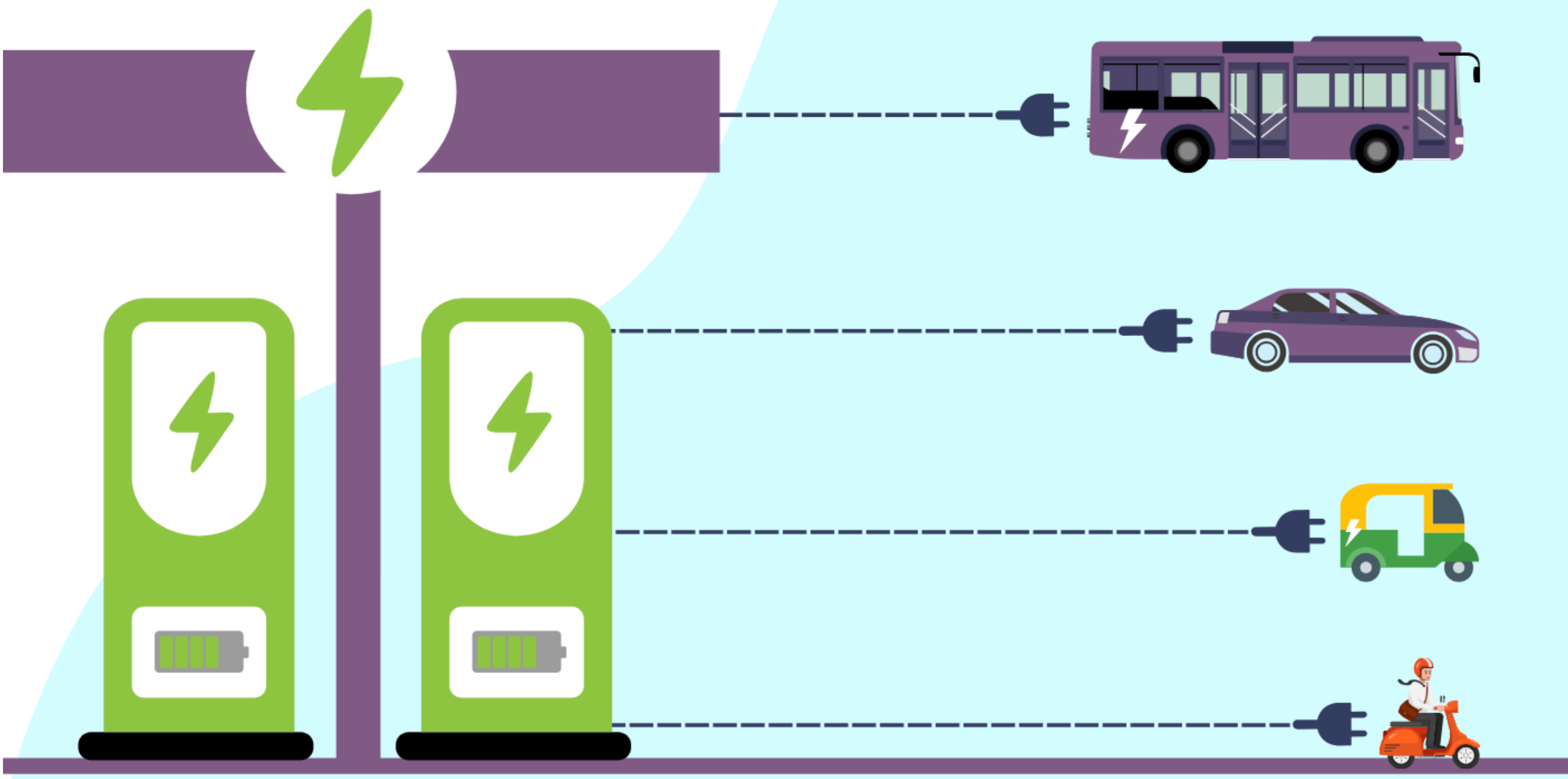
Bengaluru 2030

EV Charging Demand and Infrastructure



Bengaluru 2030: EV Charging Demand and Infrastructure

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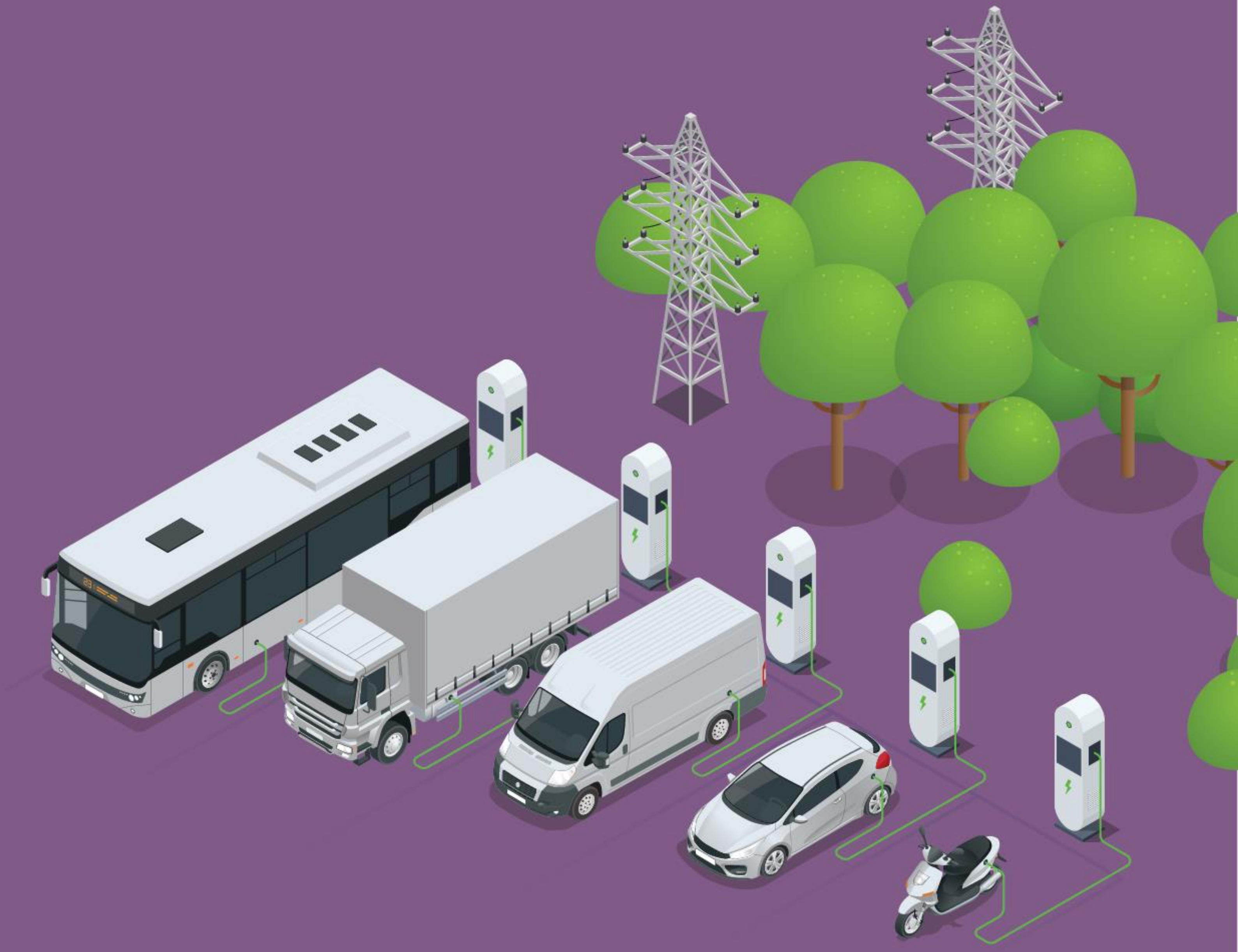


Executive Summary

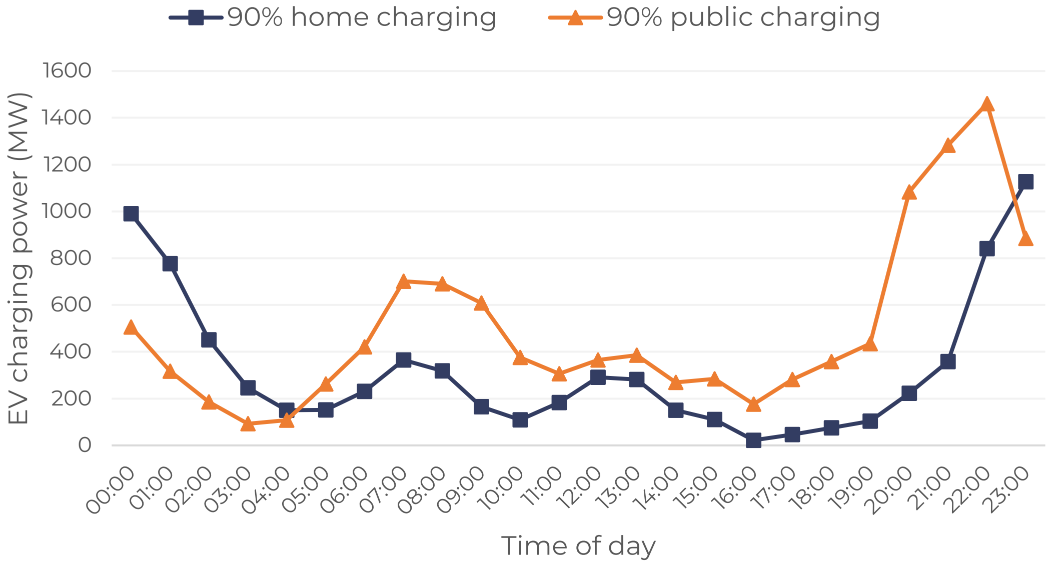
The environmental and health hazards associated with fossil-fuel-based vehicles are driving city dwellers towards electric vehicles (EVs), which have zero emissions and lower operating costs. As per the Center for Study of Science, Technology and Policy's (CSTEP's) report 'Bengaluru 2030: Impact of EVs on Vehicular Emissions', Bengaluru would have more than 23 lakh EVs (> 85% electric two wheelers [e-2Ws]) by 2030, helping curb beyond 3 million tonnes of CO_2 emissions annually (CSTEP, 2023). However, the relatively higher upfront costs of EVs and underdeveloped charging network could challenge this growth.

Therefore, to support EV adoption in Bengaluru, this study attempted to gauge perceptions about EVs and their charging patterns through consumer (questionnaire-based) surveys. **While widespread, accessible, and affordable public charging infrastructure could diminish consumers' range anxiety, it would have implications for the electricity grid**. In this regard, an assessment of Bengaluru's EV charging infrastructure demand for 2030 was performed using survey results as inputs. The number of charger guns required in 2030, impact of these guns on the grid, and potential locations for setting them up were assessed. Moreover, EV charging tariffs were proposed for 2030 by considering the current utilisation rates, tariffs, and anticipated demand in 2030.

Charging patterns (location, frequency, and time of charging) of EV users (personal users/commercial users; e-2W/-3W/-4W users) were also captured through the surveys. Personal EV users (~50%) prefer charging at home, while commercial users across all EV categories prefer public or workplace charging (~85%). In terms of charging time, overnight charging, which is performed using AC slow chargers, is preferred by ~45% of personal users and ~60% of commercial users. These location preferences and charging patterns along with EV stock were used as key inputs to estimate demand for EV chargers and its impact on the grid.

As per the results, **more than 36,000 public charger guns would be required in 2030 (25 times the guns in 2023)** to meet the charging needs of ~23 lakh EVs. Of these, more than 90% would be of 3.3 kW rating, which is used essentially for e-2Ws. Moreover, the peak load due to EV charging is expected to reach 1.2 GW by 2030 (13.5% of city's projected peak power demand) from 96 MW in 2023. The estimated annual energy demand from EV charging in 2030 is expected to be 3.3–4.1 BU, accounting for 7%–9% of the city's projected annual energy demand in 2030.

Two extreme charging scenarios, i.e. 90% of EV users charging at home and 90% at public charging venues, were also considered. The scenario wherein **90% of EV users charge at public stations could lead to a peak power demand of 1.4 GW (16% of city's projected peak power demand).** On the contrary, the peak power demand when 90% of EV users charge at home would be 1.1 GW (~7% lower than the 1.2 GW projection for 2030), resulting in relatively lower stress on the grid.



Power demand from EV charging under two extreme scenarios

To meet the demand from EVs in 2030, approximately 400 potential charging locations (e.g. IT parks, metro stations, fuel stations, and shopping malls) were identified (based on GIS analysis) in nine Regional Transport Office (RTO) zones across Bengaluru after assessing the demand for public charger guns in each zone. Moreover, **additional land required for establishing these charging stations would be 141 acre (6 million sq. ft), which is equivalent to the land for ~ 700 petrol pumps.**

Commercial analysis was also performed to assess the business viability for charge point operators (CPOs) to set up charging stations in the metropolis. Viable charging tariffs at various utilisation rates were estimated by setting a realistic internal rate of return (IRR) as the financial target. We estimated that the charger utilisation rates will be 25%–50% in 2030, and the corresponding tariffs for various types of charger guns can be capped at INR 11–15/kWh to achieve an IRR of 15%.

In conclusion, the establishment of supporting infrastructure (charging stations), as estimated in this study, will play a vital role in maintaining or improving the current momentum of EV uptake in the city. Further, overnight home charging (slow AC) results in the least strain on the grid. However, going ahead, promoting daytime charging at workplace or public charging stations, through policy measures, may be beneficial for increasing the share of renewable energy used for EV charging, thereby reducing the carbon intensity of EVs and making them more green.

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1. Introduction

1.1. Bengaluru mobility

Bengaluru (or Bangalore), the Silicon Valley of India and Karnataka's capital, is home to thousands of IT companies along with many biotech, textile, and Fortune 500 companies. It contributes to more than 80% of Karnataka's gross state domestic product (GSDP). The city is experiencing rapid growth, with 6% rise in its GDP in 2023 (Oxford Economics, 2023). The metropolis also attracts foreign direct investment (FDI) and is a major start-up hub in the Asia–Pacific.

Given the per capita income of INR 0.54 million (5.5 times the national average of INR 0.09 million), more than 80% of households in Bengaluru own at least one motor vehicle (Economic Survey of Karnataka 2021-22; Ministry of Statistics and Programme Implementation, 2023). The resulting vehicular traffic accounts for more than 65% of particulate matter (PM_{10}) and about 60% of nitrogen oxides (NO_x) emissions in the city (CSTEP, 2021). These vehicular exhaust pollutants pose a grave danger to human health and the environment.

In this context, electric vehicles (EVs) are advantageous over traditional fossil-fuel vehicles as they do not have tailpipe exhaust emissions and have lower running costs. A recent study by the Center for Study of Science, Technology and Policy (CSTEP) reported the following:

- Vehicle stock on Bengaluru roads will increase by 1.5 times during 2021–2030, reaching ~9 million by 2030.
- The corresponding vehicular emissions will only increase by 1.25 times due to the adoption of approximately 23.4 lakh EVs (20% of total on road vehicles; CSTEP, 2023).

Thus, the study concluded that vehicle electrification is the most practical approach to curb these vehicular emissions.

However, for a smoother transition to EVs, some challenges related to their refuelling or battery charging need to be overcome. While refuelling a petrol/diesel vehicle takes just a couple of minutes, recharging an EV battery takes a couple of hours (at least about an hour), depending on battery size, state of charge (SOC), and charger specifications, among others.

1.2. Study objectives and approach

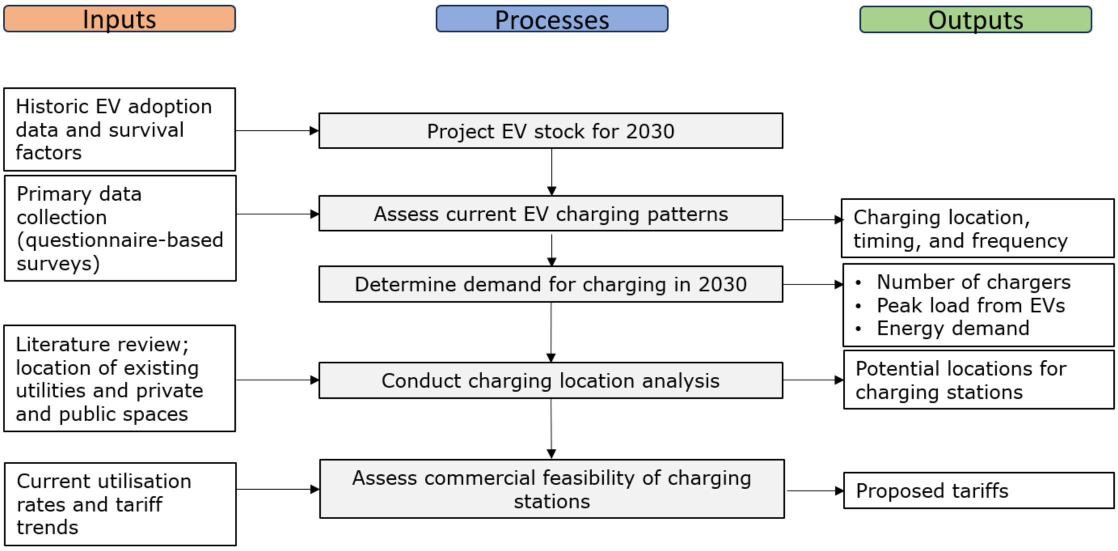
As discussed above, EV adoption is a feasible solution to curb vehicular emissions and alleviate the associated impacts on human health. However, adequate charging infrastructure is vital to support the EV uptake.

Thus, the objectives of the study are to answer the following questions in the context of Bengaluru:

1) What are the current charging and usage patterns of EVs in the city?
2) What will be the demand for charger guns in 2030, and which are the potential locations for setting them up?
3) What will be the impact of EV charging on the grid (in kW and kWh)?

The study attempts to answer the above questions by performing a detailed analysis using on-ground data collected through surveys. The step-by-step approach adopted by the study is described in the flow chart below (Figure 1). Bengaluru's EV stock by 2030 was projected using current uptake trends and vehicle survival factors. Charging patterns of current EV users (both personal and commercial users) were assessed using primary data collected through questionnaire-based surveys. This and the projected EV stock for 2030 were used to determine the demand for charging infrastructure in 2030 across the city. The impact on the grid and energy demand from EV charging were estimated as well. Furthermore, a spatial analysis was performed to identify potential locations for setting up charging stations. Lastly, by studying the current utilisation rates and tariffs and considering the anticipated demand in 2030, viable charging tariffs were proposed for 2030.

Figure 1: Study approach



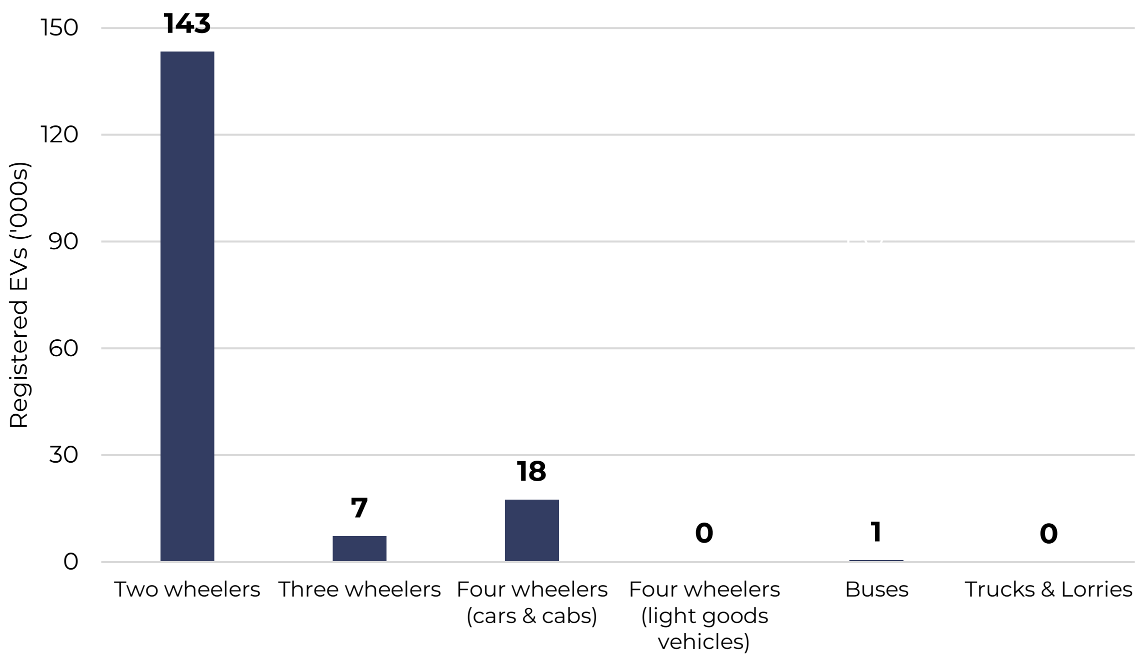
The following chapters present the approach, inputs, analyses, and calculations for each of these stages along with the results.

2. EV Uptake, Stock, and Perceptions in Bengaluru

2.1. EV uptake in Bengaluru

Bengaluru stands out as a prominent Indian city that has embraced EVs, showcasing concerted efforts from both private and public entities to expedite the transition outlined in Karnataka's EV policy. As of October 2023, Bengaluru had a noteworthy count of ~1,69,000 EVs (Figure 2), with more than 150% increase in EV registrations in the financial year (FY) 2023[1]. This increase indicates a robust momentum towards EV adoption in Bengaluru.

Figure 2: Vehicle segment-wise EV uptake trends in Bengaluru (October 2023)



Moreover, Bengaluru has prioritised the augmentation of its charging infrastructure to facilitate the widespread adoption of EVs. Bangalore Electricity Supply Company Limited (BESCOM) has established 310 EV chargers at 74 locations within Bengaluru, highlighting its role in EV adoption. Notably, in October 2023, BESCOM issued letters of agreement (LOA) for nine lots under the public–private partnership (PPP) model. These agreements aim to facilitate the set-up of EV charging stations at 530 locations across nine districts, including Bengaluru Urban and Bengaluru Rural (BESCOM, 2023).

Numerous private companies have also contributed to this initiative, establishing around 800 charging stations across various locations within the city (Zigwheels, n.d). Ather Energy Private Limited, a manufacturer of electric two wheelers (e-2Ws), has strategically installed approximately 140 charging points at diverse sites, including malls, gyms, cafes, and tech parks within Bengaluru (Ather Energy, n.d.). Furthermore, Ola has set up 33 hyperchargers at strategic points to boost the EV transition (Ola Cabs, n.d.). While Kazam has more than 120 charging stations spread across the city, the state-owned Indian Oil Corporation

[1] CSTEP analysis based on Vahan data

Limited (IOCL) has established more than 90 charging stations in the city. These points offer subsidised charging services for both e-2Ws and e-4Ws.

In addition, the electric cab service provider rydS (owned by Baghirathi) has erected charging stations in key areas such as Banaswadi, Jigani, Kadubeesanahalli, Electronic City (E-city), and Nagawara. Major players in the EV industry, including Mahindra & Mahindra Limited and Lithium Urban Technologies, have also contributed to the charging infrastructure by setting up stations in select technology parks.

As of October 2023, the total registered EV fleet in Bengaluru was approximately 1.69 lakh, which includes all vehicle segments. Of this, e-2Ws contribute the maximum at ~85%. The EV fleet composition in 2023 is shown in Table 1. The e-4W segment is yet to see substantial uptake because of the higher upfront cost and total cost of ownership of EVs. Another major reason is that only a few such EV models are eligible for subsidy under the Faster Adoption and Manufacturing of (Hybrid) and EVs II (FAME-II) scheme. With the aim of 100% electrification of public transport, Bengaluru Metropolitan Transport Corporation (BMTC) has been constantly procuring e-buses and has placed an order for ~900 more such buses (Vivan, S., 2023).

