	Lead-acid (Lohia Auto, n.d.-b)	48	105	5.04	100	5.04			1,950	

	Lead-acid (Kinetic Green, n.d.-a)	48			80		15		850	
	Lead-acid (Junction, n.d.)	60	80	4.8	50	9.6	5		1,000	
	Lead-acid(Junction, n.d.)	60	150	9	70	12.86	15		1,280	100
	Lithium-ion (Kinetic Green, n.d.-b)	48		5.76	80–100	5.76			1,500	
	Lithium-ion (Kinetic Green, n.d.-b)	48		7.2	80–100	7.2			3,000	
	Lithium-ion (Mahindra Last Mile Mobility, n.d.-a)	48	120	5.76					1,000	
3W-CV (3-wheeler commercial vehicle)	Lithium-ion (Carwale, n.d.-a)	54	280	15	140	10.71	16		19,000	
	Lithium-ion (Carwale, n.d.-a)	54	210	11	110	10	16		19,000	
	Lithium-ion (Carwale, n.d.-b)	72	288	21.2	181	11.71			31,000	
	Lithium-ion (Tata EV, n.d.)	72		21.5	213	10.09	15			
	Lithium-ion (MG Motors, n.d.)	350		44.5	340	13.09				
	Lithium-ion (Hyundai, n.d.)	350		39.2	452	8.67				
4W-CV (4-wheeler commercial vehicle)	Lithium-ion	320		30.2	312	9.68	15			
	Lithium-ion	72	200	14.4	112–115	12.52	15		25,000	
	Lithium-ion			15	100	15.00				
Bus	Lithium-ion (BYD, n.d.)		600	300	249	1.5	126		160,000	
	Lithium-ion (Tata Motors, n.d.)	24 V		186	150	124			245,000	

Note: A = ampere. Ah = ampere-hour. km = kilometer. kWh = kilowatt-hour. W = watt.

Source: Compiled by WRI India authors from the Web pages given in the table.

APPENDIX B. INPUTS REQUIRED TO RUN THE TOOL AND THEIR EXPLANATION

Table B1 | **Inputs required to run the tool and their explanation**

NAME	EXPLANATION	SOURCE
Percentage of load share	How the total load is shared among categories such as Industrial, Commercial, or Residential	Power department
CAGR	Annual growth in categories such as Industrial, Commercial, or Residential (based on 5-year historical data)	Power department
Number of vehicles	Number, type (e.g., 2-wheeler/3-wheeler) and ownership (e.g., government vehicles, private, public) of vehicles for simulating the tool	Parivahan Portal (https://vahan.parivahan.gov.in/)
Battery capacity	Battery capacity of the selected vehicle category for simulating the tool, based on available data	Appendix A
Charging power of vehicle	Charging power of vehicle	Appendix A
Charging efficiency	Charging efficiency of the selected vehicle category for simulating the tool	Appendix A
Vehicle range	Vehicle range of the selected vehicle category for simulating the tool	EV database (https://ev-database.org/cheatsheet/range-electric-car)
Average charging time (start)	Average charging time (start) for simulating the tool	User interviews or approximation to build different scenarios
Standard deviation of average charging time (start)	Standard deviation of average charging time (start) for simulating the tool	Standard deviation (SD) can be calculated using the bell curve/normal distribution formula
Average daily trip length	Average daily trip length for simulating the tool	User interviews or approximations to build different scenarios
SD of average daily trip length	SD of average daily trip length for simulating the tool	SD can be calculated using the bell curve/normal distribution formula
Probability of end state of charge (SoC)	Probability of end SoC metric for simulating the tool. End SoC is the battery charge level when an electric vehicle (EV) is disconnected from the charger. For example, when a phone is charging, it could be disconnected from the charger at, e.g., 90% charge, 100% charge, or 25% charge	User interviews or approximations to build different scenarios
SD of probability of end SoC	SD of probability of end SoC for simulating the tool	SD can be calculated using the bell curve/ normal distribution formula
EV CAGR	EV CAGR for simulating the tool	Utility running the tool
Base tariff electricity	Base tariff electricity of EVs for simulating the tool	Utility running the tool
Utility cost of procurement	What is the cost of procuring electricity for the utility, including the peak, off-peak, and normal cost for different seasons as well? The cost of procurement is the cost at which utilities buy electricity. This could vary depending on the season and time (peak or off-peak hours)	Utility running the tool
Summer and winter seasons	For seasonal patterns in the particular geography, the start and end of seasons (such as the dry or rainy season)	Utility running the tool
Peak and off-peak times with summer and winter seasons	Depends on the different rates and energy demand for different seasons, or peak day and night demand variations	Utility running the tool