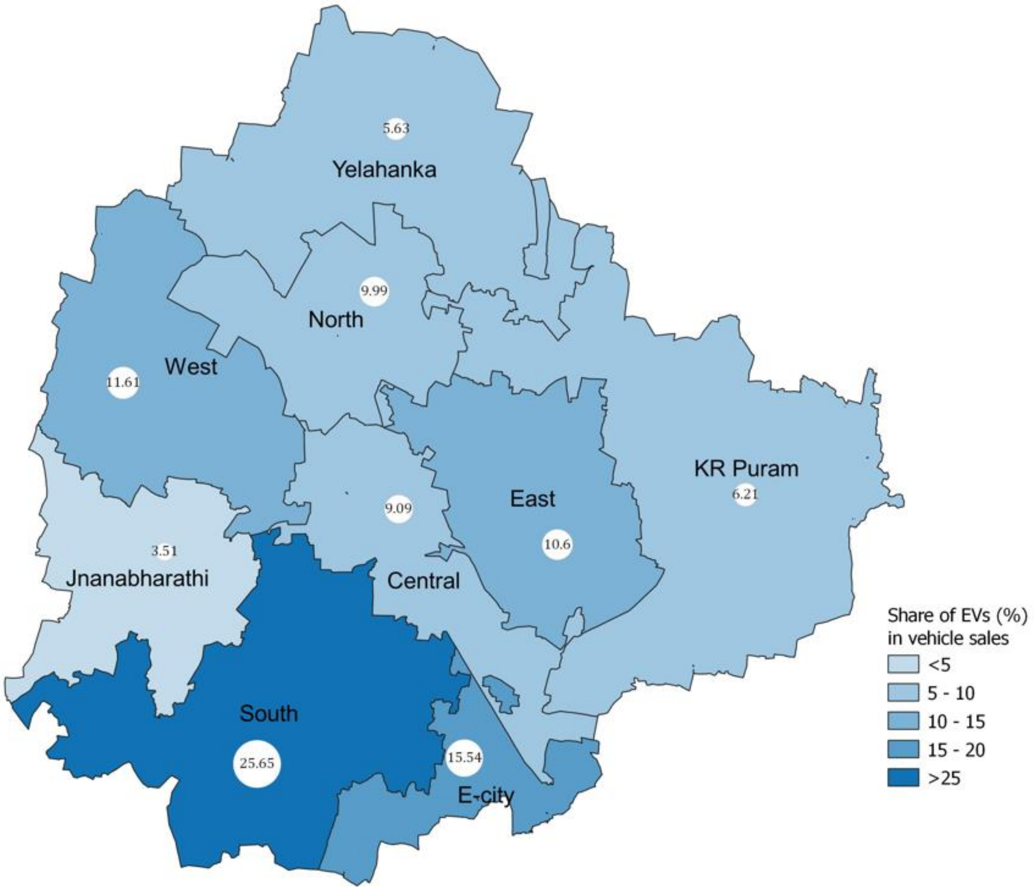
Table 1: Current EV stock in Bengaluru (2023)

S. No.	Vehicle segment	Registered EVs (to date)	EV stock (% of corresponding vehicle segment stock)
1	2W	1,43,382	3.60%
2	3W	7,290	5.01%
3	4W (car and cab)	17,578	0.93%
4	4W (light goods vehicle; LGV)	210	0.25%
5	Bus	552	3.81%
6	Truck and lorry	3	0.00%

There are 11 Regional Transport Office (RTO) zones in the city, and data obtained from the Vahan database[2] indicate that the registration of EVs is unevenly spread across the city. As of October 2023, the Bengaluru South RTO zone recorded the highest EV registrations (26%), followed by the E-city RTO zone (Vahan, n.d.). Figure 3 shows the distribution of EV registrations across all RTO zones as on 31 October 2023.

[2] Vahan is the centralised database by the Ministry of Road Transport and Highways (MoRTH), GoI, with public access to the web portal.

Figure 3: RTO-wise share of EVs in Bengaluru (as on 31 October 2023)



2.2. EV stock projection 2030

In this study, EV sales for 2030 were projected by considering 2023 stock as the base. RTO zone-wise historical EV registration trends and vehicle segment-wise survival fractions were used to project the EV registrations for 2030 by using the approach detailed in our previous study (CSTEP, 2023).

The projected EV stock in Bengaluru for 2030 (Figure 4) is about 23.4 lakh, and its distribution across different RTO zones is presented in Figure 5. By 2030, e-2Ws would constitute more than 85% of EVs in the city while e-3Ws and e-cars/cabs would account for 6% each.

Figure 4: Projected EV stock in Bengaluru by 2030

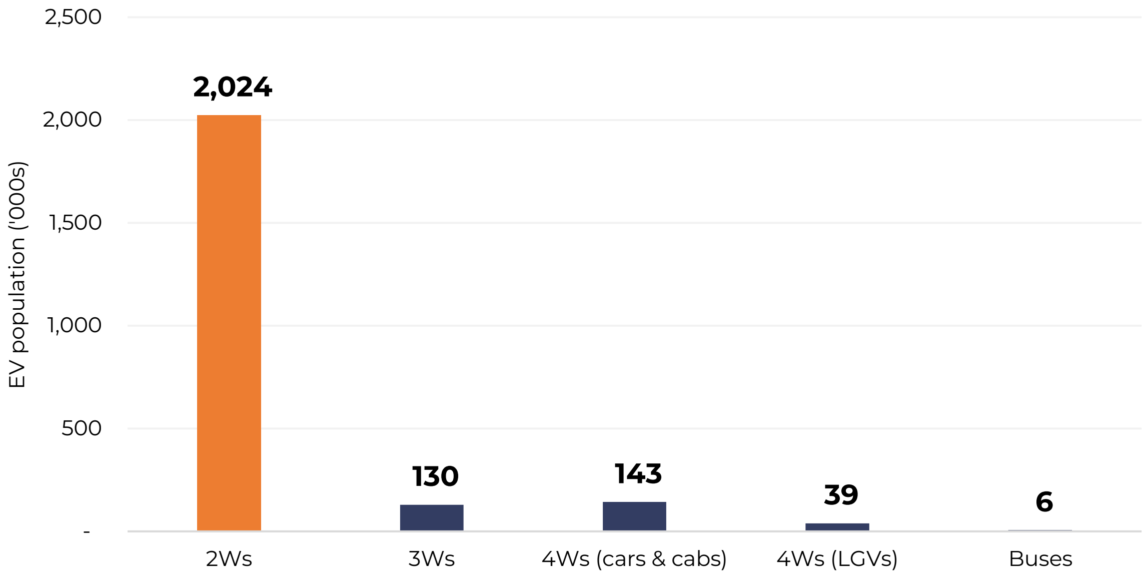
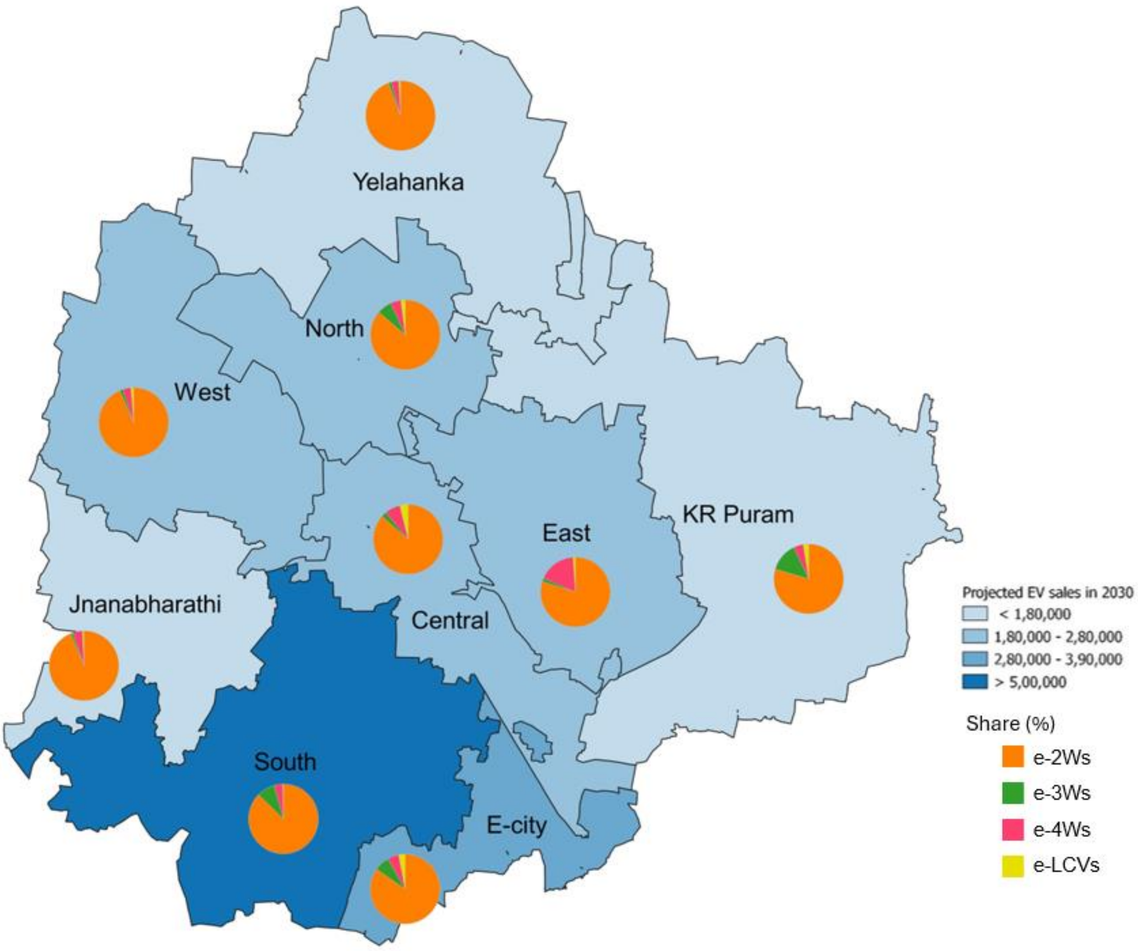


Figure 5: RTO zone-wise EV stock share in 2030



Note: It was assumed that the EV stock share of each RTO zone (i.e. number of EVs in an RTO zone relative to other RTO zones) in the horizon year [2030] will be the same as in the base year [2023]).

2.3. EV perceptions in Bengaluru

In addition to assessing the current EV stock and projecting its growth by 2030, it is vital to understand the perceptions about EVs among both current users and future (potential) buyers. Further, capturing the motivations for or barriers to EV adoption among different users (personal and commercial users) along with challenges (if any) faced by them is essential to assist industry and policymakers in adopting changes in product design and pricing, incentive type and quantum, investments towards charging infrastructure, etc.

Perceptions towards EVs (a new technology), socio-economic and travel characteristics, and EV charging patterns vary from one individual to another. Questionnaire-based surveys ensure that the same information is collected across the target population for consistency in analysis. Therefore, this study administered questionnaire-based surveys on potential and existing EV owners (personal users and commercial users, Table 2). A random sampling technique was adopted in this study.

Table 2: Survey description and sample sizes

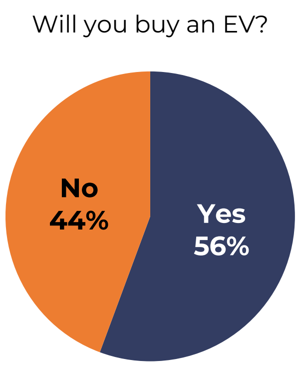
Potential EV owner (personal use) survey	To capture perceptions about EVs, benefits of/barriers to EV purchase, and socio-economic and travel characteristics	600+ samples
Current EV owner (personal use) survey	To capture motivations for purchasing EVs, challenges faced, charging patterns, and socio-economic and travel characteristics	300+ samples
Current EV owner (commercial use) survey	-do-	100+ samples

Key takeaways from the surveys are presented below while the survey details and analysis are discussed in Appendix 1.

2.3.1. Perceptions about EVs in Bengaluru

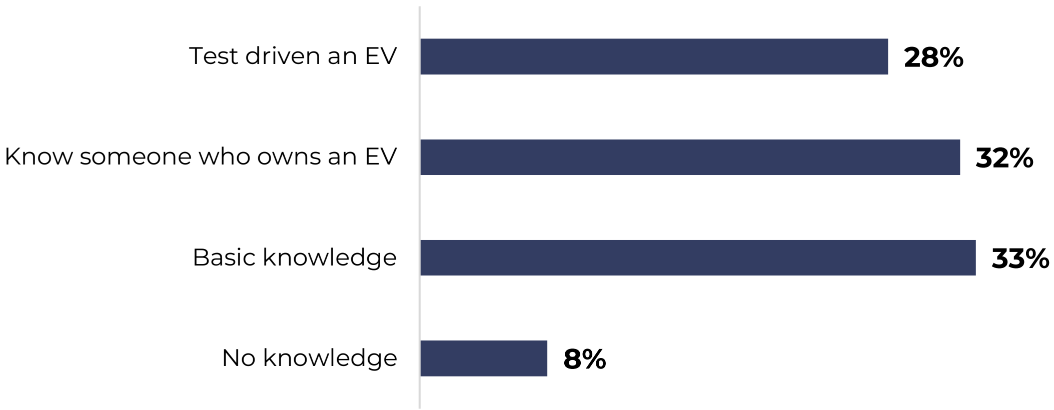
Interviews with more than 600 potential vehicle owners (persons likely to buy a vehicle in the next 5 years) revealed that 56% of these owners prefer to buy EVs over conventional vehicles (Figure 6).

Figure 6: Willingness to buy EVs



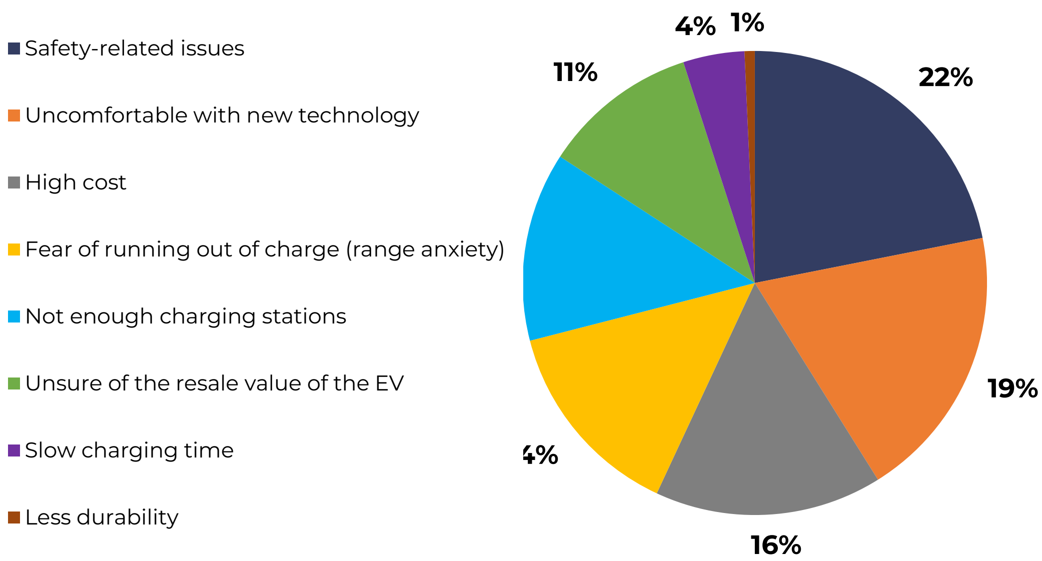
More than 90% of respondents were aware of EVs and their advantages. While only 28% had test-driven an EV, 8% had no knowledge about EVs (Figure 7).

Figure 7: EV knowledge



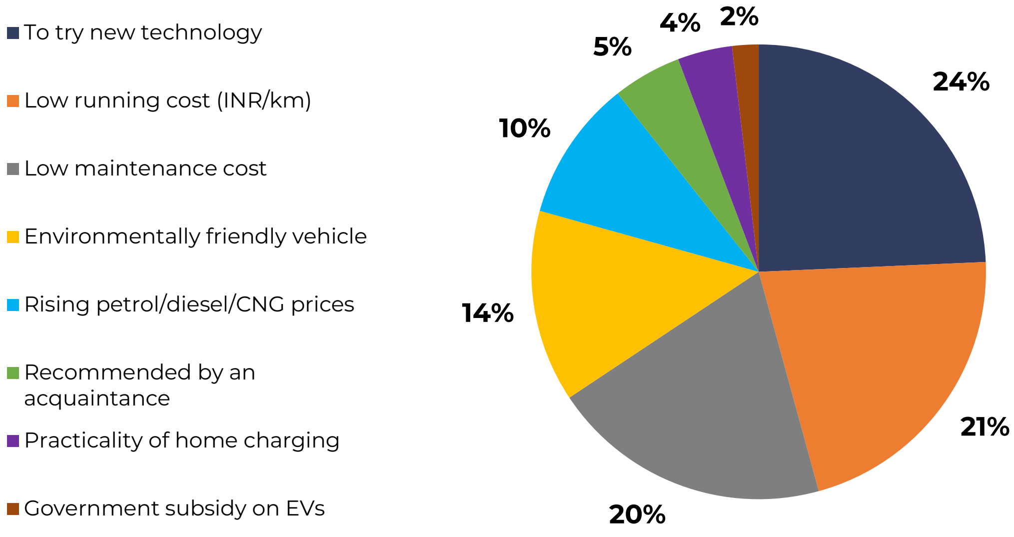
Further, enquiries with potential vehicle owners revealed that the safety aspect of EVs, followed by discomfort with new technology and the high upfront cost of EVs, are the top three reasons hindering EV adoption (Figure 8).

Figure 8: Drawbacks of EVs as perceived by potential vehicle owners in Bengaluru



Interviews with respondents currently using EVs for personal or commercial purposes indicated eagerness to try new technologies, savings in fuel expenditure (due to lower running costs), and lower maintenance costs as the main motivations behind EV purchases (Figure 9).

Figure 9: Motivations for EV purchases



2.3.2. Charging patterns

Similar to refuelling of petrol/diesel vehicles, EVs need to be recharged for unhindered operations. The charging patterns—where, when, and how often does one recharge their EVs—are of utmost importance to assess the energy demand and, thereby, the impact on the grid. Charging patterns are specific to the vehicle segment (2W, 3W, etc.) and are influenced by users' travel characteristics (e.g. daily vehicle kilometres travelled [DVKT]).

The preferences for charging location, frequency, and time of different EV users—personal and commercial users—and vehicle segments were captured through the questionnaire-based surveys, and the values are tabulated below (Table 3: EV charging location preference, Table 4 and Table 5).

More than 55% of personal e-2W and e-4W users charge either at their residence or workplace (Table 3). About 40% of commercial e-2W users prefer to charge at public charging stations. Company/employer-provided designated charging stations were the most popular among commercial e-3W and e-4W users.

Table 3: EV charging location preference

Vehicle segment	Charging location (% of respondents)		
	Home	Public	Workplace
e-2W personal	44	42	14
e-2W commercial	18	40	42
e-3W commercial	00	08	82
e-4W personal	54	41	05
e-4W commercial	09	09	82

It was observed that the majority of EV users recharge their vehicles overnight (10 PM to 08 AM), except for personal e-2W users (Table 4).

Table 4: EV charging time preference

Vehicle segment	Time of charging (% of respondents)		
	8 AM to 4 PM	4 PM to 10 PM	10 PM to 08 AM
e-2W personal	17	44.5	38.5
e-2W commercial	20	20	60
e-3W commercial	20	20	60
e-4W personal	19	30	51
e-4W commercial	19	17	64

Further, it was noted that commercial EV users recharge more frequently than personal EV users (Table 5).

Table 5: EV charging frequency

Vehicle segment	Frequency of charging (% of respondents)			
	Everyday	Alternate day	Twice a week	Once a week
e-2W personal	25	28.5	25	21.5
e-2W commercial	83	17	00	00
e-3W commercial	83	17	00	00
e-4W personal	10.8	29.7	30.6	28.9
e-4W commercial	80	11	09	00

To summarise, relatively more Bengalurians (56%) expressed interest to buy EVs rather than conventional vehicles, which may boost EV uptake in the city. However, improvements in EV technology and confidence-building measures by EV manufacturers will be critical as safety is one of the major barriers to EV adoption, followed by high upfront cost. **Appendix 1** provides the complete analysis of data obtained from the questionnaire-based surveys.

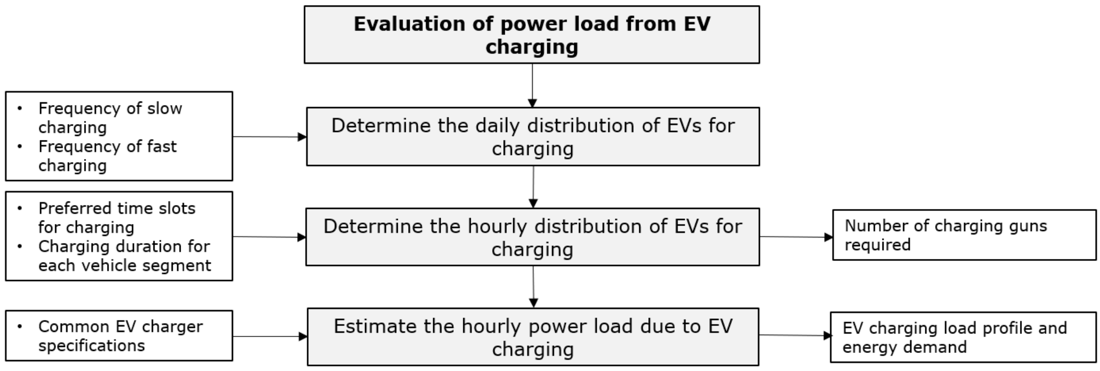
3. EV Charging Needs in Bengaluru 2030

As highlighted in the previous section, the number of registered EVs is expected to reach 23.4 lakh by 2030. In this section, we examine whether the escalating number of EVs translates into a greater load on the grid and enhanced energy requirements for EV charging. This may warrant installing new components (sub-stations, feeders, etc.) and augmenting existing components of the grid. The details of the number of charger guns required in 2030 and the associated power/energy demand in Bengaluru were estimated, with the results discussed below.

3.1. Approach

The flow chart in Figure 10 describes the methodology adopted for analysing the charging infrastructure, with inputs on the left and outputs on the right. The current (2023) and projected (2030) EV stock, charging patterns captured through questionnaire-based surveys, and charger specifications were used as inputs. Two ways of charging EVs, i.e. slow charging (usually at home) and fast charging (usually at public charging stations), were considered. These differ in the relative time taken to charge the EV battery of a vehicle segment: a slow charger (SC) gun takes relatively more time than a fast charger (FC) gun to charge an EV battery to the same level. For example, an e-2W may need 2 hours or more to charge from 20% to 80% SOC when charged through an SC gun, whereas for an FC gun, 1 hour may be sufficient.

Figure 10: Methodology for assessing the impact of EV charging on the grid



3.2. Key assumptions

The study assumed the SOC of a battery to rise from 20% to 80% during a charging session. This is considering that deep discharge and overcharge of a battery are detrimental to its health. The power input during this phase was presumed to remain constant.

The input power from the grid (kW) and the expected time taken for charging the EVs in 2023 and 2030 are listed in Table 6 and Table 7, respectively.

Table 6: EV charger gun specifications in 2023

	Slow charging		Fast charging	
Vehicle segment	Input power from the grid (kW)	Charging time (hr)	Input power from the grid (kW)	Charging time (hr)
e-2W personal	0.78	2	3.3	1
e-2W commercial	0.78	2	3.3	1
e-3W commercial	3.3	4	NA	NA
e-4W personal	3.3	6	25	1
e-4W commercial	7.2	3	50	0.5
e-bus	50	3	150	1

Source: Based on market review

Table 7: EV charger gun specifications in 2030

	Slow charging		Fast charging	
Vehicle segment	Input power from the grid (kW)	Charging time (hr)	Input power from the grid (kW)	Charging time (hr)
e-4W personal	7.2	3	50	0.5
e-4W commercial	7.2	3	50	0.5
e-bus	50	3	150	1

Source: Based on market review

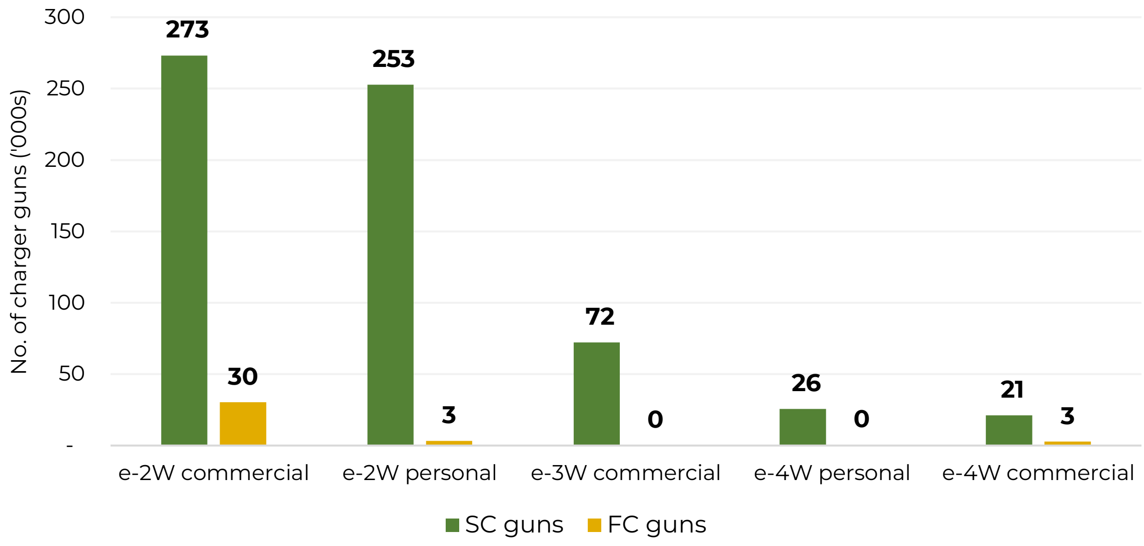
Note: For other vehicle segments, the specifications remain the same as in 2023

The number of public charger guns (FC guns) determined is such that at least 80% of the daily demand is met. The detailed step-by-step procedure adopted to determine the number of EV charger guns and their impact on the grid are described in **Appendix 2**.

3.3. Number of EV charger guns and power requirements

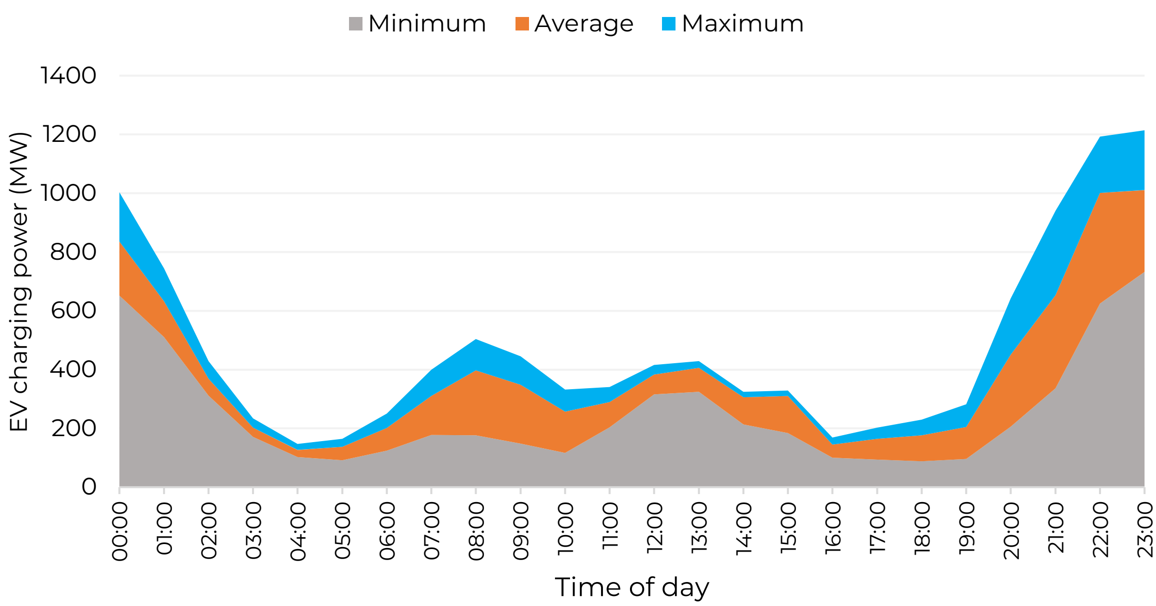
It is estimated that around 7 lakh EV charger guns (including more than 36,000 FC guns) would be required by 2030; of which, about 80% of demand would be from e-2Ws (Figure 11). Moreover, to house these charger guns, ~141 acre of land would be needed. This study disaggregated the demand for charger guns at the RTO level, with the results indicating that the Bengaluru South and E-city RTO zones would account for more than 40% of the demand. This corresponds to their larger EV stock compared with other zones.

Figure 11: Demand for charger guns in Bengaluru 2030



Assuming that the current preferences observed through the surveys will continue to be relevant in 2030, the resulting power demand in 2030 from EV charging is presented in Figure 12. It can be inferred that the maximum/peak value of power demand occurs at 11 PM in all three cases (minimum, average, and maximum), with the minimum value occurring early in the morning (4 AM/5 AM). On the average power demand curve, the least value is around 130 MW and the highest 1,010 MW.

Figure 12: EV charging load profile 2030



It is worthwhile to note that about 35% of peak power demand from EV charging in 2030 would be from e-2Ws. Further, corresponding to the EV stock increase from 1.6 lakh in 2023 to 23.4 lakh in 2030, the average and maximum power demand from EV charging is expected to increase by 11.96 (Figure 13) and 12.65 times (Figure 14), respectively.

The estimated peak power demand due to EV charging would constitute around 13.5% of the city's projected peak power demand by 2030 (8.88 GW; CEA, 2022).

Following the power demand calculations, the energy required for EV charging was also calculated. The daily average and maximum energy demand from EV charging in 2030 were estimated to be 9,320.6 MWh and 11,368 MWh, respectively.

Figure 13: Comparison of the average EV charging load profile in 2023 and 2030

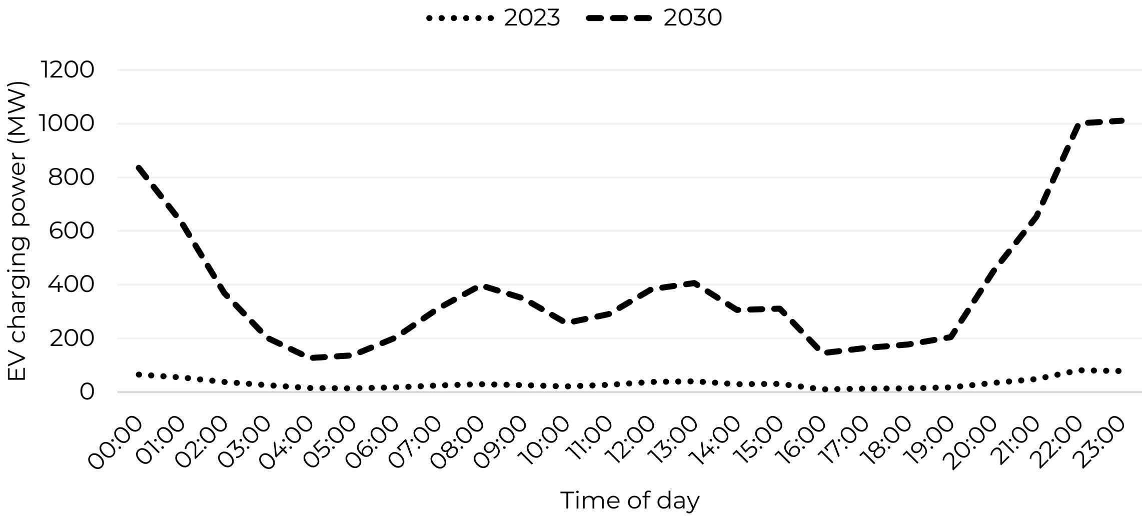
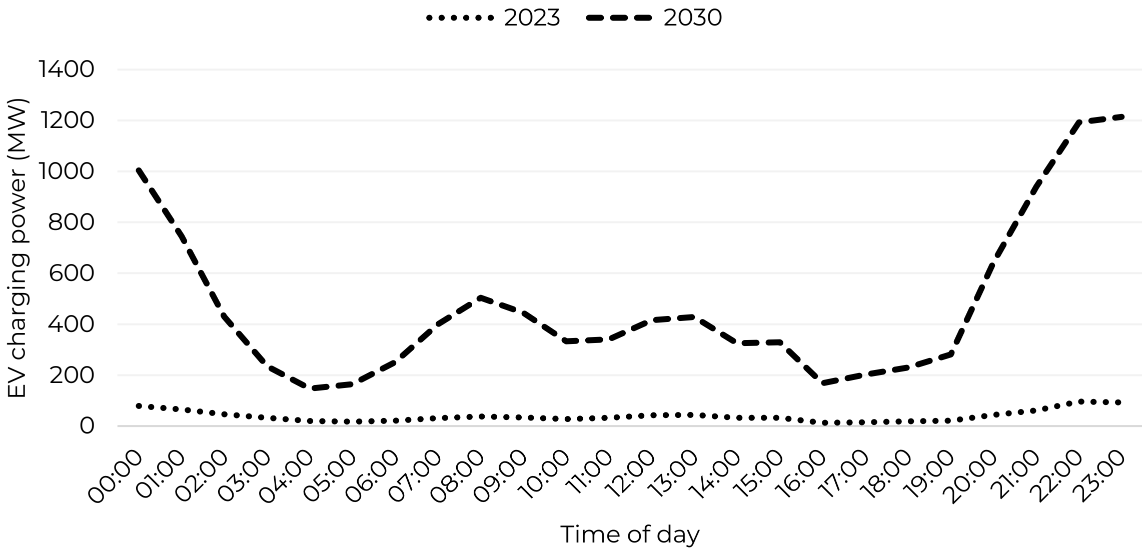


Figure 14: Comparison of the maximum EV charging load profile in 2023 and 2030



The following can be concluded from the results discussed above:

- Peak load in Bengaluru due to EV charging in 2030: ~1.2 GW (Figure 14).
- Contribution of EV charging in Bengaluru to city's projected peak power demand in 2030: 13.5% (CEA, 2022).
- Average daily energy demand due to EV charging in 2030: 9.3 MU (3.3 BU annually, which is about 7% of city's projected annual energy demand [48 BU; CEA, 2022]).

3.4. Charging scenario analysis

To account for the impact of changes in charging patterns, two scenarios were considered. In the first scenario, home charging was considered to be widely popular, i.e. 90% of all EVs will charge at home (slow charging). In the second scenario, public charging was considered to be predominant, i.e. 90% of EVs will charge at public charging stations (fast charging).

In the scenario with 90% home charging, about 14,000 FC guns would be required by 2030, whereas in the scenario with 90% public charging, ~2,40,000 FC guns would be required (Figure 15). The load profiles of the two scenarios are presented in Figure 16.

Figure 15: Demand for FC guns in 2030 for different charging scenarios

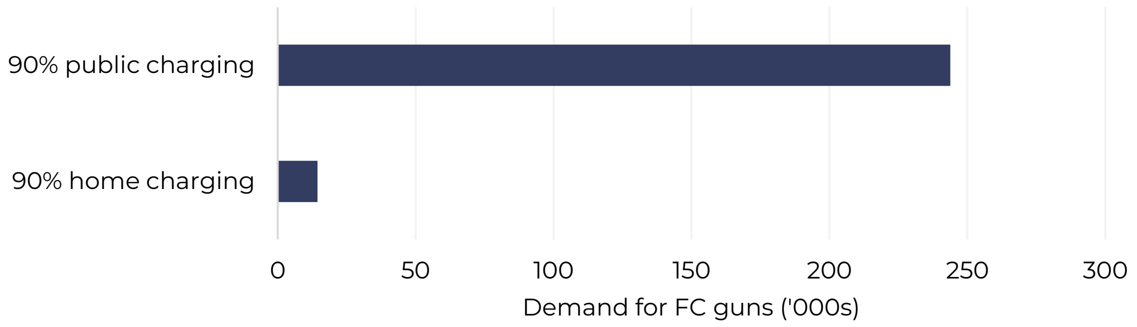
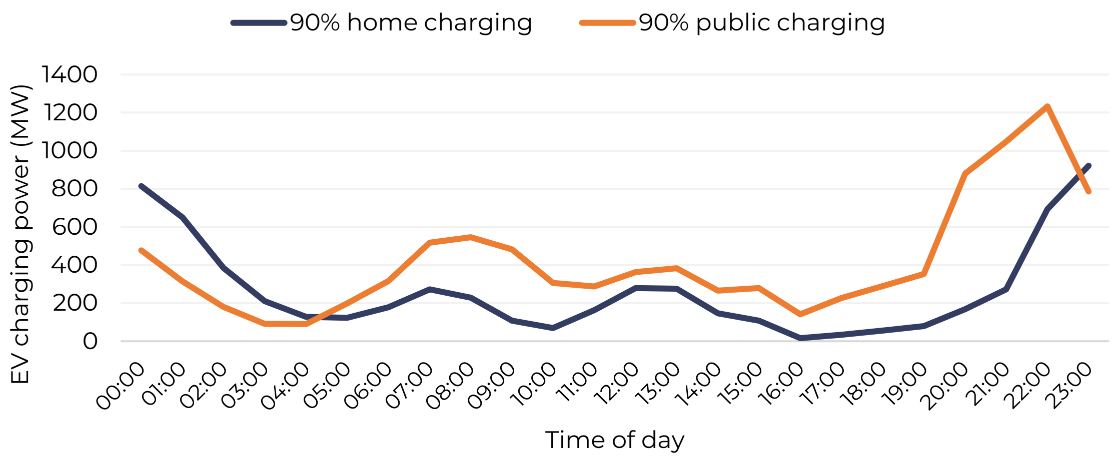


Figure 16: Load profile for the two scenarios (90% home charging and 90% public charging)



Most of the load due to EV charging in both scenarios was noticed between 7 PM and 12 AM, which can be attributed to 80% or more preferring (as per survey) to charge EVs in the evening (4 PM to 10 PM) and overnight (10 PM to 8 AM). This could be related to the return of employees/students back to their residence and increased commercial activity during late evening hours. Peak load for 90% home charging and 90% public charging are 1.1 GW and 1.4 GW, respectively.

The following can be concluded at this stage:

- Number of FC guns required in the scenario with 90% public charging is 17 times more than that in the scenario with 90% home charging.

- Peak power demand in the scenario with 90% public charging is 1.20 times higher than that projected for 2030 (Section 3.3). However, the demand in case of 90% home charging is ~7% lower than that projected for 2030 (Section 3.3).
- Land required in the scenario with 90% public charging is ~7 times higher than the ~141 acre estimated for 2030 (Section 3.3). Moreover, the locations for public charging stations are prime real estate land parcels, which can increase the charging tariffs.
- In case of 90% home charging, the land requirement is 60% lower than the ~141 acre estimated for 2030 (Section 3.3), making a case for investments and policies towards home charging.

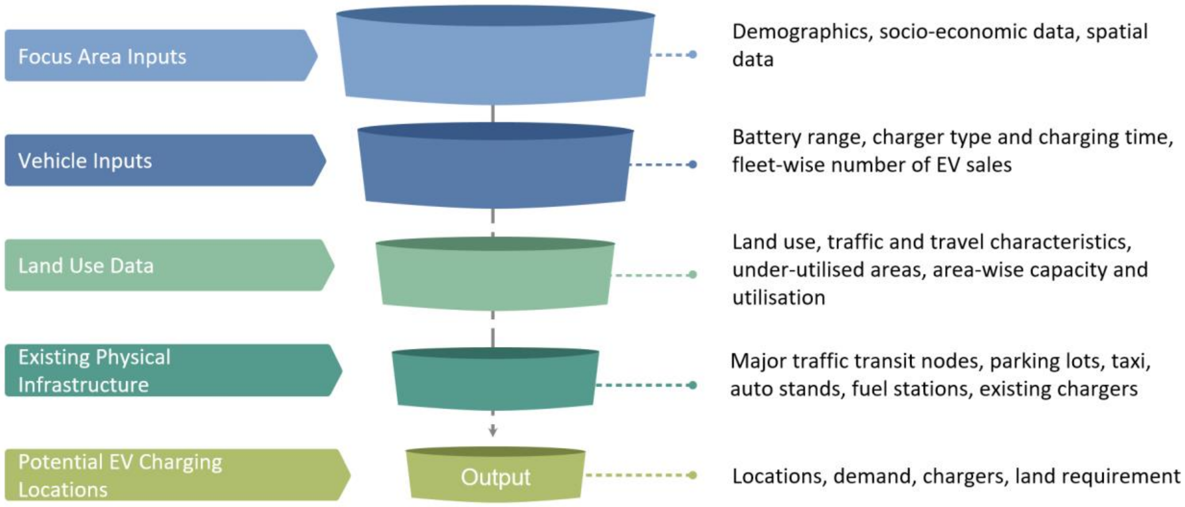
3.5. Spatial analysis for the location of EV charger guns

Extensive research and direct interactions with both potential and current EV users indicated that the presence of a robust EV charging infrastructure is a pivotal factor in promoting EV adoption. As discussed before, Bengaluru has 800 EV charging stations as of 2023. This equates to 252 EVs/EVSE[3], which falls too short of the global average of around 10 EVs[4]/EVSE (Global EV Outlook, IEA, 2022). Thus, to stimulate further EV adoption and meet the anticipated surge in demand, a more extensive network of charging stations will be necessary to meet the global standards.

Aspects important for an EV charging station extend beyond mere availability; strategic considerations such as location and accessibility are equally crucial. CSTEP previously conducted a study aimed at developing a framework to assist decision-makers in identifying suitable locations for public charging stations (CSTEP, 2021). The framework considered various factors, including electrical service availability, charging time, the characteristics of drivers and vehicles targeted by the charging stations, traffic density during different hours of the day, land ownership, policy goals for EV penetration, major transit nodes, and the existing charging infrastructure. Largely inspired from the previously developed framework, a detailed approach (Figure 17) was adopted in this study to identify suitable locations for setting up charger guns in Bengaluru. This approach should align with the specific needs of the area and seamlessly integrate with BESCOM's electricity supply and transmission networks.

[3] Electric Vehicle Supply Equipment (EVSE), another term for EV charger gun.
[4] Light-duty electric vehicles; does not include e-2Ws.

Figure 17: Approach for identifying charging station locations



Citation: CSTEP. (2021). Assessment Framework to Identify Location for Public Charging Stations. (CSTEP-PB-2021-07)

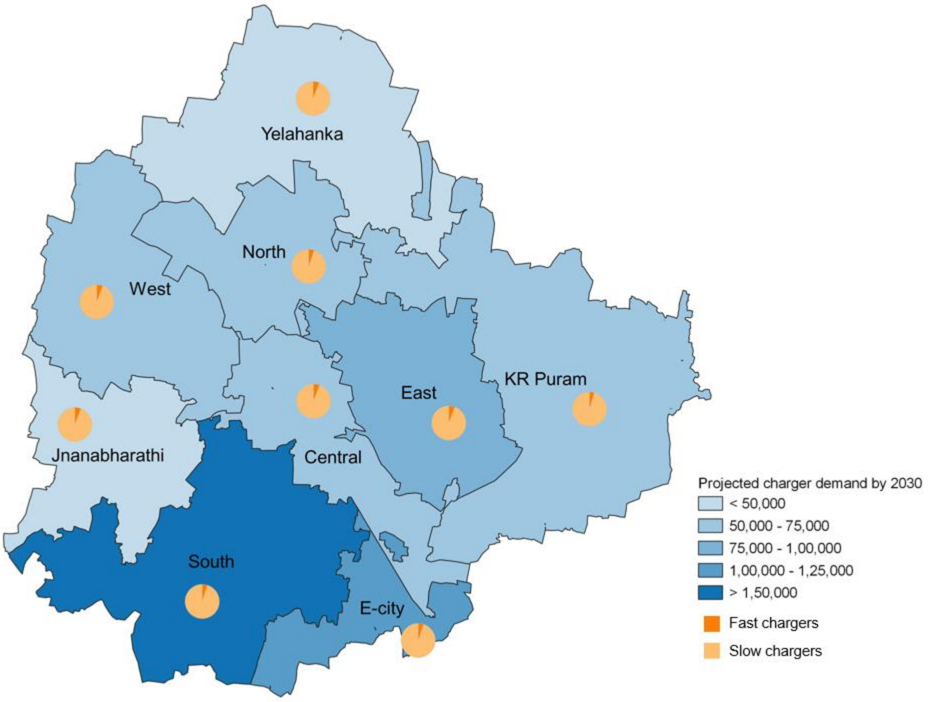
To analyse and integrate these diverse factors effectively, GIS tools were employed in the spatial analysis. The analysis considered key factors outlined in Table 8 and was limited to nine RTO zones (out of the 11) due to data constraints.

Table 8: Factors considered for the spatial analysis

Potential demand for EV charging stations	Site suitability for EV charging stations
Demographics and usage preferences of existing EV users Commercial and residential clusters Tariff (BESCOM and private) Energy consumption EV charging technologies	Existing parking lots Public transit stations (metro and buses) Traffic and transit management centres Fuel (petrol, diesel, CNG) stations Commercial spaces (tech parks and malls) Bus depots

The distribution of the 36,000 public chargers (FC guns; as discussed in Section 3.3) across different RTO zones is shown in Figure 18. Corresponding to the relative EV stock in respective RTO zones, the number of FC guns required by 2030 in the Bengaluru South RTO zone is the highest (9,100) while that in the Jnanabharathi RTO zone is the lowest (1,200).

Figure 18: Demand for charger guns in 2030



The spatial analysis identified ~400 prospective sites for EV charging stations within the nine RTO zones in Bengaluru to accommodate the demand for FC guns (Figure 19). In addition to these 400 identified sites, around 2,500 existing bus stops could be modified to house charging infrastructure. This, thus, takes the total number of potential sites to ~3,000. These initial locations encompass various settings such as tech parks, malls, and Traffic and Transit Management Centres (TTMCs). The same is presented in (Figure 20).

Figure 19: Distribution of potential charging locations across different RTO zones

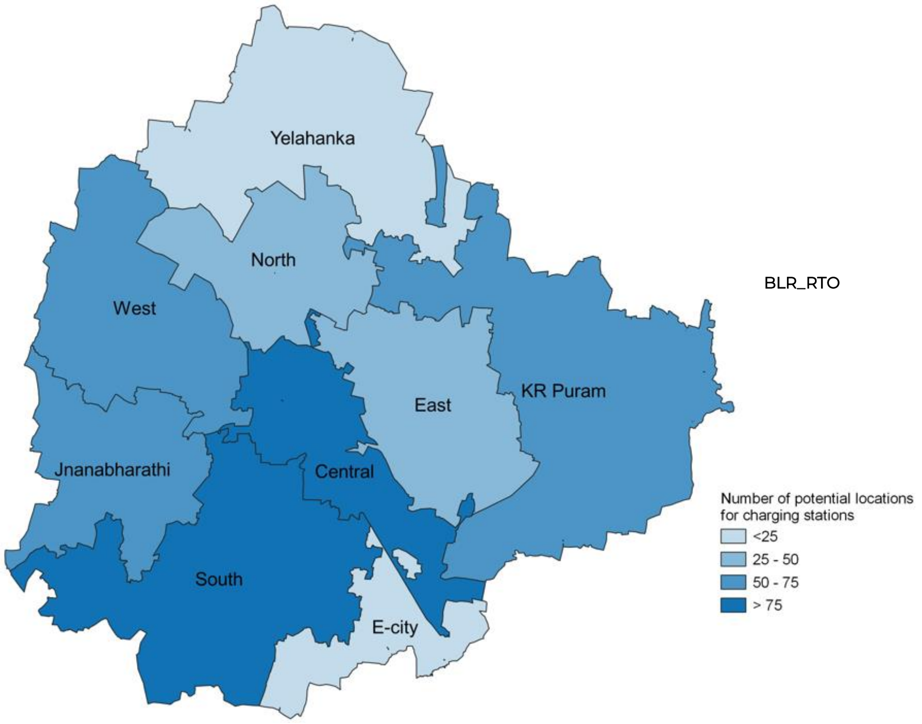
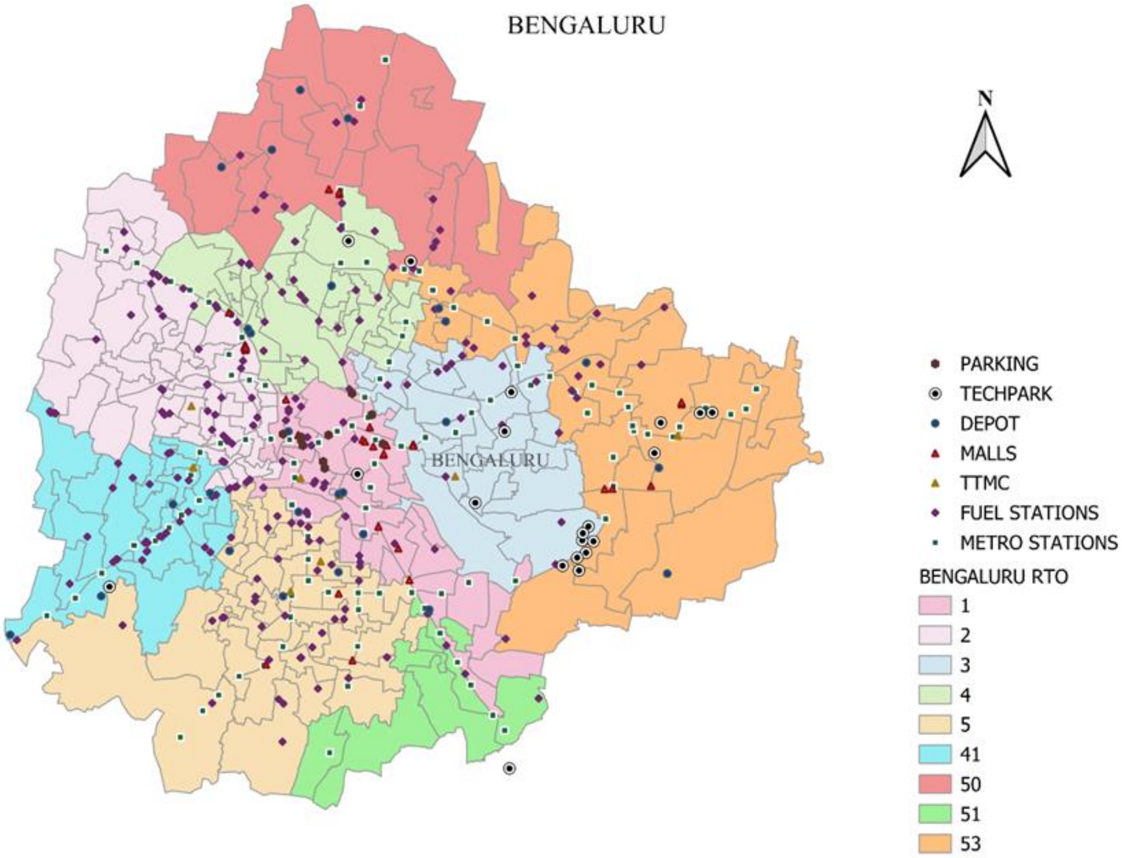


Figure 20: City-wide potential locations for charging stations



In the Bengaluru South RTO zone, which accounts for more than a quarter of the total EV stock in the city, above 60 potential locations were identified for setting up charging stations (Figure 21). The break-up of potential locations within the zone is provided in Table 9. Potential locations within other zones along with the break-up are provided in Appendix 3.