Table B1 | **Inputs required to run the tool and their explanation, cont..**

NAME	EXPLANATION	SOURCE
Capacity	This is the capacity of the transformer, denoted in kilovolt-amperes (kVA). The capacity of transformers to carry an electrical load is determined by their kVA nameplate ratings, which are specified based on their rated output voltage and current	Utility running the tool
CT ratio	The CT ratio refers to the current transformer ratio, which is the ratio of the primary current to the secondary current of a current transformer. The CT ratio is a critical parameter for measuring and protecting high-voltage power systems. CTs ensure safe and accurate measurement of primary currents, helping protect equipment from damage due to faults. Data can be obtained from the utility or calculated using the primary and secondary current	Utility running the tool
Meter number	The unique identifier of the distribution transformer (DT)	Utility running the tool
ACTIVE_B_PH	This refers to the active power in Phase B of a three-phase system	Utility running the tool
ACTIVE_Y_PH	This refers to the active power in Phase Y (sometimes called Phase C) of a three-phase system	Utility running the tool
ACTIVE_R_PH	This refers to the active power in Phase R (sometimes called Phase A) of a three-phase system	Utility running the tool
REACTIVE_B_PH	This refers to the active power in Phase B of a three-phase system	Utility running the tool
REACTIVE_Y_PH	This refers to the active power in Phase Y (sometimes called Phase C) of a three-phase system	Utility running the tool
REACTIVE_R_PH	This refers to the active power in Phase R (sometimes called Phase A) of a three-phase system	Utility running the tool
VBV	Phase-to-ground voltage of the Blue phase	Utility running the tool
VYV	Phase-to-ground voltage of the Yellow phase	Utility running the tool
VRV	Phase-to-ground voltage of the Red phase	Utility running the tool

Note: CAGR = compound annual growth rate.

Source: WRI India authors.

ENDNOTES

1. Intuitively, the NZS scenario is expected to exhibit higher electricity demand than the ETS scenario due to electrification of transport, and it does in absolute terms: 70,000 TWh in NZS versus 35,000 TWh in ETS. However, in NZS, all other sectors are also getting electrified (heating, industry, and electrolyzer use for hydrogen production); hence, the share of transport as a percentage is lower.
2. Shared segment refers to a category of vehicles that are commonly used for shared mobility services, where multiple users can access and utilize the same vehicle at different times.
3. A third iteration of FAME was launched in December 2024 (PIB 2024).
4. The numbering system followed in this technical note is the Indian numbering system. Typical values used are lakhs (1 lakh = 100,000) and crores (1 crore = 10 million).
5. This includes two-wheelers, three-wheelers, four-wheelers, and e-buses.
6. EVs are also used for bidirectional charging of the grid and for vehicle-to-everything charging, commonly known as V2G and V2X, respectively. They can also be considered as real-time ramping services.
7. Grid frequency regulation, also known as frequency control, refers to the process of maintaining the frequency of an electrical power grid at or near its nominal value. It is essential for ensuring stable and reliable operation of the electrical grid. Real-time ramping services, often referred to as "ramping services," are a type of service in the electricity grid industry that focuses on the ability to quickly increase or decrease electricity generation to match changing demand or supply conditions.
8. See ScienceDirect (n.d).
9. A stochastic approach is a mathematical and statistical method used to model and analyze systems or processes that involve randomness or uncertainty. It is a way of describing and predicting outcomes in situations where there is inherent variability, randomness, or uncertainty in the underlying data or parameters.
10. Deterministic approaches are mathematical and modeling methods used to analyze systems or processes where outcomes are completely predictable and certain. In contrast to stochastic approaches, which consider randomness and uncertainty, deterministic approaches assume that all variables, parameters, and inputs are known with precision and that the system's behavior can be precisely predicted based on these inputs and equations.
11. A highly rigid model typically refers to a model or system that exhibits very limited flexibility or adaptability. In various contexts, "rigid" can imply different aspects of inflexibility or constraints.
12. The IEA in its report has defined slow and fast charging based on the speed of Levels 1, 2, and 3 charging for light vehicles.
13. Because the only criterion for calculating the EV load is the number of vehicles that will connect at a particular point of time, the state of charge, and the duration of charging, no distinction is made between fast and slow charging. All types of chargers will ultimately be mapped to a particular DT.
14. The primary users of the tool are distribution companies. The tool is useful for energy planners, bureaucrats who are decision-makers, and researchers who would like to understand the impact of EVs on grids in developing countries.
15. The Vahan platform is the website of the Ministry of Road Transport and Highways, Government of India, and serves as a data repository for vehicle registrations and driver's licenses.
16. In subsequent iterations of the tool, the authors intend to explore algorithms to randomly distribute EV sales statistics across DTs in the utility's service area. Factors such as whether the area is residential, commercial, and so on, will play a role in the distribution.

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WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and liveable cities and working towards a low carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization. Know more: www.wri-india.org

Our challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to inform government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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