Figure 21: Potential charging station locations in the Bengaluru South RTO zone

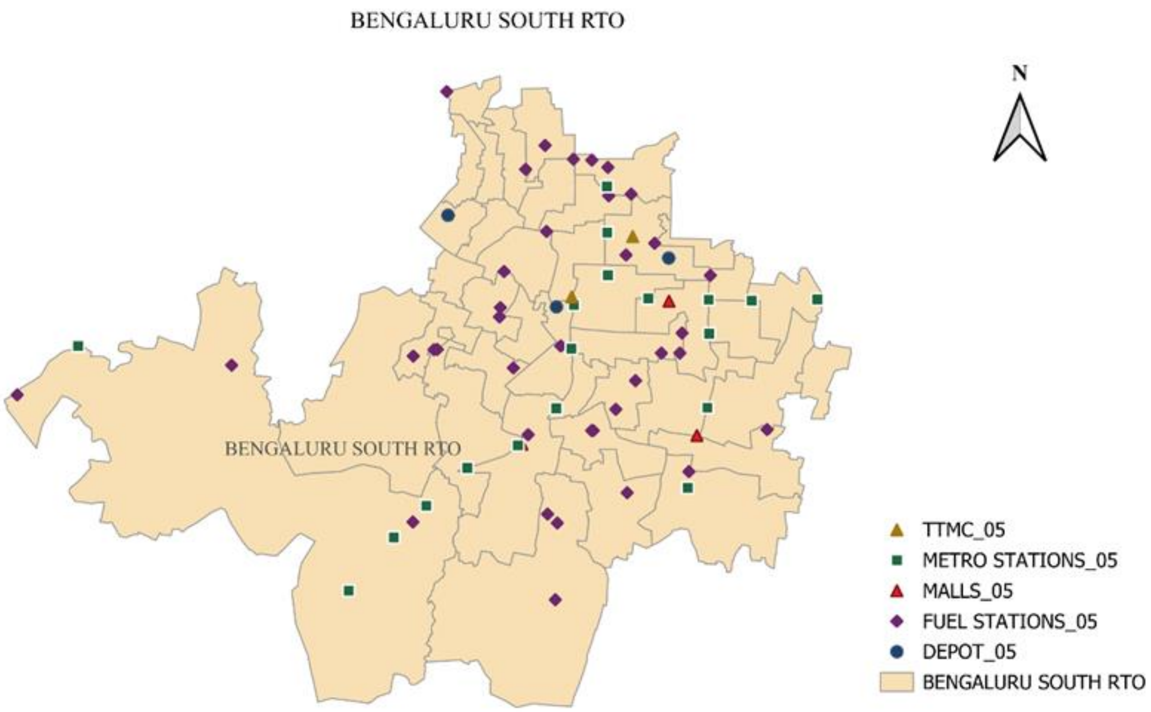


Table 9: Break-up of potential charging station locations within the Bengaluru South RTO zone

S. No.	Potential identified location	No.
1	TTMC	2
2	Bus depot	3
3	Metro station	19
4	Fuel station	37
5	Tech park	0
6	Mall	3
7	Off-street parking	0
	Total	**64**

Further, to confirm the optimal placement of charging stations, a comprehensive site suitability analysis must be conducted by considering factors such as land availability, electricity supply, traffic patterns, and demand.

The following can thus be concluded:

- The 36,000+ FC guns can be installed in over 400+ locations across Bengaluru.
- Approximately, 141 acre of land would be required to house these guns.

4. Commercial Analysis for Charging Infrastructure

4.1. Review of existing tariffs and utilisation rates

As of December 2023, the cost of petrol and diesel in Bengaluru stood at approximately INR 102 per litre and INR 88 per litre, respectively. In contrast, the price of electricity used to charge the EVs is around INR 8 per kWh for BESCOM chargers and INR 15–30 for private chargers[5], which translates to a running cost of INR 1–2 per km for EVs compared to INR 9-10 per km for petrol vehicles (BESCOM, n.d.). This places EV charging tariffs at the forefront of the contemporary energy and transportation landscape, carrying significant implications for the ongoing transition towards sustainable mobility.

The charging tariffs hold sway over the accessibility, affordability, and overall feasibility of EVs for consumers, businesses, and public institutions.

In Bengaluru, BESCOM functions as the state nodal agency responsible for establishing and managing public EV charging stations. Notably, private entities impose higher charging tariffs for their services than BESCOM. Table 10 provides a summary of the tariffs imposed by various charge point operators (CPOs).

Table 10: Tariffs by various operators in Bengaluru

CPO	Price (INR per kWh)
BESCOM AC charging	7.62
BESCOM DC charging	8.31
BESCOM CCS charging	8.07
Private operators	15 to 30

(Source: BESCOM and market analysis)

This discrepancy is primarily attributed to BESCOM's capacity to offer services as a government entity. Conversely, private operators are faced with elevated operational expenses, encompassing capital investment, maintenance, and corporate taxes, factors that significantly impact their tariff structures.

Moreover, Bengaluru confronts a noteworthy challenge evident in the underutilisation of EV charging stations. Through primary engagements with CPOs and BESCOM, it was ascertained that the average utilisation of EV charging stations stands at approximately less than 10%, and the same was noticed in the literature (Ahmad, F. & Bilal, M., 2023). There exists an indirect correlation between utilisation rates and tariffs. The lower utilisation necessitates private CPOs to augment their tariffs, seeking to optimise their operations and maintenance. The complexities contributing to this phenomenon are diverse, encompassing issues such as charging station accessibility, an evolving charging network, and perceptions surrounding the evolving EV ecosystem.

Consequently, it becomes imperative to delve into sustainable business models for CPOs that strike an appropriate balance between tariff structures and utilisation rates.

[5] Based on review of tariffs offered by private CPOs.

4.2. Approach: Assumptions and analysis

EV charging tariffs are important factors that greatly influence the pace of adoption. This study investigated the correlation between utilisation rates and end-user costs. As the primary focus is on the feasibility of operations of EV charging stations from the perspective of private entities, a 15% internal rate of return (IRR; representing average returns from equity markets) was considered for the analysis.

A financial model was built upon a set of assumptions derived from interactions with CPOs, BESCOM, and potential investors. Four types of EV charger guns (Table 11) and utilisation rates ranging from 5% to 50% were considered. The ensuing section outlines the assumptions and inputs (Table 12 and Table 13) employed to establish financial feasibility and determine the optimal tariff for the CPO, drawing insights from these diverse sources of information.

Table 11: Charger types (e-AMRIT, NITI Aayog, n.d.)

S. No.	Charging station	Power (kW)	Vehicle segment	Type of compatible charger
1	Level 1 (AC)	3.3	4W, 3W, 2W	Type 1, Bharat AC-001
2	Level 1 (DC)	15	4W, 3W, 2W	Bharat DC-001
3	Level 2 (AC)	22	4W, 3W, 2W	Type 1, Type 2, GB/T, Bharat AC-001
4	Level 3 (AC)	22	4W	Type 2
5	Level 3 (DC)	Up to 400	4W	Type 2, CHAdeMO, CCS1, CCS2

Source: https://e-amrit.niti.gov.in/standards-and-specifications

Table 12: Charger costs

Charger type	Charger rating (kW)	Guns	Charger cost (INR)	Annual maintenance cost (INR/year)	Installation & commissioning charge (INR)
Bharat AC001	9.9	3	50,000	3,500	3,000
AC fast	7	1	52,500	3,500	3,000
Bharat DC001	15	1	2,12,500	17,500	7,500
DC wallbox (CCS/ CHAdeMO)	25	1	5,55,000	32,000	5,000
DC fast charger (DCFC) (CCS2)	60	1	10,25,000	55,000	8,000
	120	2	15,25,000	92,000	15,000
	240	2	23,00,000	1,35,000	20,000

(Source: Market analysis)

Table 13: BESCOM energy tariffs (Electricity tariffs 2025, KERC, 2024)

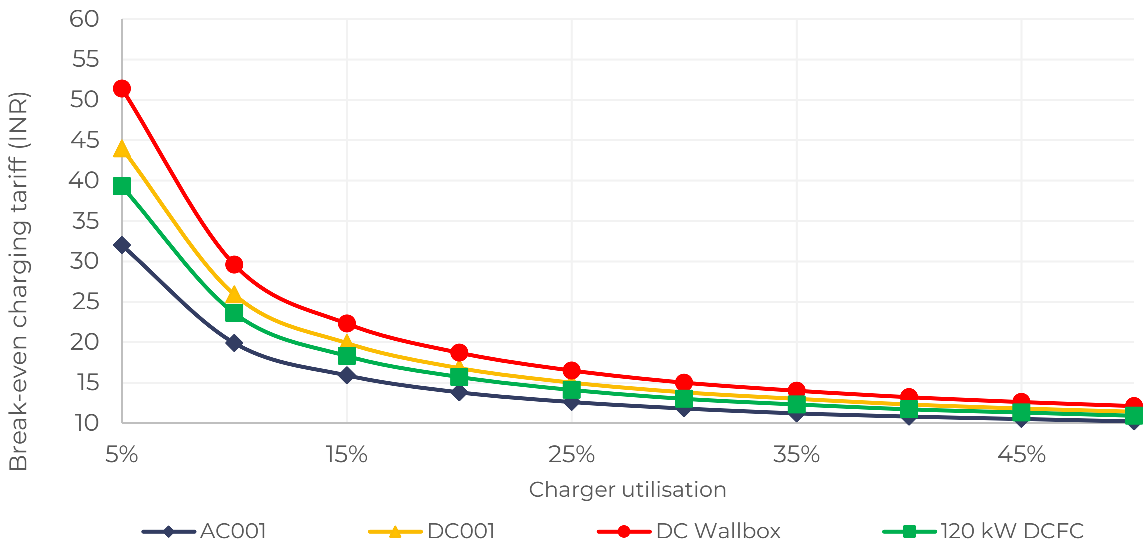
Fixed charge	70	INR/kW per month up to 50 kW	LT-6c category
	170	INR/kW per month above 50 kW	
Energy charge	5	INR/unit	

(Source: ElectricityTariff2025.pdf (karnataka.gov.in))

Further, it was assumed that the CPO would secure land for establishing charging stations through a revenue-sharing arrangement with either BESCOM/BBMP or the relevant agency. It was further presumed that the CPO would allocate 15% of the net revenue (excluding GST) to be shared with the pertinent authority.

The analysis was conducted using the aforementioned assumptions, assessing the minimum charging tariffs required to achieve an IRR of 15% for all charger types across utilisation rates ranging from 5% to 50% (Figure 22).

Figure 22: Charging tariffs vs utilisation at IRR 15%



The computation of IRR is based on a 5-year cash in-flow period, with utilisation levels remaining constant throughout the entire timeframe. Extensive interactions with CPOs revealed that a 15% IRR is deemed the optimal case for most charging stations.

As per our analysis, the weighted average utilisation of chargers in 2030 would be around 30%. Figure 22 also indicates that beyond a 30% utilisation level, there exists only a marginal difference in the tariffs required to achieve the expected returns. This establishes the upper tariff limits for users as INR 11.5–15.8 per kWh across different charger types. Charging EV users within this specified range will ensure anticipated returns for the CPOs and contribute to the long-term sustainability of the business. Moreover, the reduced tariffs imposed by private operators, resulting from increased utilisation levels, will alleviate the financial burden on users while simultaneously preserving profits for the CPO.

The following can be concluded on the basis of the analysis above:

1) Break-even tariffs stabilise (do not change much) at and beyond 30% utilisation level.
2) Tariffs of INR 11.5–15.8 per kWh will ensure long-term business sustainability of CPOs.

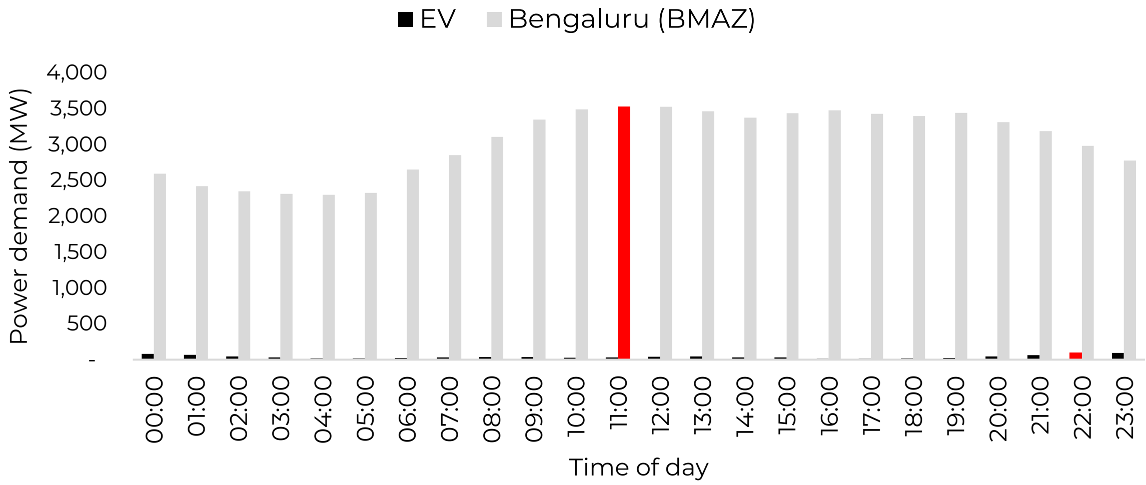
5. Concluding Remarks and Way Forward

Adopting (relatively) cleaner vehicle technologies such as EVs is an effective solution (due to zero tailpipe emissions from EVs) to curb vehicular emissions in Bengaluru and alleviate their negative impacts on citizen health. More than 23 lakh EVs (of which, more than 20 lakh will be e-2Ws) are expected to ply on Bengaluru roads by 2030, which will help avoid above 3 M tonnes of CO_2 emissions annually. This rising EV stock demands adequate and affordable charging infrastructure; therefore, this study assessed the charging infrastructure requirement and its implication on the grid in 2030.

Survey responses revealed that about 56% of potential vehicle owners in the city are likely to choose EVs over their conventional counterparts. Further, the safety aspect of EVs and higher upfront costs were reported to be the major barriers to EV adoption. Similar interviews with current EV users revealed that lower running and maintenance costs of EVs compared with their conventional counterparts were key motivations to buy EVs.

Charging patterns (location, frequency, and time of charging) of EV users (personal users/commercial users; e-2W/-3W/-4W users) were also captured through questionnaire-based surveys. Most EV users prefer charging at home or the workplace. In terms of timing, overnight charging is the most popular. These charging patterns were used as key inputs to estimate demand for EV charging and its impact on the grid in 2030.

Figure 23: Comparison of power demand from EV charging with overall Bengaluru power demand in 2023 (The Bengaluru Metropolitan Area Zone [BMAZ] peak is at 11:00 hr and EV peak is at 22:00 hr, denoted by red bars)



The results revealed that the peak load due to EV charging in 2023 was 0.096 GW and occurred at 10 PM. Interestingly, this demand forms less than 1% of the city's peak load, occurring at 11 AM (Figure 23). Further, two charging scenarios, i.e. 90% of EV users charging at home and 90% at public charging venues, were analysed. The peak power demand due to EV charging in 2030 is expected to be about 1.4 GW in the latter scenario. However, the peak power demand when 90% of EV users charge at home would be 1.1 GW, resulting in relatively lower stress on the grid.

Further, the estimated daily energy demand from EV charging in 2030 is expected to be between 9,320 MWh and 11,370 MWh.

Overall, installing charging stations, as quantified in this study, is crucial for sustaining and boosting EV uptake in the city.

It is to be noted that although EVs do not emit any exhaust emissions, they are not considered fully green alternatives to conventional vehicles as EVs use power from fossil-fuel-based plants for charging. Thus, to make EVs fully green, they need to be recharged using electricity generated from renewable sources. This could be achievable as 52% of Karnataka's power demand is being met by renewable sources, with the share being 47% for Bengaluru (K. H. Pavan, 2023). Going ahead, policy measures to encourage daytime charging at workplaces or public charging stations are essential to increase the utilisation of renewable energy for EV charging. Techno-economic feasibility studies for integrating renewable energy with charging infrastructure can answer key questions on opportunities, challenges, etc. Further, pilot studies on charging stations powered by 'green' electricity in both urban and rural areas are essential steps to demonstrate and enable the reduction of carbon footprint through EVs.

*****End*****

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Appendix 1: EV Perceptions in Bengaluru

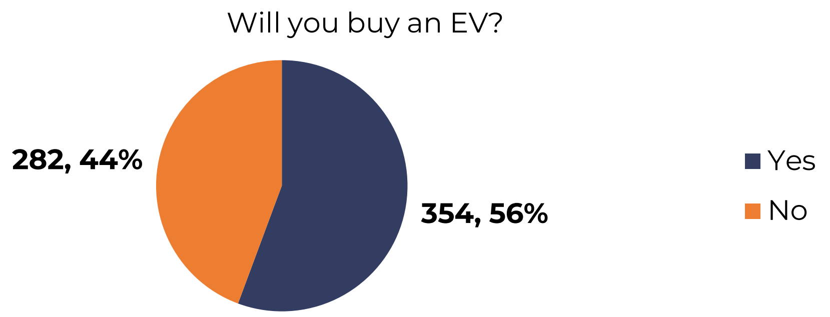
Detailed analysis and insights from three questionnaire-based surveys are presented in the following sections.

Part A: Insights from potential (personal use) EV owner survey

More than 600 potential EV owners were randomly selected and interviewed for the questionnaire-based survey. The sample consisted of 62% males, 50% graduates, and 40% of those aged between 25 and 35 years.

In general, 56% of Bengaluru respondents were in favour of purchasing EVs instead of conventional ones (Figure 24).

Figure 24: Willingness to buy EVs over conventional vehicles



Examining interest towards EVs with respect to age (Figure 25) and gender (Figure 26) revealed relatively more interest in EV purchases among those aged above 35 years. Further, there was no difference in EV interest between females and males.

Figure 25: EV preference across age groups

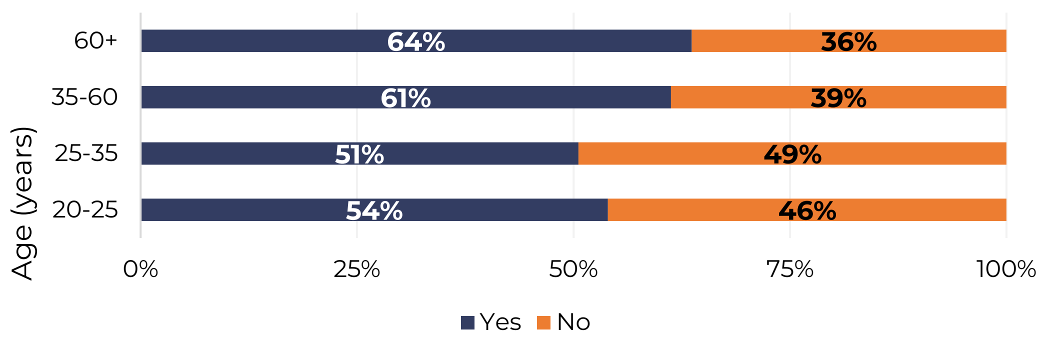
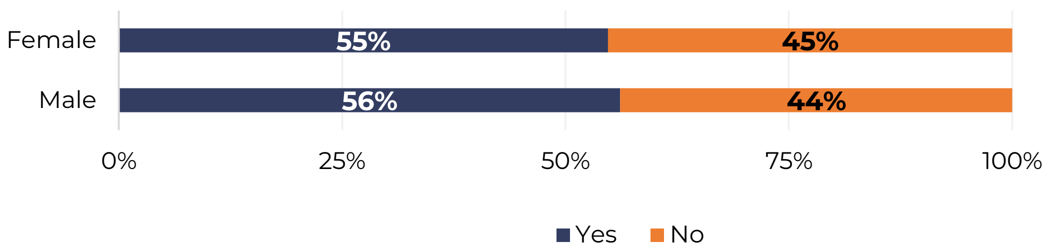


Figure 26: EV purchase intention among males and females



Graduates and postgraduates had a higher interest towards EVs than those with lower educational qualifications (Figure 27). Business owners and self-employed persons were relatively more interested in EVs than other professionals (Figure 28).

Figure 27: EV preference across people with different educational backgrounds

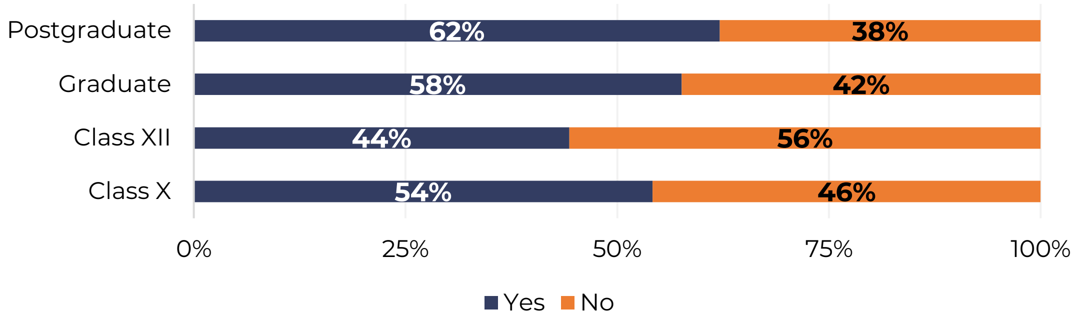
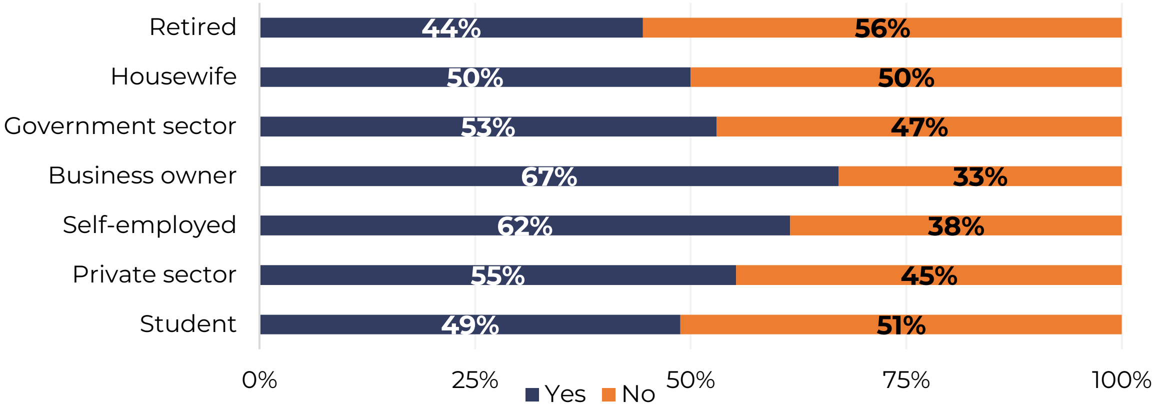
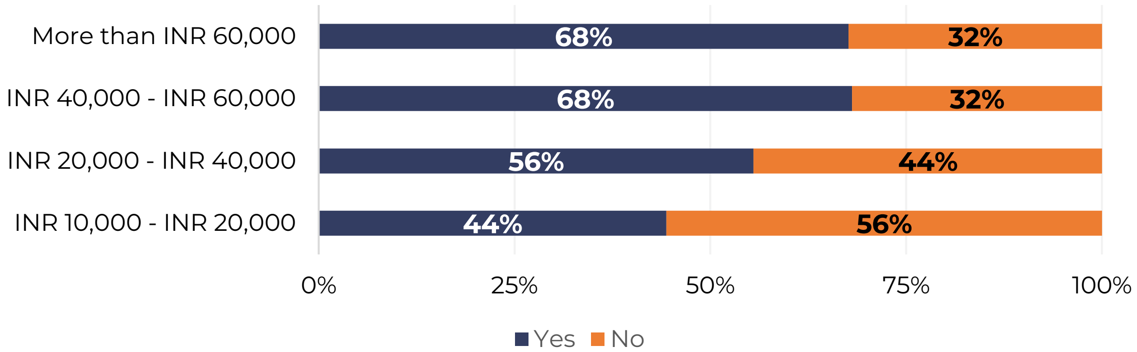


Figure 28: Intention to buy EVs across different occupations



It is well established in the literature that India is a cost-conscious market. The same is validated in this study as respondents with higher monthly expenditure had a higher interest in opting for EVs, which have relatively higher purchase prices than conventional vehicles (Figure 29).

Figure 29: EV purchase preference based on monthly expenditure



Persons owning a vehicle were marginally more inclined towards EVs than those not owning one (Figure 30). Interestingly, respondents who own a car were more interested in buying EVs than those with 2Ws. Overall, EVs were most preferred as a 2nd/3rd/4th vehicle than as a first vehicle (Figure 31).

Figure 30: EV preference based on vehicle ownership

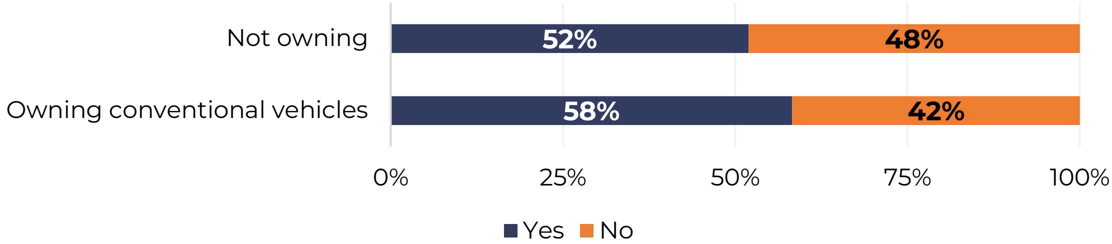
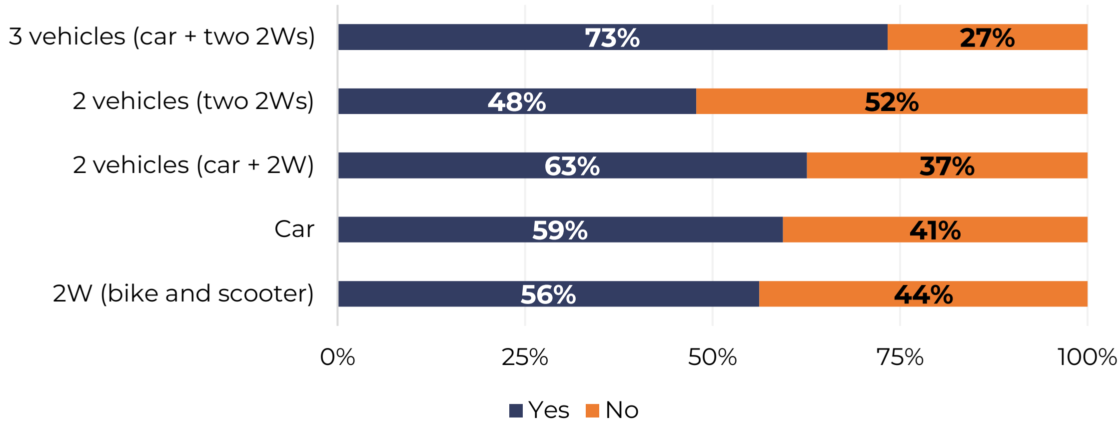
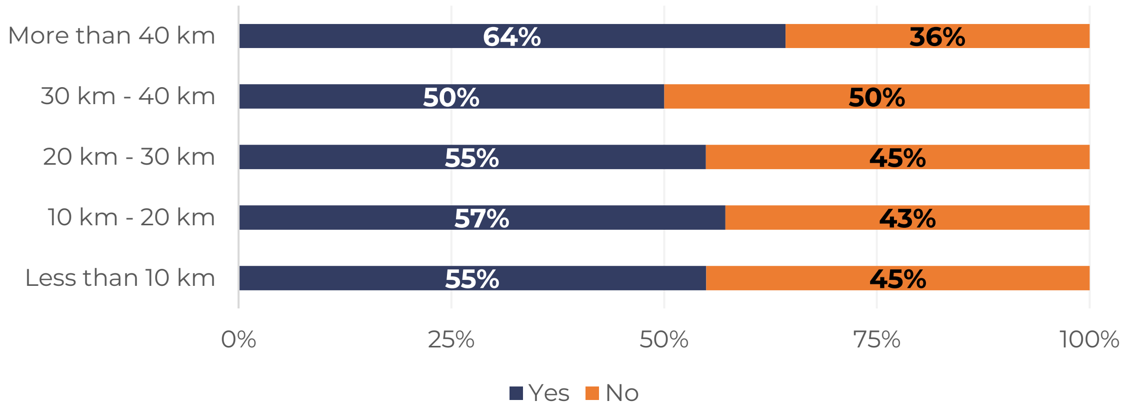


Figure 31: EV preference based on the number of vehicles owned



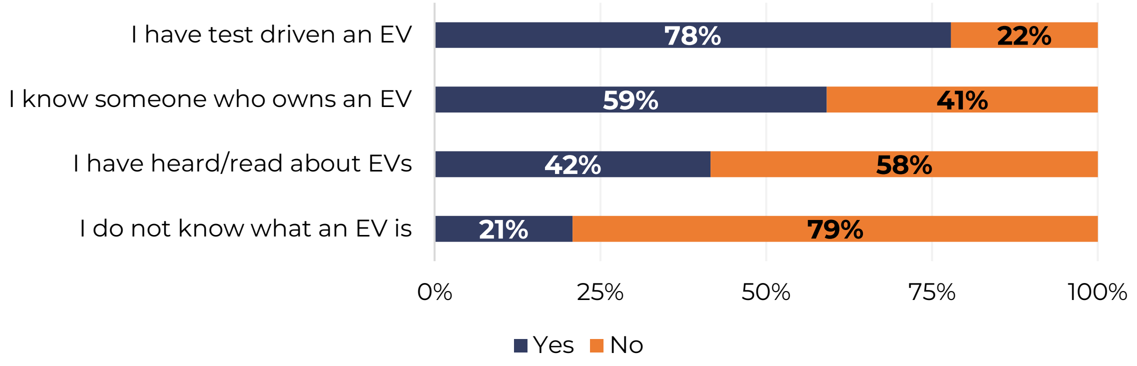
Respondents travelling more than 40 km a day were more likely to choose EVs than those travelling shorter distances (Figure 32).

Figure 32: Variation in willingness to buy EVs based on DVKT



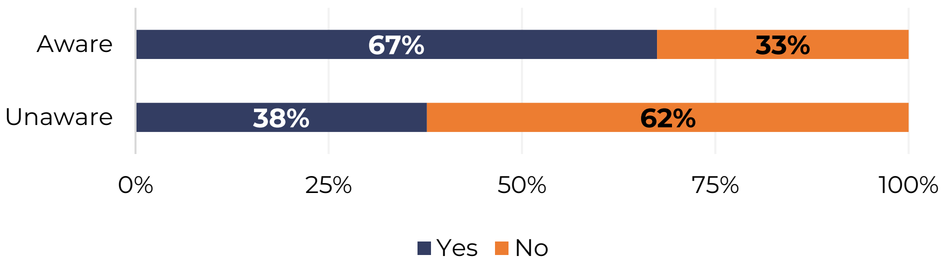
Given that vehicle electrification is a new technology in the auto market, the penetration depends on knowledge dissemination among the public. The same was evident from the responses to survey questions. Those who have test-driven or have a colleague/friend owning an EV are more likely to buy an EV than those who do not have basic knowledge about EVs (Figure 33). This is a clear indication to policymakers to continue investments in information dissemination and education on EVs.

Figure 33: Willingness to buy EVs based on EV knowledge, interest, and familiarity



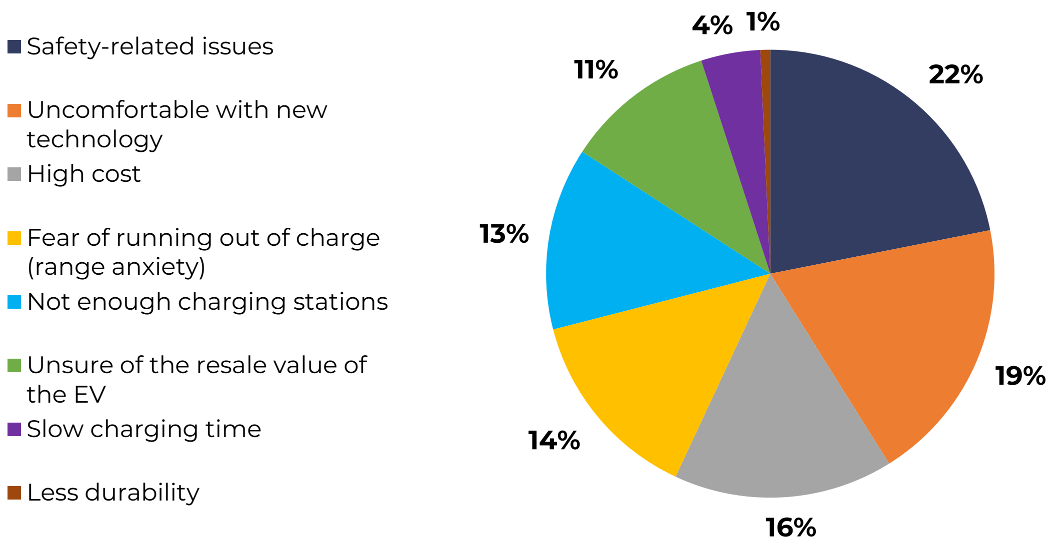
To encourage and compensate consumers against the relatively higher purchase cost of EVs, subsidies are provided under the FAME scheme. The awareness of the benefits provided under the scheme largely influenced respondents' preference towards EVs (Figure 34).

Figure 34: EV purchase preference based on FAME subsidy awareness



After understanding how preference for EVs changes with different socio-economic and travel characteristics, it is equally important to assess why some respondents did not opt for EVs. Analysis of responses indicated safety concerns about EVs, followed by discomfort trying a new technology and the higher upfront cost of EVs as the top reasons (Figure 35).

Figure 35: Top reasons for not opting for EVs



Part B: Insights from current EV owner (personal use) survey

More than 200 e-2W owners and 100 e-car owners in Bengaluru were randomly selected and interviewed. Their responses to various questions pertaining to travel and charging patterns are presented below.

More than 60% of e-2W owners were males (Figure 36) while 62% of e-car users were females (Figure 37). Further, e-2Ws were mostly owned by persons aged above 25 years (Figure 38) and e-cars by those aged above 35 years (Figure 39).

Figure 36: Gender break-up of e-2W owners

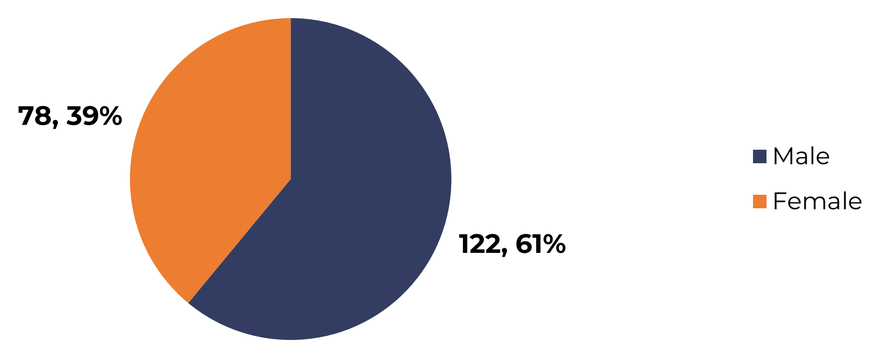


Figure 37: Gender break-up of e-car owners

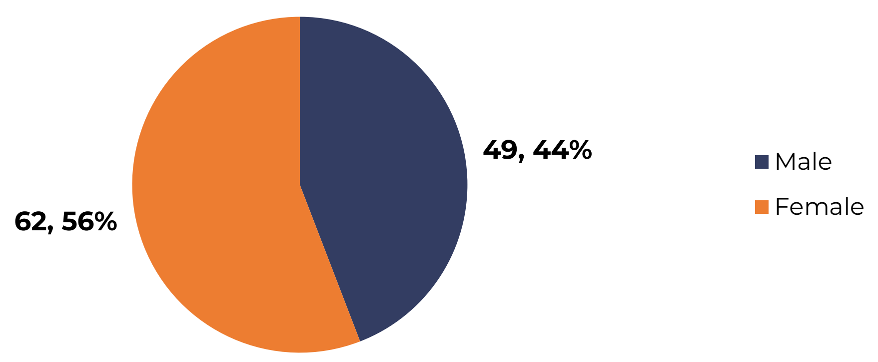


Figure 38: Age break-up of e-2W owners

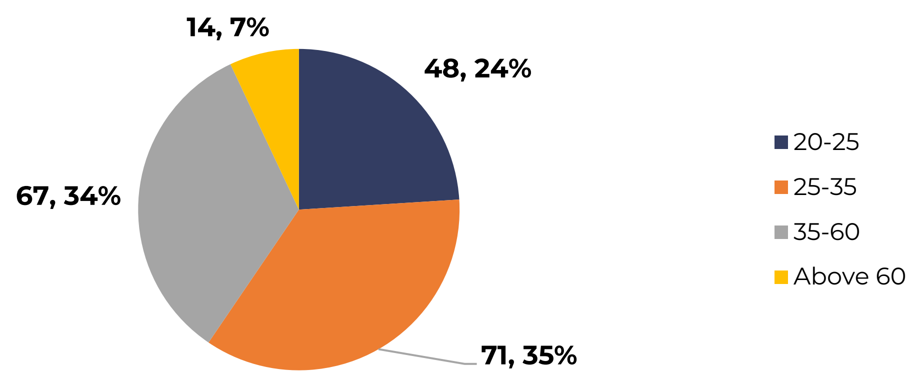
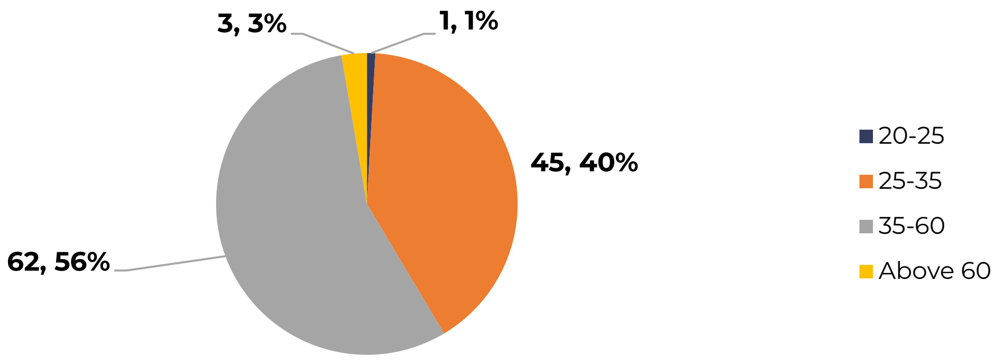


Figure 39: Age break-up of e-car owners



In terms of educational qualification of EV owners, graduates and postgraduates owned most EVs (Figure 40 and Figure 41).

Figure 40: Distribution of e-2W owners based on education

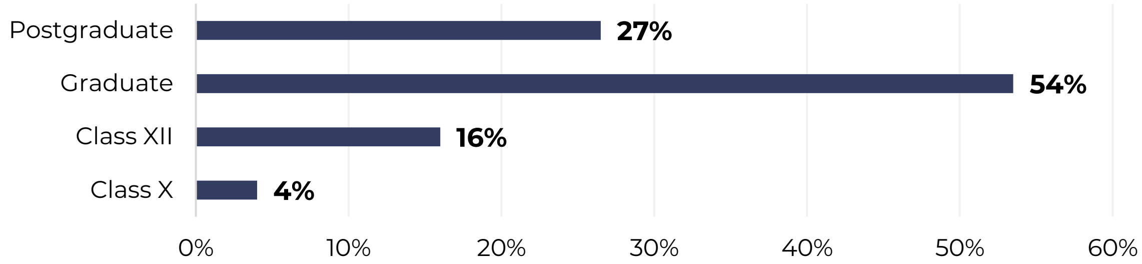
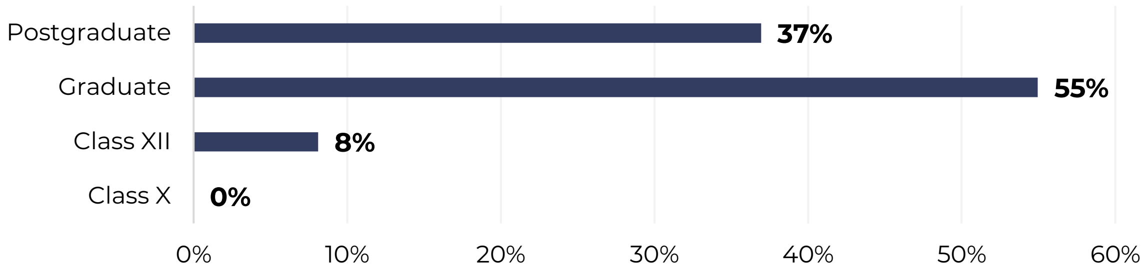


Figure 41: Distribution of e-car owners based on education



Further, e-2Ws were popular among private-sector employees and students (Figure 42), whereas e-cars were mostly used by private-sector employees and business owners (Figure 43).

Figure 42: Distribution of e-2W owners based on occupation

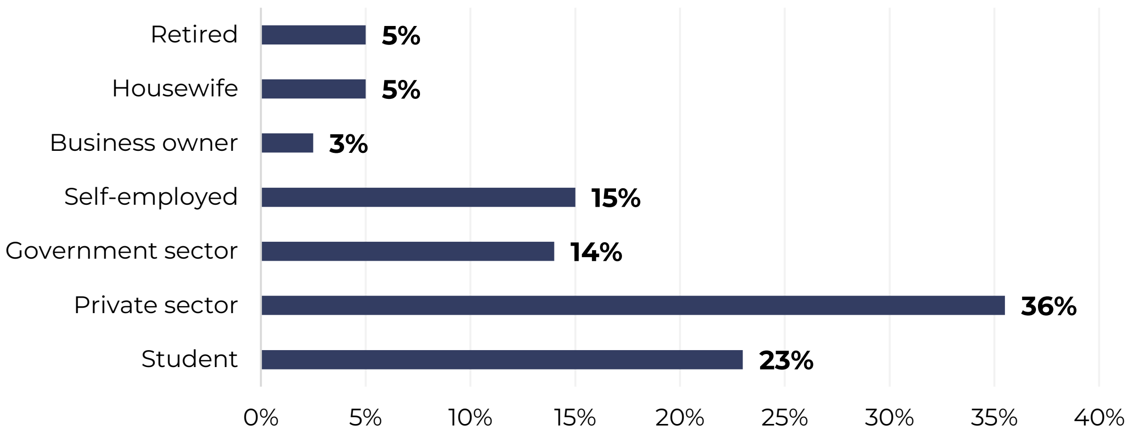
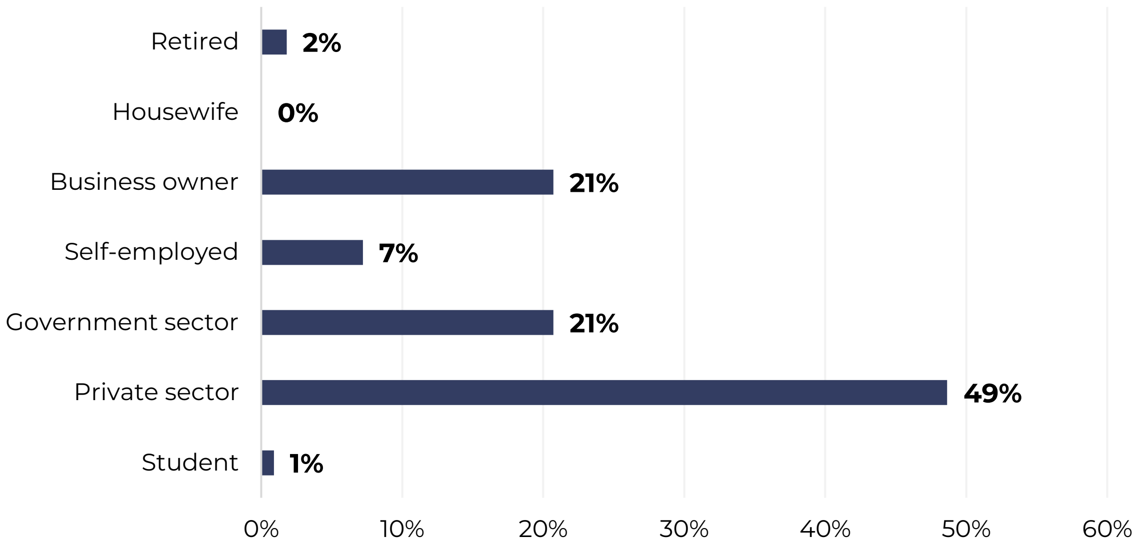


Figure 43: Distribution of e-car owners based on occupation



Income largely influences purchase decisions. Household monthly expenditure was captured as a proxy for income and EV ownership in low- to high-income households. E-2Ws were more popular in households with INR 40,000 or less monthly expenditure (Figure 44), while e-cars were more popular in households with INR 40,000 or more monthly expenditure (Figure 45).

Figure 44: Distribution of e-2W owners based on monthly expenditure

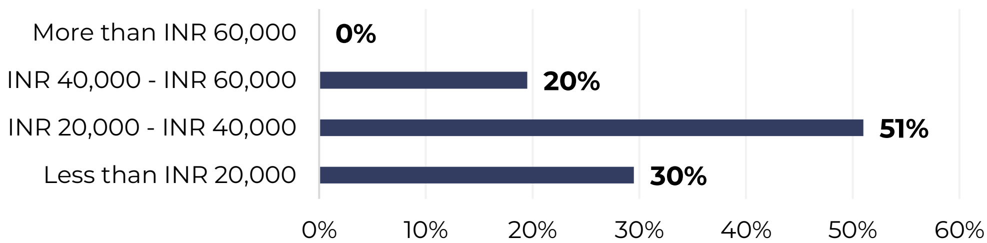
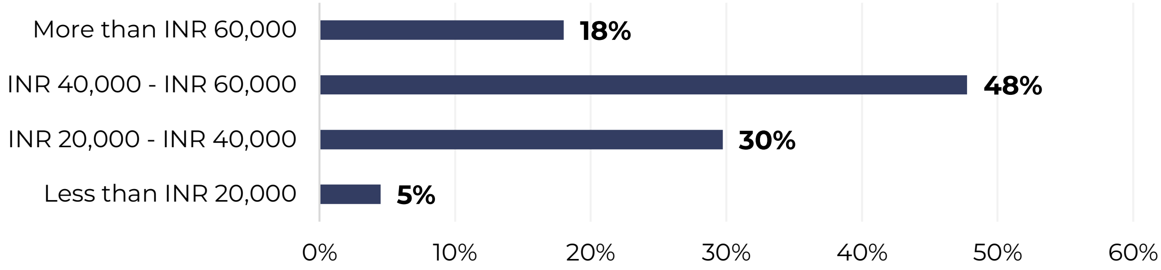


Figure 45: Distribution of e-car owners based on monthly expenditure



In terms of EVs being the individuals' first vehicle, 48% of e-2W owners mentioned that the EV was their first vehicle (Figure 46). However, only 21% of e-car owners mentioned that it was their first vehicle (Figure 47).

Figure 46: E-2W ownership variation with existing vehicle ownership

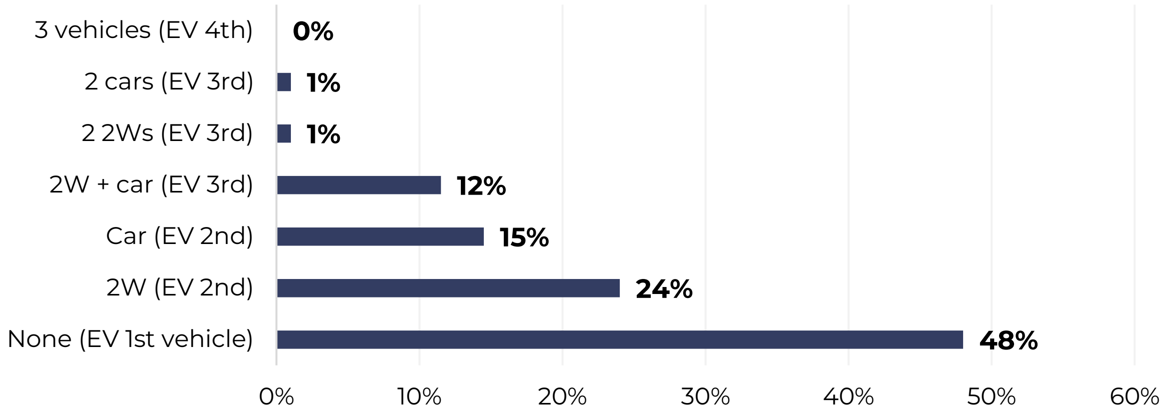
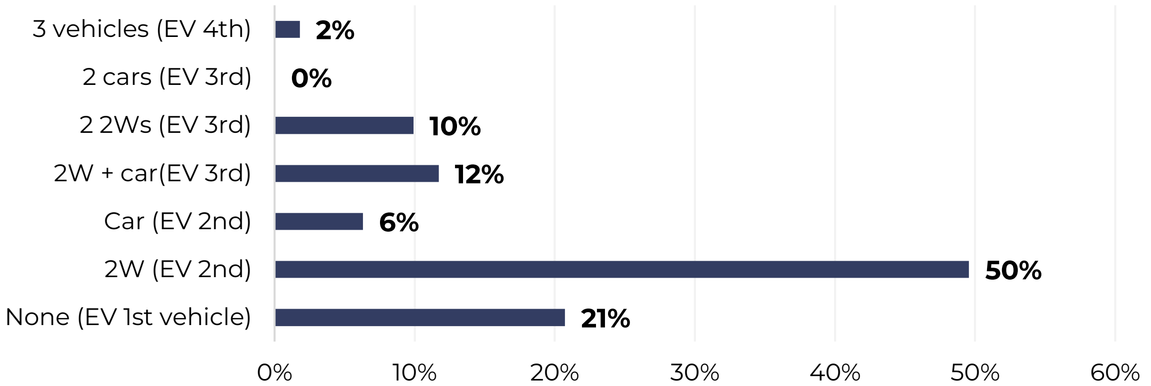


Figure 47: E-car ownership variation with existing vehicle ownership



Given the relatively higher purchase price of EVs than petrol/diesel vehicles, it is essential to capture how consumers financed their EV purchases; 41% of e-2W owners (Figure 48) and 51% of e-car owners (Figure 49) opted for bank loans while the rest purchased with outright cash payments.

Figure 48: E-2W financing patterns

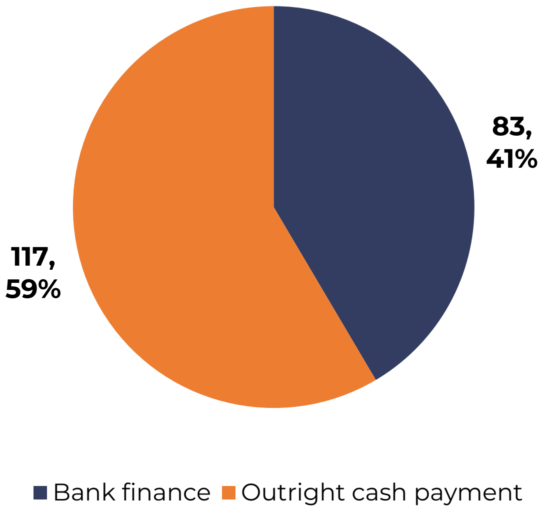
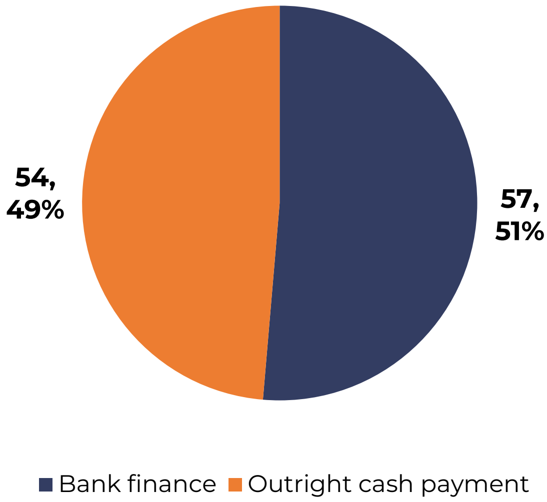


Figure 49: E-car financing patterns



Investigations into motivations for purchasing EVs were also carried out. Most users opted for EVs due to savings resulting from lower operating and maintenance costs and to try new technology. Both e-2W and e-car owners reported similar motivations (Figure 50 and Figure 51).

Figure 50: Motivations for purchasing e-2Ws

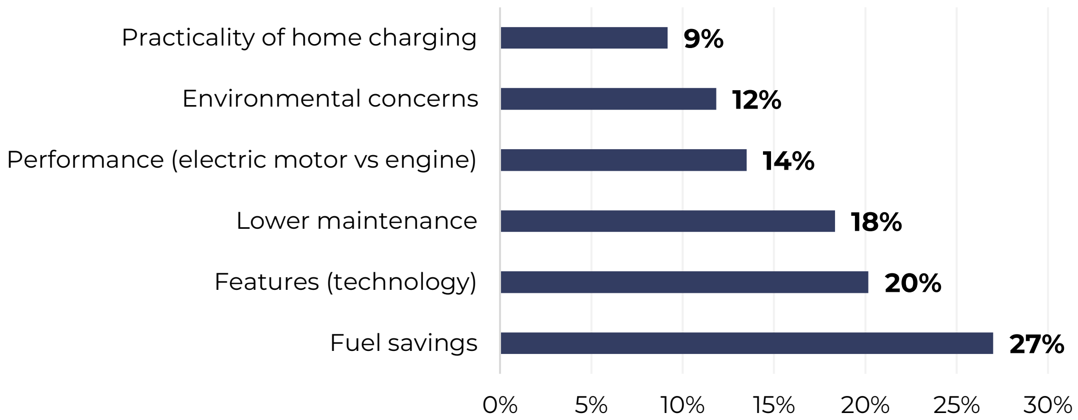
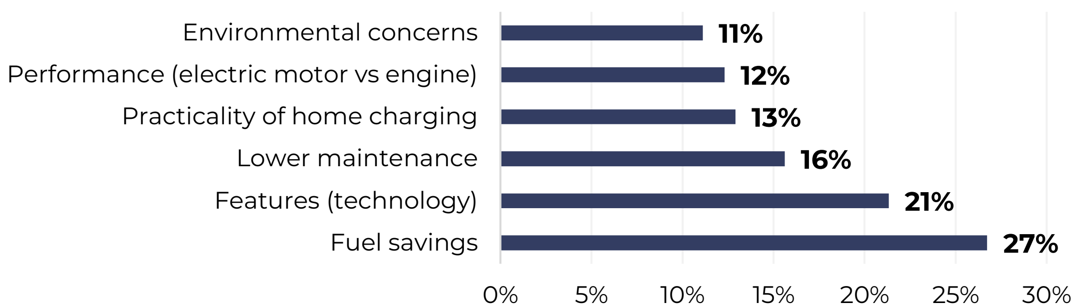


Figure 51: Motivations for purchasing e-cars



DVKT is a measure of the daily commute intensity of users. In the case of petrol/diesel vehicles, it is constrained by fuel tank size and the location of refuelling stations. Similarly, for EVs, it is governed by battery size and location of charging stations. Most e-2Ws travelled 50 km or less (Figure 52), whereas e-cars drove between 25 and 75 km in a day (Figure 53).

Figure 52: E-2W DVKT

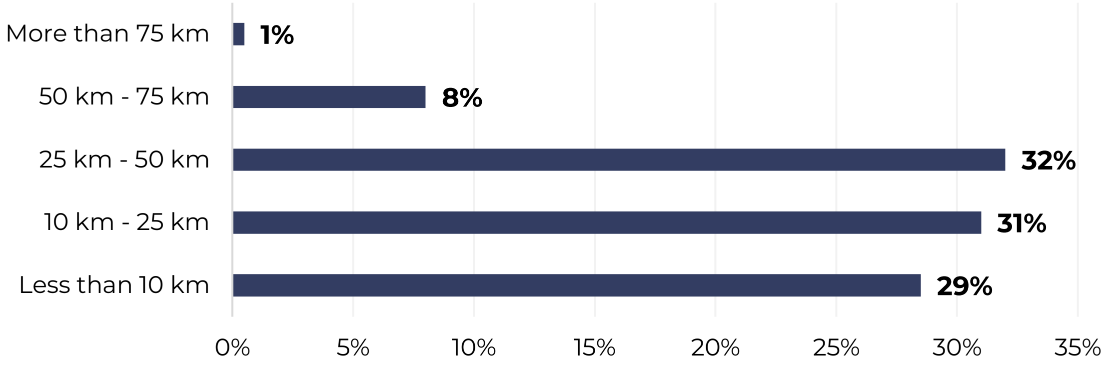
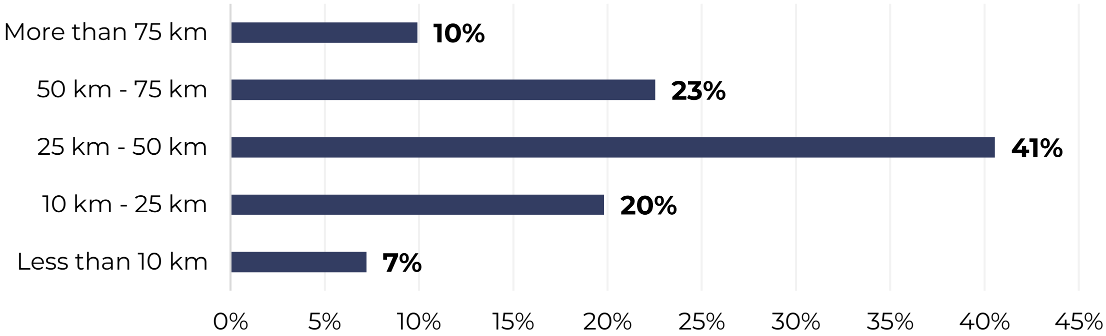


Figure 53: E-car DVKT



Further, EV users were enquired about their preferred location for charging. Both home and public charging were equally popular with e-2W owners (Figure 54). In the case of e-car owners, 54% reported charging mostly at home, followed by 41% using public charging facilities (Figure 55).

Figure 54: Charging location preference among e-2Ws (personal use)

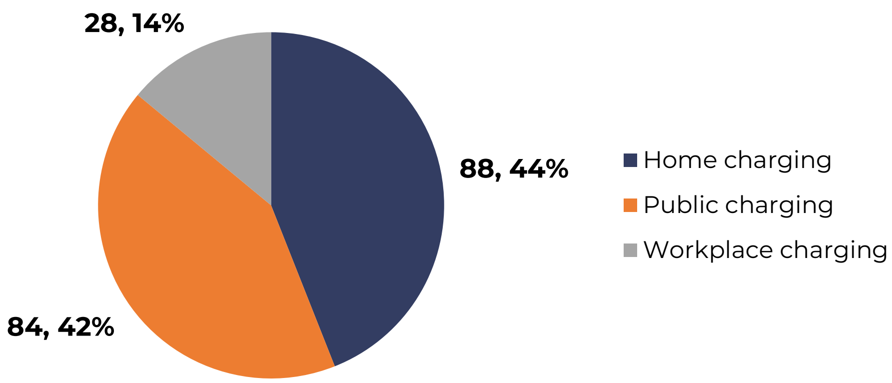
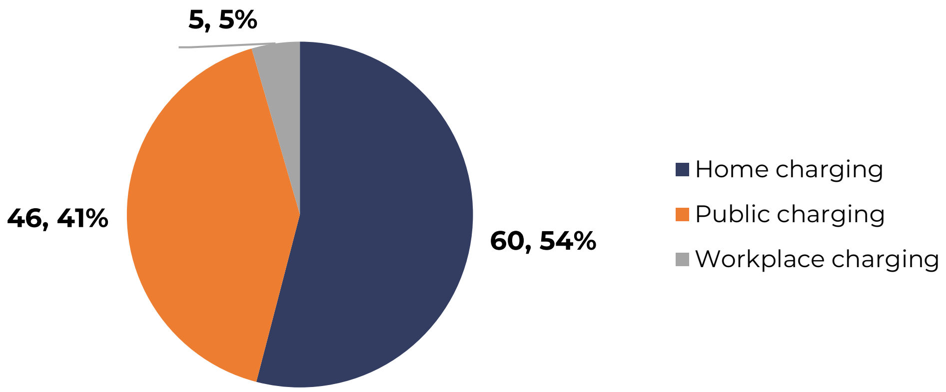


Figure 55: Charging location preference among e-cars (personal use)



In terms of frequency of charging, 54% of e-2Ws reported charging every day or on alternate days (Figure 56). Further, 60% of e-car users charged either once or twice a week (Figure 57).

Figure 56: Charging frequency among e-2Ws (personal use)

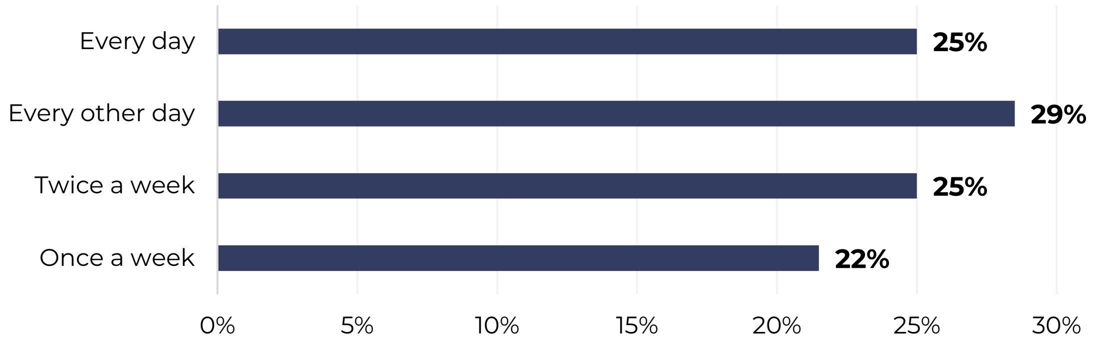
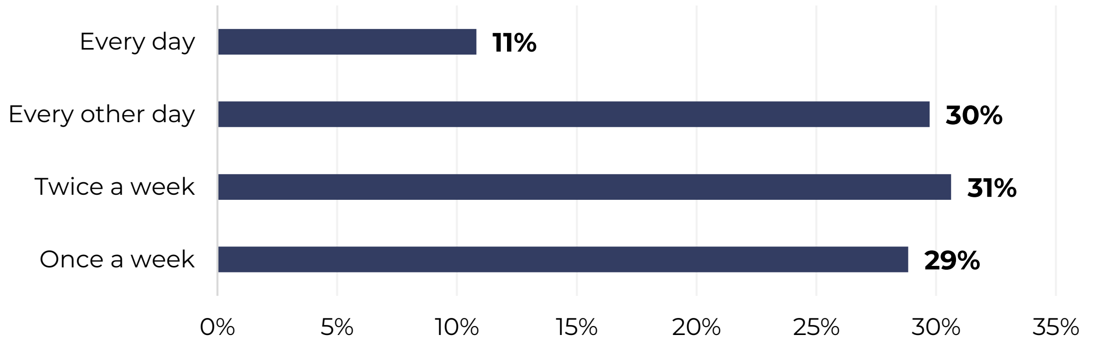


Figure 57: Charging frequency among e-cars (personal use)



The timing of EV charging largely depends on individuals' travel characteristics and the location of charging. Further, 44% of e-2W owners reported charging between 4 PM and 10 PM (Figure 58), and 51% of e-car owners charged overnight (10 PM to 8 AM, Figure 59).

Figure 58: Charging time preference among e-2Ws (personal use)

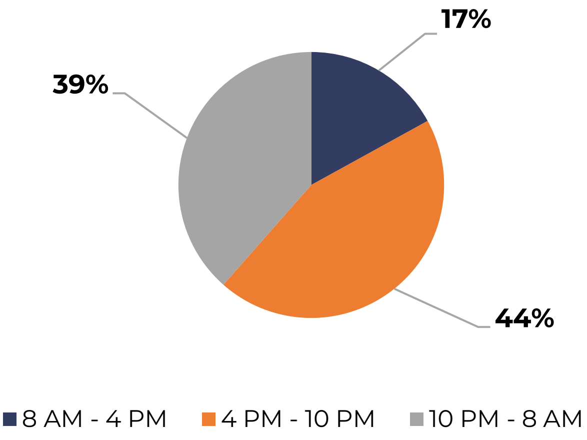
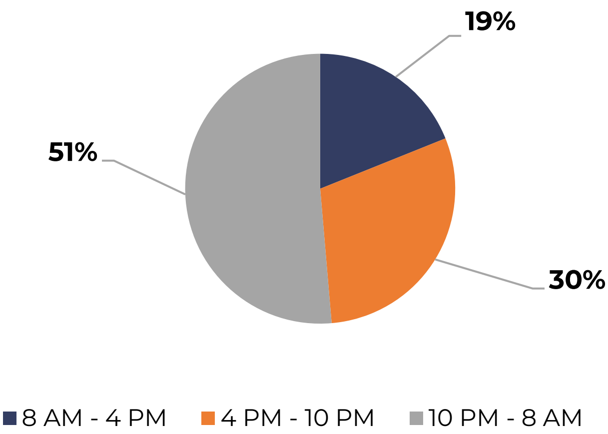


Figure 59: Charging time preference among e-cars (personal use)



Fast charging offers the convenience and opportunity to EV users to charge their EVs in a relatively short duration. In this study, 57% of e-2Ws and 58% of e-cars surveyed were compatible with fast charging (Table 14). Further, 53% of these e-2W owners reported fast charging once a month (Figure 60), with the proportion being 30% for e-car users (

Figure 61).

Table 14: Compatibility of vehicles with fast charging as per the survey

Vehicle segment	Compatibility with fast charging
2W	57%
4W	58%

Figure 60: Fast charging frequency of e-2Ws (personal use)

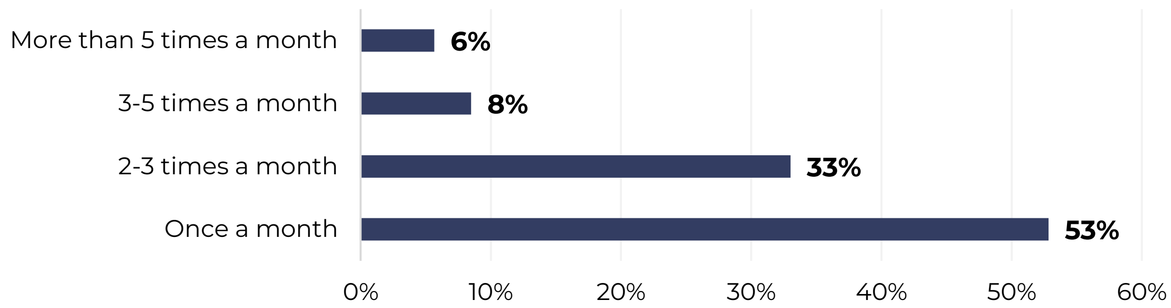
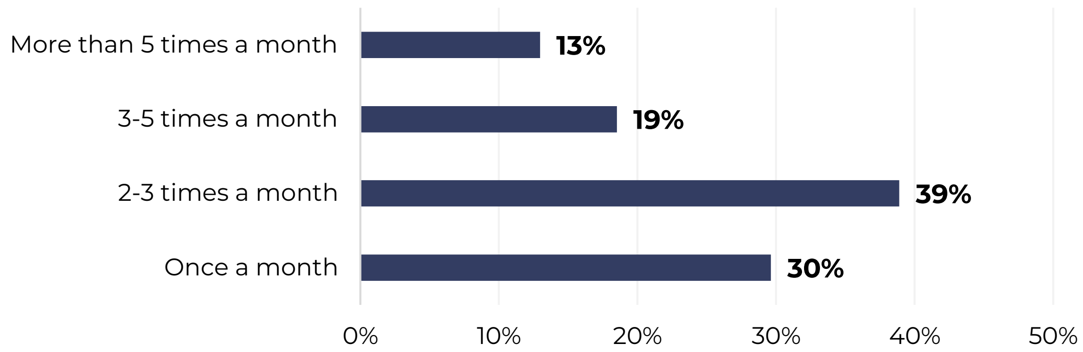


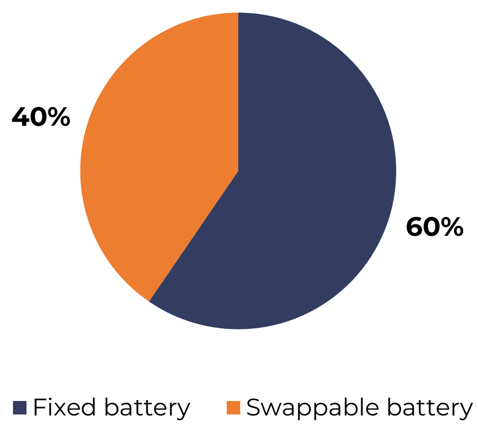
Figure 61: Fast charging frequency of e-cars (personal use)



Part C: Insights from current EV owner (commercial use) survey

Travel characteristics largely vary between personal and commercial EV users. In this study, 50 e-2Ws, 39 e-3Ws, and 47 e-cars used for commercial purposes were randomly selected and their owners/drivers were interviewed. About 40% of these EVs were compatible with battery swapping (Figure 62).

Figure 62: Commercial use EV type (fixed and swappable battery)



Unlike personal-use EV owners, commercial users are likely to choose between owning, renting, and leasing. Responses collected indicated that only in the case of e-2Ws, substantial ownership (32%) was noticed (Figure 63) and the same was miniscule for e-3Ws and e-cars (Figure 64 and Figure 65). Also, more than 70% of the interviewed e-3W and e-car users were drivers/operators, i.e. employees of a company.

Figure 63: Ownership patterns of e-2Ws (commercial use)

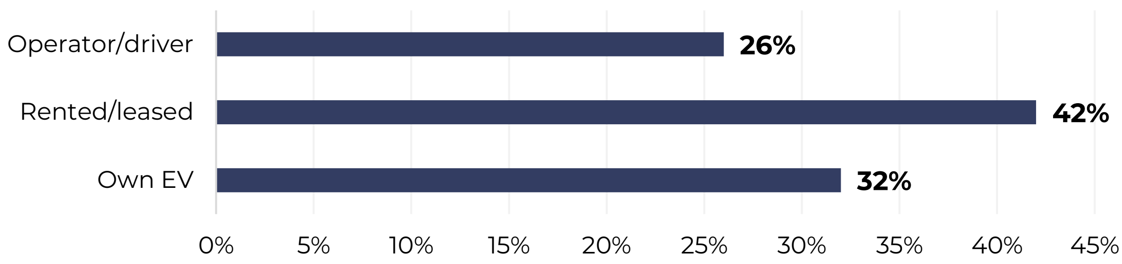


Figure 64: Ownership patterns of e-3Ws (commercial use)

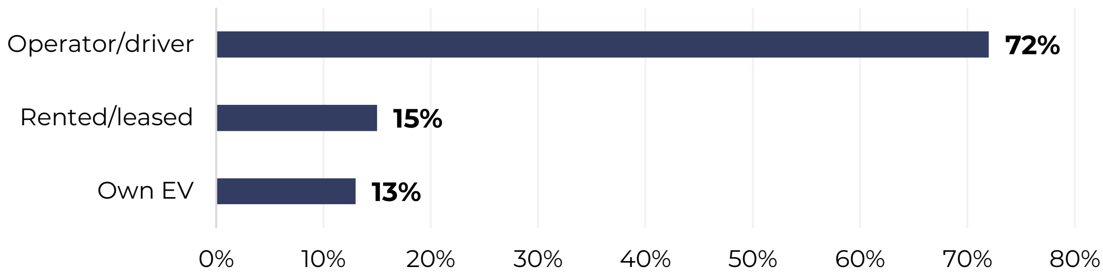
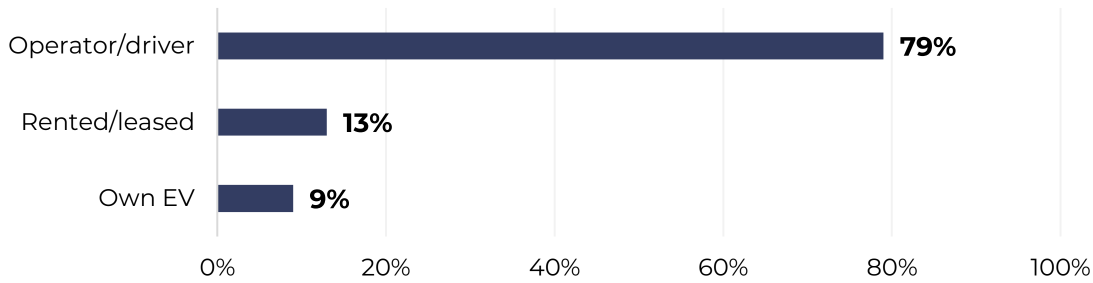


Figure 65: Ownership patterns of e-cars (commercial use)



Enquiries on methods of financing revealed that 69% of e-2W owners self-financed their purchases (Figure 66). Further, 60% of e-3Ws were purchased using bank loans (Figure 67), and 50% of e-cars were purchased with assistance from private financiers (Figure 68).

Figure 66: Financing of e-2Ws (commercial use)

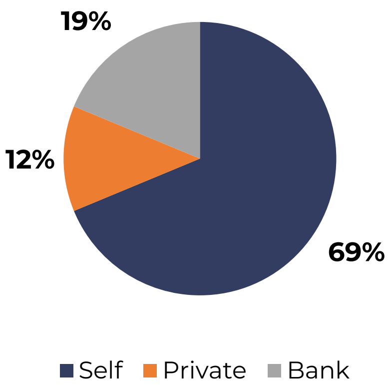


Figure 67: Financing of e-3Ws (commercial use)

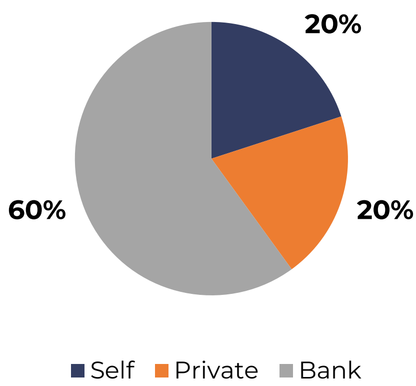
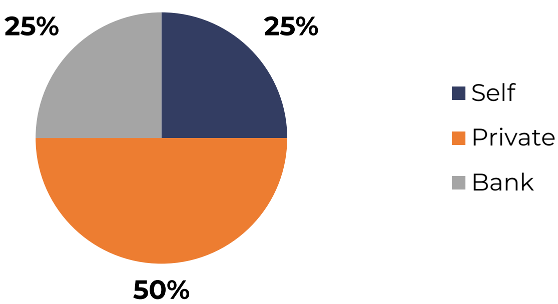


Figure 68: Financing of e-cars (commercial use)



Commercial-use EV owners listed lower operating and running costs and the eco-friendly nature of EVs as the main motivations for using EVs over conventional vehicles (Figure 69, Figure 70, and Figure 71).

Figure 69: Motivations for buying/using e-2Ws for commercial purposes

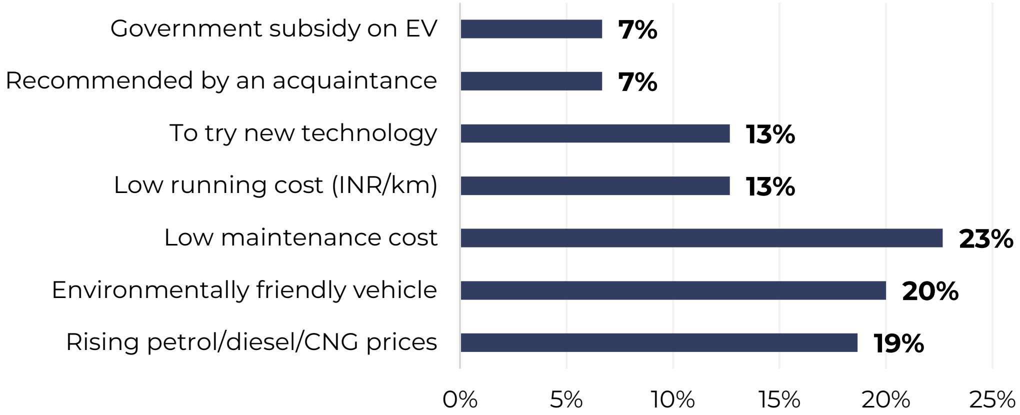


Figure 70: Motivations for buying/using e-3Ws for commercial purposes

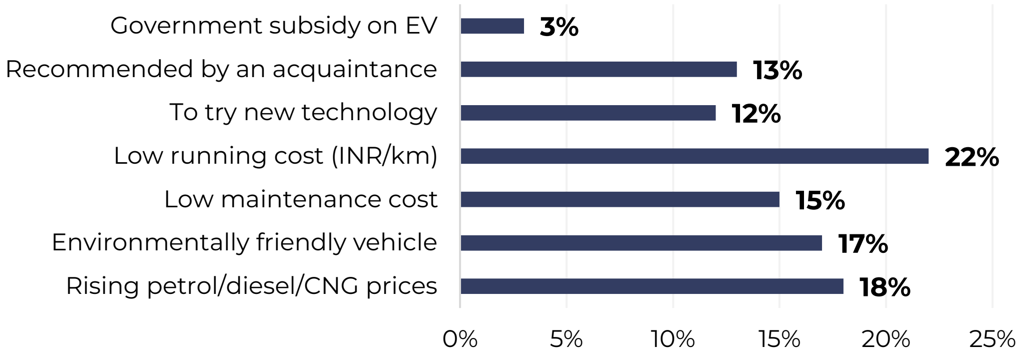
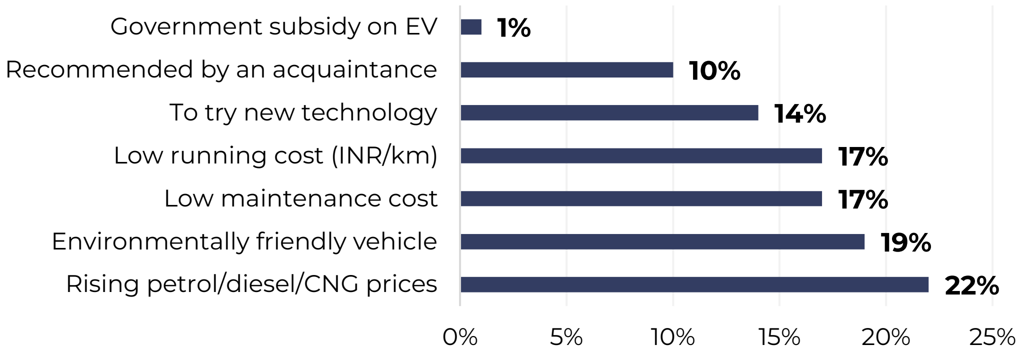


Figure 71: Motivations for buying/using e-cars for commercial purposes



The intensity of everyday EV usage (DVKT) varies among e-2Ws, e-3Ws, and e-cars. Further, 90% of e-2Ws travelled 90 km or less in a day (Figure 72), 87% of e-3Ws travelled between 50 and 120 km a day (Figure 73), and 81% e-cars travelled more than 70 km a day (Figure 74).

Figure 72: DVKT by e-2Ws (commercial use)

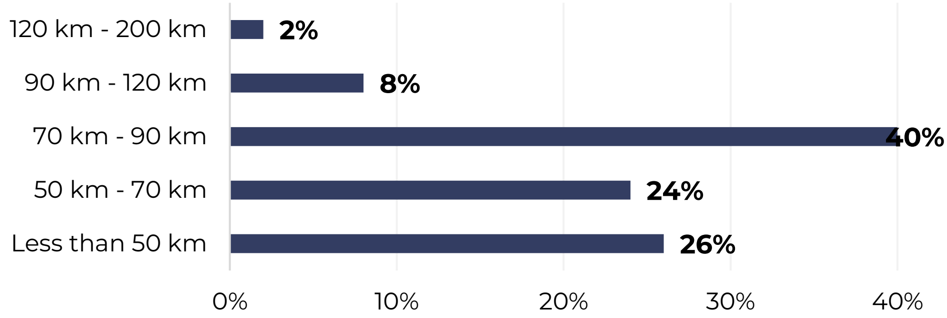


Figure 73: DVKT by e-3Ws (commercial use)

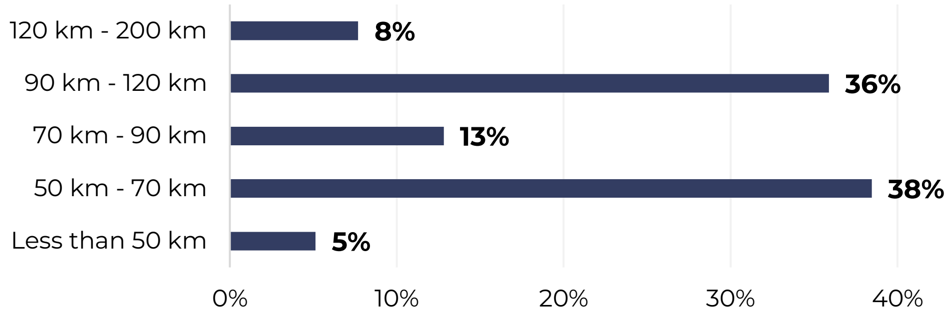
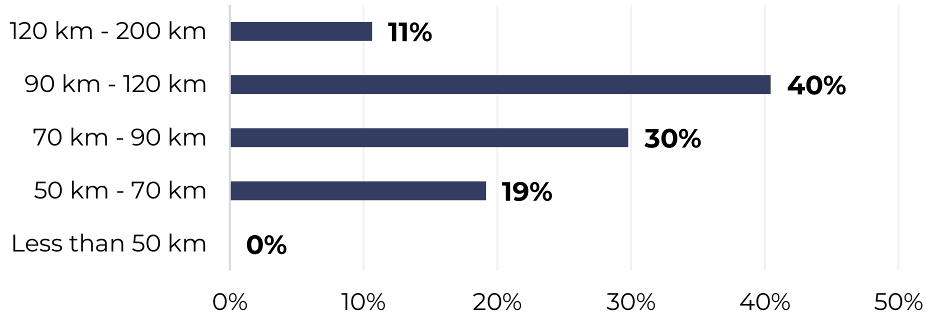


Figure 74: DVKT by e-cars (commercial use)



The choice of charging location of commercial-use e-2W, e-3W, and e-cars is presented below. Most e-3W and e-car users reported charging or swapping batteries at exclusive charging stations set up by their respective companies (with whom they work, Figure 76 and Figure 77). In the case of e-2Ws, both public and company charging stations were popular (Figure 75).

Figure 75: Charging location preference among e-2Ws (commercial use)

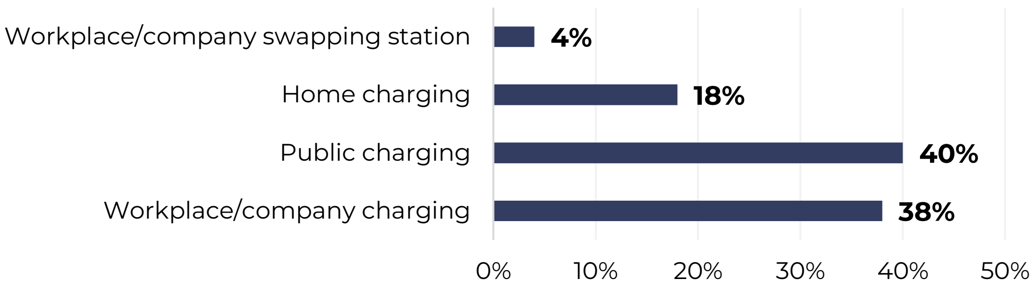


Figure 76: Charging location preference among e-3Ws (commercial use)

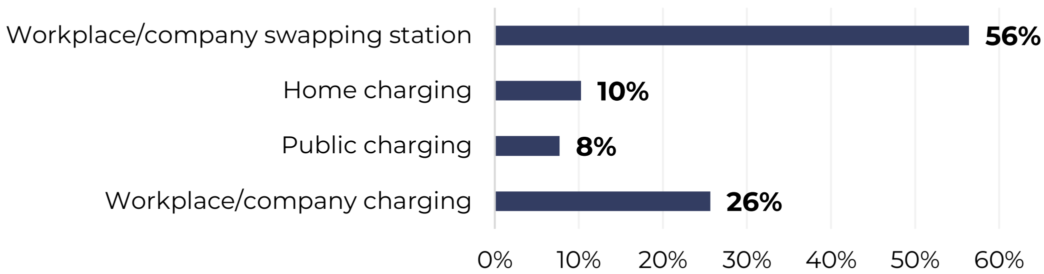
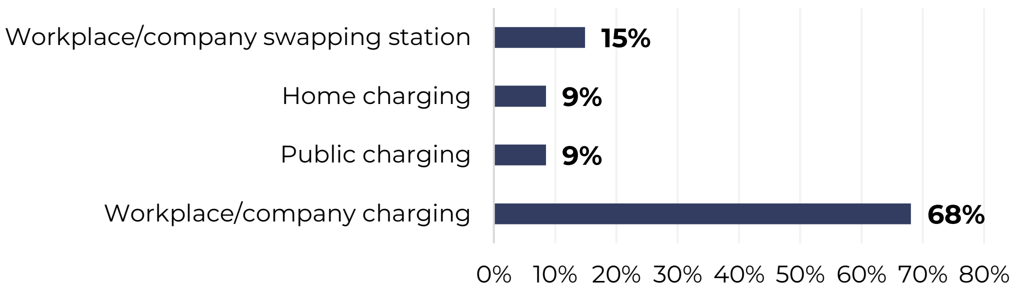


Figure 77: Charging location preference among e-cars (commercial use)



Consistent with their higher travel per day (DVKT), commercial-use EVs, unlike personal-use EVs, charge more frequently. This was observed across e-2Ws, e-3Ws, and e-cars (Figure 78, Figure 79, and Figure 80).

Figure 78: Frequency of charging e-2Ws (commercial use)

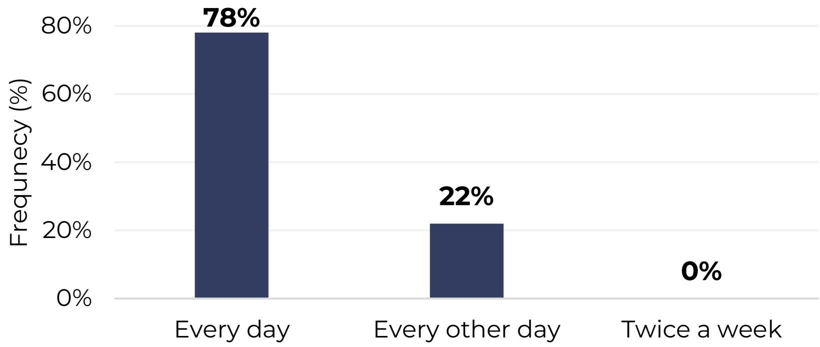


Figure 79: Frequency of charging e-3Ws (commercial use)

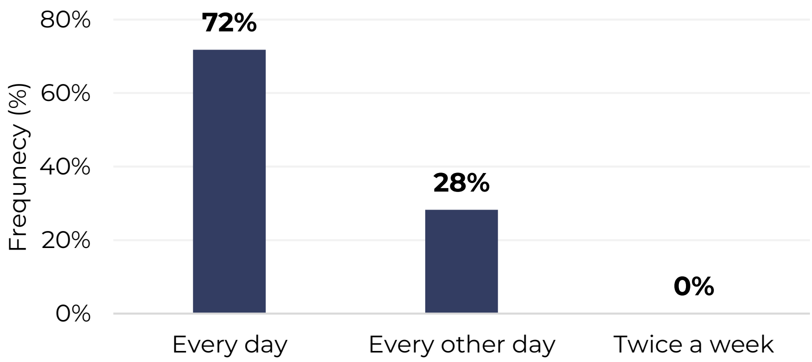
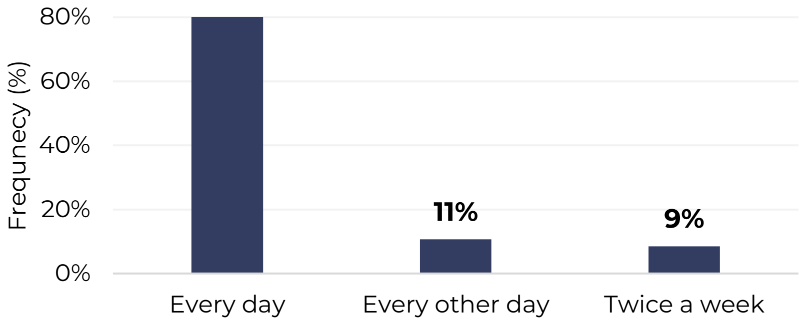


Figure 80: Frequency of charging e-cars (commercial use)



Further, investigations into the timing of charging revealed that most commercial-use EVs are charged overnight, primarily to avoid or minimise downtime during business hours (Figure 81, Figure 82, and Figure 83).

Figure 81: Charging timing preference among e-2Ws (commercial use)

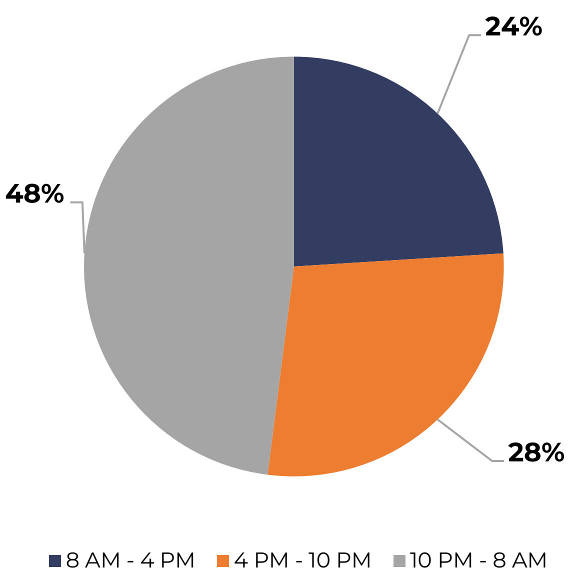


Figure 82: Charging timing preference among e-3Ws (commercial use)

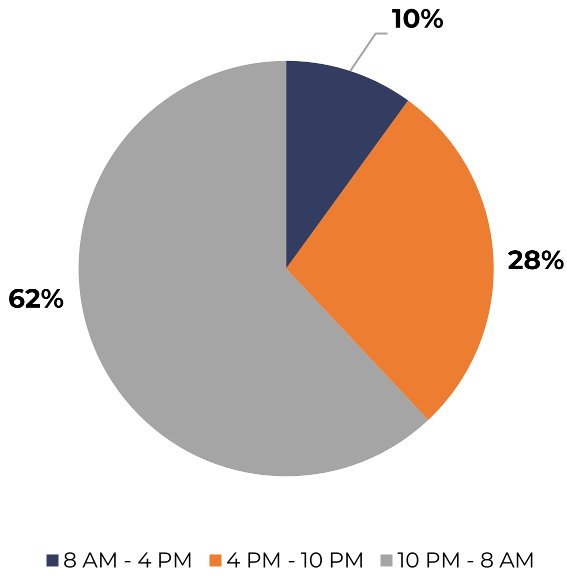
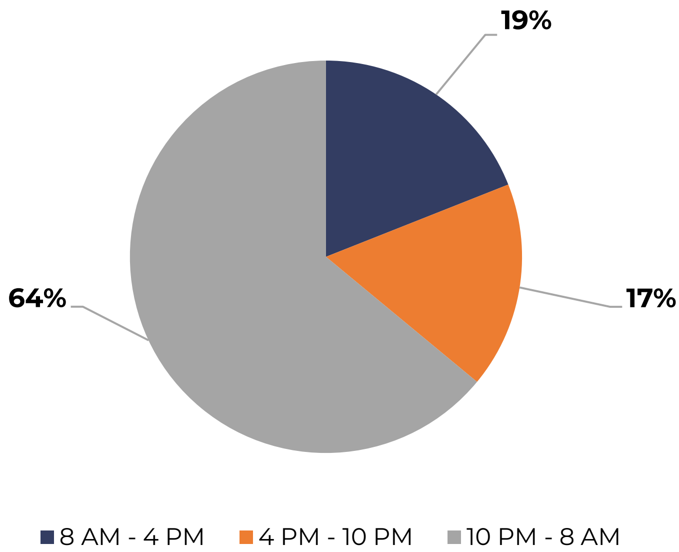


Figure 83: Charging timing preference among e-cars (commercial use)



Appendix 2: EV Charging Infrastructure Demand Assessment - Inputs, Assumptions, and Estimates

The details of the approach (Figure 1) adopted for estimating demand for EV charger guns and their impact on the grid are described in this section.

The steps for analysing charging infrastructure demand and determination of the load profile are as follows:

Step 1: Determination of the daily distribution of EVs for charging

The number of EVs of a particular vehicle segment charged on each day was computed. Subsequently, based on the survey results (Table 4), the distribution of vehicles that were charged across three time slots (8 AM to 4 PM [time slot 1], 4 PM to 10 PM [time slot 2], and 10 PM to 8 AM [time slot 3]) was determined.

The following inputs, obtained through the surveys, were employed:

- Frequencies (%) of slow and fast charging of EVs (e-2Ws and e-4Ws)
- Share of EVs compatible with fast charging mechanism (%)
- Preference for slow charging/fast charging of a particular EV segment at different time slots (%)

Let the total vehicle stock of a particular vehicle segment in the given year be ‘v’. The following are the remaining notations:

- Share of vehicles (%) preferred to be slow charged everyday = a
- Share of vehicles (%) preferred to be slow charged every other day = b
- Share of vehicles (%) preferred to be slow charged twice a week = c
- Share of vehicles (%) preferred to be slow charged once a week = d
- Share of vehicles (%) preferred to be slow charged in time slot 1= t1
- Share of vehicles (%) preferred to be fast charged once a month = p
- Share of vehicles (%) preferred to be fast charged 2–3 times a month = q
- Share of vehicles (%) preferred to be fast charged 3–5 times a month = r
- Share of vehicles (%) preferred to be fast charged more than 5 times a month = s
- Share of vehicles (%) preferred to be fast charged in time slot 1 = w
- Share of vehicles (%) compatible with fast charging mechanism = f

On the first day of the month, it was assumed that only those vehicles belonging to category ‘a’ would be charged. Further, vehicles belonging to category ‘b’ would be charged on every 2nd day, i.e. day 2, 4, 6, etc., those belonging to category ‘c’ on the 3rd and 6th day of the week, and those belonging to category ‘d’ on the 7th day of the week[6].

[6] This study acknowledges that numerous charging patterns are possible for category ‘b’, ‘c’, and ‘d’; however, the study considered only the stated case for the analysis.

The number of vehicles preferred to be slow charged on days 1, 2, and 3 in time slot 1 was calculated as follows:

$$Number\ of\ EVs\ slow\ charged\ on\ day\ 1 = a * t1 * v$$

$$Number\ of\ EVs\ slow\ charged\ on\ day\ 2 = (a + b) * t1 * v$$

$$Number\ of\ EVs\ slow\ charged\ on\ day\ 3 = (a + c) * t1 * v$$

A similar computation was performed for all time slots for all 30 days of the month. The same procedure was adopted for other vehicle segments also.

The survey results revealed that EV users preferred to fast charge their EVs at four different frequencies: once a month (p%), 2–3 times a month (q%), 3–5 times a month (r%), and more than 5 times a month (s%). Considering that q% of vehicles charge 3 times a month, r% of vehicles 4 times a month, and s% of vehicles 6 times a month, their charging is considered to take place on every 10th day, 7th day, and 5th day of the month, respectively.[7] However, taking into account real-life practices and diverse stakeholder views, the number of vehicles that are fast charged was evenly distributed across the days of the month. Hence, the number of vehicles fast charged in time slot 1 on any given day was calculated as follows:

$$Number\ of\ vehicles\ fast\ charged\ on\ a\ day = \left(\frac{p}{30} + \frac{q}{10} + \frac{r}{7} + \frac{s}{5}\right) * w * f * v$$

Similarly, the exercise was repeated for all other days of the week, considering suitable combinations of slow charging frequency and constant number of fast-charged vehicles. This exercise resulted in the computation of the number of vehicles that were slow and fast charged in each time slot of the 30 days of the month.

Step 2: Determination of the hourly distribution of EVs for charging

The slot-wise distribution of the number of EVs to be charged served as the basis for the calculation of the hourly distribution of the vehicles for charging. The main inputs for this computation are as follows:

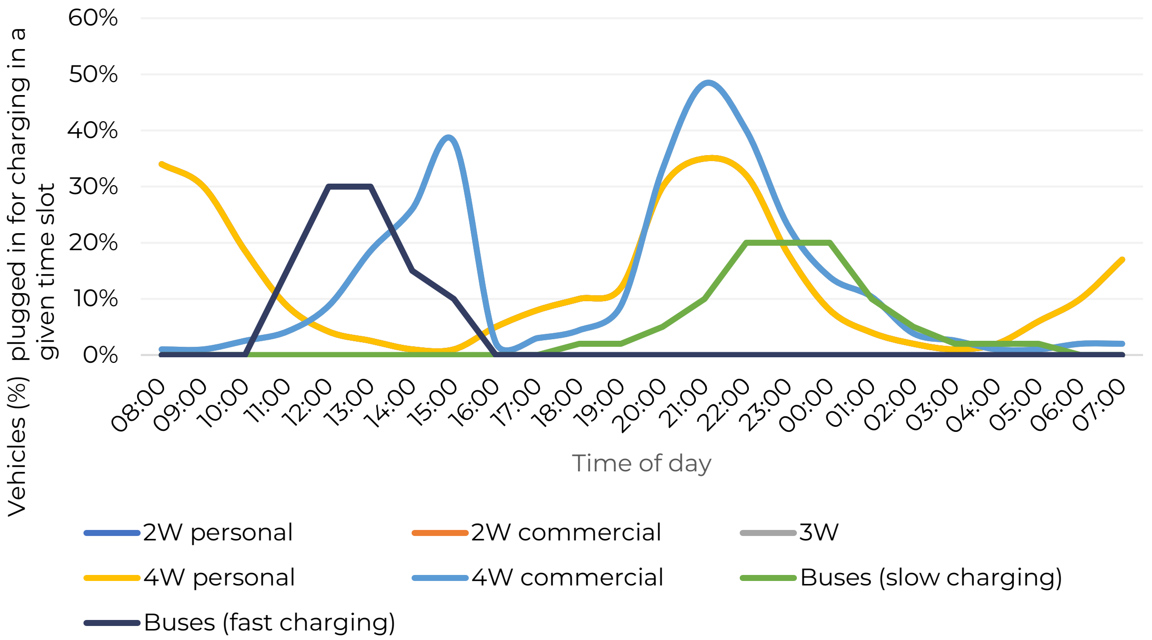
- The preference for slow and fast charging in different time slots from the survey
- The time required to charge each vehicle segment for both slow and fast charging mechanisms

The objective of the analysis is to determine the hourly distribution of the number of EVs being charged. Charging patterns captured through surveys (Table 3, Table 4, and Table 5), typical working hours of offices/establishments, and the daily routine of vehicle owners formed the key inputs for the analysis. Inspiration was also drawn from municipal water demand curve to ascertain the skewness of hourly demand for EV charging (NPTEL, n.d.). An appropriately skewed temporal distribution was considered for EVs being plugged in every hour of a day, instead of considering a uniform distribution. Accordingly, the percentages of their hourly distribution (Figure 84) were considered[8] for computing the number of vehicles. The analysis revealed that the majority of EVs were plugged in between 7 PM and 12 AM.

[7] This study acknowledges that numerous charging patterns are possible for category 'p', 'q', 'r', and 's'; however, the study considered only the stated case for the analysis.

[8] This study acknowledges the possibility of other hourly distribution(s) of vehicles plugging in for charging; however, for simplicity in analysis and ease of understanding the study considered only one distribution, which is more realistic.

Figure 84: Hourly distribution of EVs plugging in for charging throughout a day



In continuation with step 1, let the total number of vehicles slow charged on any day and in time slot k be z(k). Let the number of hours in the time slot k be l. Consider the percentage of vehicles being newly plugged in for charging in a random hour i of slot k as o(i) and the total charging time of the vehicle (Table 7) as t.

Hence,

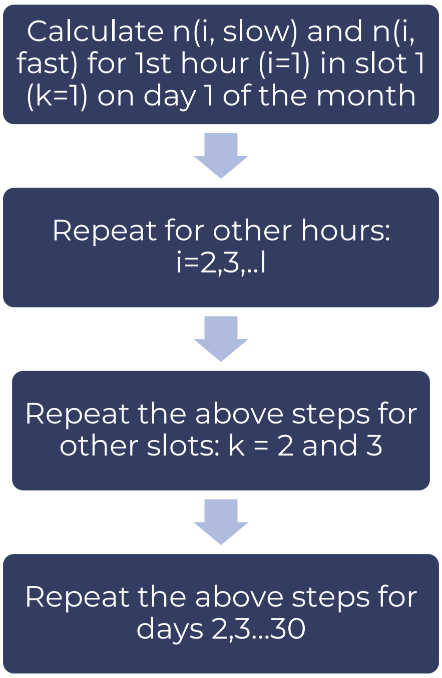
$$Number\ of\ EVs\ newly\ plugged\ in\ for\ charging\ in\ hour\ i = o(i) * z(k)$$

Depending on the charging time t, the number of vehicles that are to be plugged out from charging in hour i was determined. Hence, the number of vehicles that remain effectively plugged in for charging in hour i, n(i), was calculated as follows:

$n(i) = \sum_{i-t}^{i-1} o(i) * z\,(k)$ (1)

Let the number of vehicles being slow charged and fast charged effectively in hour i be n(i, slow) and n(i, fast), respectively.

Thereafter, the following calculations were performed:



This gives the intended outcome of the number of vehicles being effectively charged through slow or fast charging in any hour on any day of the month. Let the number of vehicles being slow charged in any hour be n(i, slow), where i can have 30 * 24 = 720 possible values. The maximum value of n(i, slow) yields the number of SC guns to be installed in the geographical area of concern. Number of FC guns were estimated with the criteria to meet **minimum of 80% of daily demand**.

Step 3: Estimation of hourly power load due to EV charging

The hourly distribution of the number of vehicles provided the backbone for the computation of the power demand on the grid due to EV charging. The vehicles were assumed to charge from an SOC of 20% to 80%, during which, the power input drawn from the grid was presumed to be constant at the rated value of the charger gun.

For each ith hour,

- Number of vehicles in a vehicle segment plugged in effectively for slow charging (as per Equation [1] of step 2) = n(i, slow)
- Power rating of an SC gun = p1
- Number of vehicles in a vehicle segment plugged in effectively for fast charging (as per Equation [1] of step 2) = n(i, fast)
- Power rating of an FC gun = p2

Input power drawn from the grid for EV charging through hour i was calculated as follows:

$$P(i) = (n(i, slow) * p1) + (n(i, fast) * p2)$$

This was repeated for all 24 hours of the day and all 30 days of the month. Using the power demand on the grid for each hour of the day, the hourly load profile was plotted for each vehicle segment. Subsequently, the monthly maximum, average, and minimum power demand for each hour were also determined to develop the associated load profiles. The load profiles of different vehicle segments were added to compute the gross monthly maximum, average, and minimum power demand on the grid due to EV charging (Figure

85, Figure 86, Figure 87, Figure 88, Figure 89, and Figure 90). Moreover, RTO-specific EV load curves were developed taking into account the EV stock in the respective zones (Figure 91).

An example calculation is performed here. The total number of e-2Ws (personal use) in Bengaluru by 2030 is estimated to be 20,24,000; of this, 11,13,143 are considered as personal-use vehicles. As per the survey results, 25% of the respondents prefer to slow charge everyday (Figure 56), and 17% prefer slow charging in time slot 1 (Figure 58). Hence, the number of personal e-2Ws slow charged in time slot 1 on day 1 is:

$$11{,}13{,}143 * 0.25 * 0.17 = 47{,}309$$

Further, the share of people who fast charge once a month is 53%; 2–3 times a month is 33%; 3–5 times a month is 8%; and more than 5 times month is 6% (Figure 60). Further, 17% prefer fast charging in time slot 1, and 57% of the vehicles are compatible with fast charging mechanism (Table 15). Hence, as per step 1, the number of personal e-2Ws fast charged in time slot 1 on any day of the month is:

$$11{,}13{,}143 * \left(\left(\frac{0.53}{30}\right) + \left(\frac{0.33}{10}\right) + \left(\frac{0.08}{7}\right) + \left(\frac{0.06}{5}\right)\right) * 0.17 * 0.57 = 7{,}993$$

As per the hourly distribution of EVs plugged in throughout the day (Figure 90), the number of e-2Ws newly plugged in at 10 AM for slow charging are as follows:

$$0.18533 * \ 47{,}309 = 8{,}768$$

Similarly, the number of e-2Ws newly plugged in at 8 AM and 9 AM were computed. The effective number of vehicles charging at 10 AM includes those newly plugged in at 9 AM and 10 AM because vehicles plugged in at 8 AM would be plugged out by then (as mentioned in Table 6, slow charging time for e-2Ws is 2 hr). Hence, the total number of vehicles effectively charging/plugged-in at 10 AM, as per step 2, are as follows:

$$14{,}193 + 8{,}768 = 22{,}961$$

The number of vehicles being effectively fast charged at 10 AM were also computed, with the number being 1,482.

The power demand at 10 AM was calculated as per step 3 in the following manner (p1 and p2 values are as mentioned in Table 6):

$$(22{,}961 * 0.78) + (1{,}482 * 3.3) = \ 22{,}800.18 \text{ kW}$$

Figure 85: Minimum power demand due to charging of different EV segments in Bengaluru in 2023

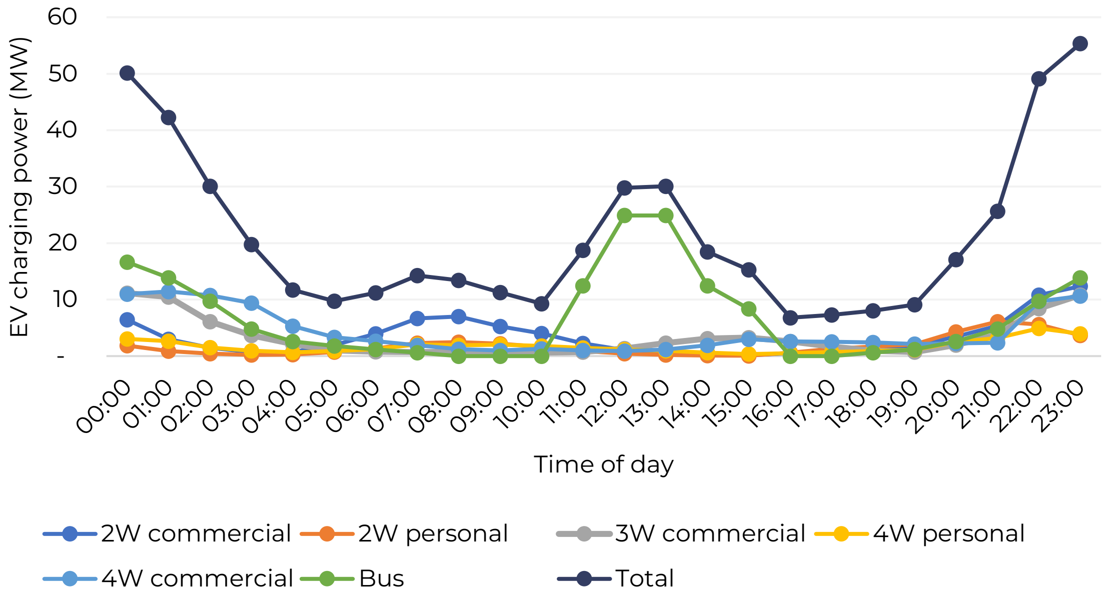


Figure 86: Average power demand due to charging of different EV segments in Bengaluru in 2023

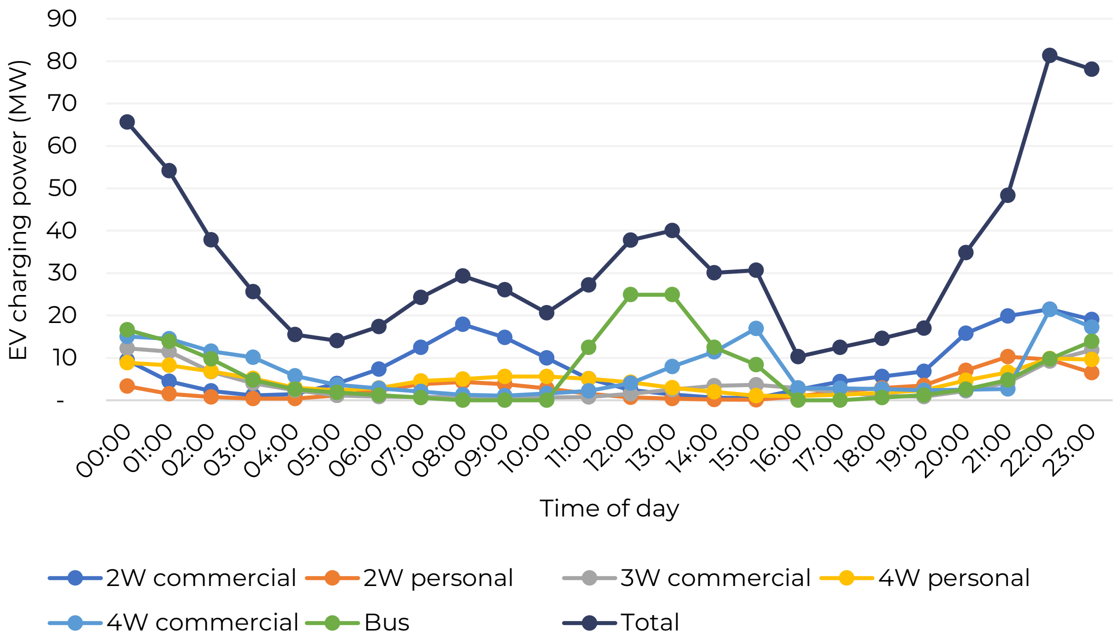


Figure 87: Maximum power demand due to charging of different EV segments in Bengaluru in 2023

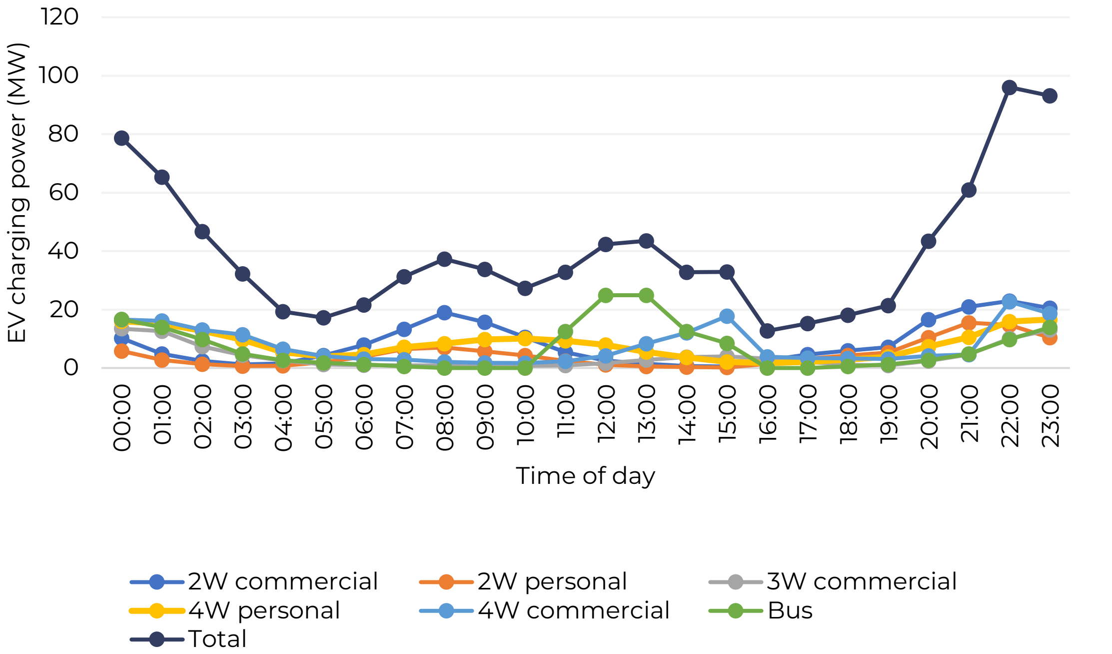


Figure 88: Minimum power demand due to charging of different EV segments in Bengaluru in 2030

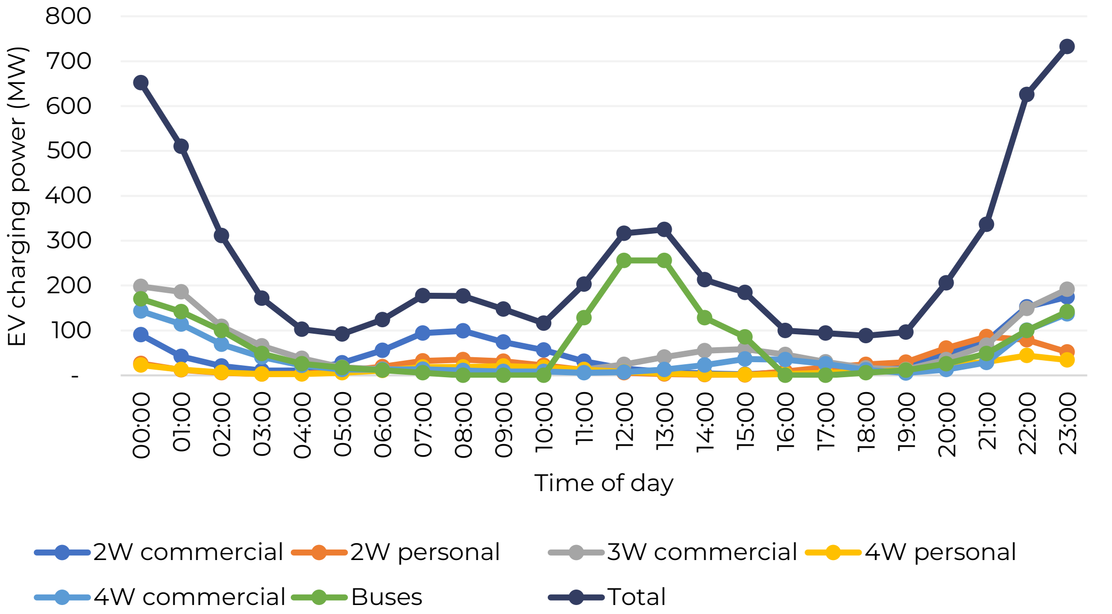


Figure 89: Average power demand due to charging of different EV segments in Bengaluru in 2030

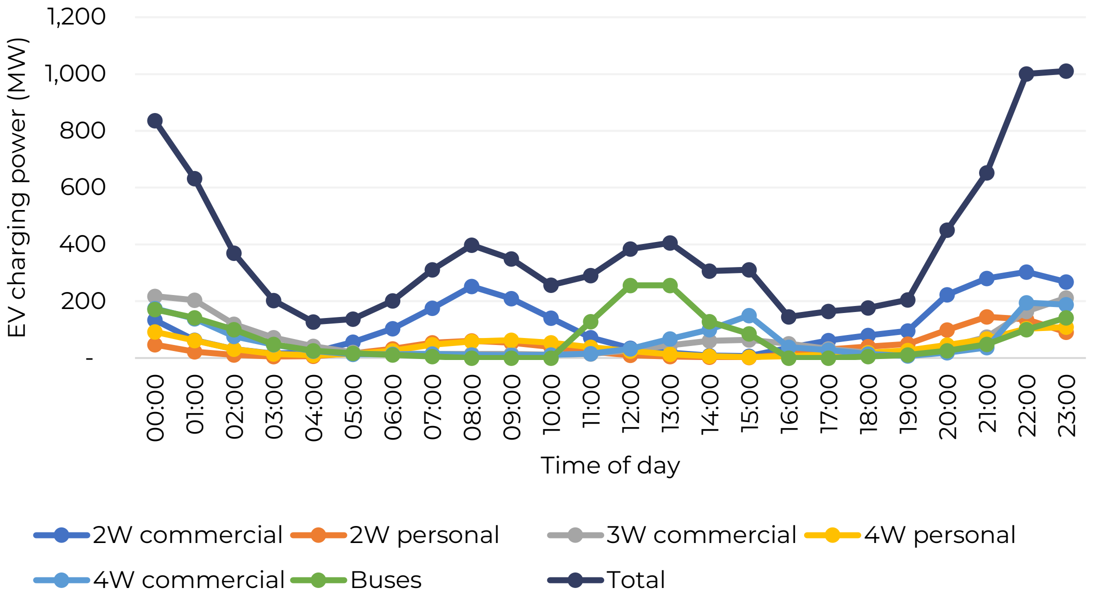


Figure 90: Maximum power demand due to charging of different EV segments in Bengaluru in 2030

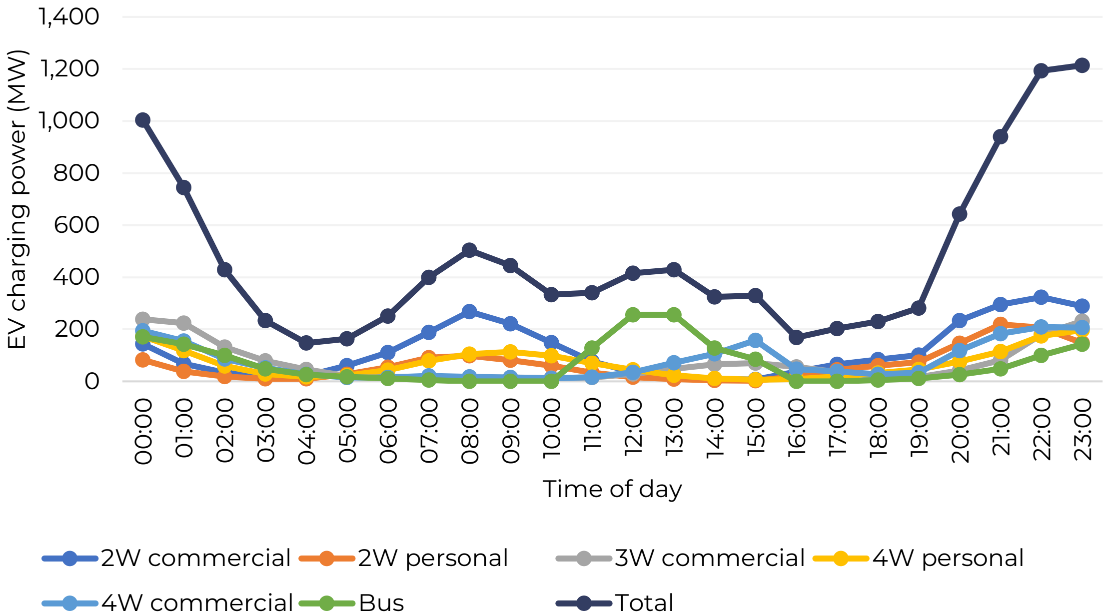
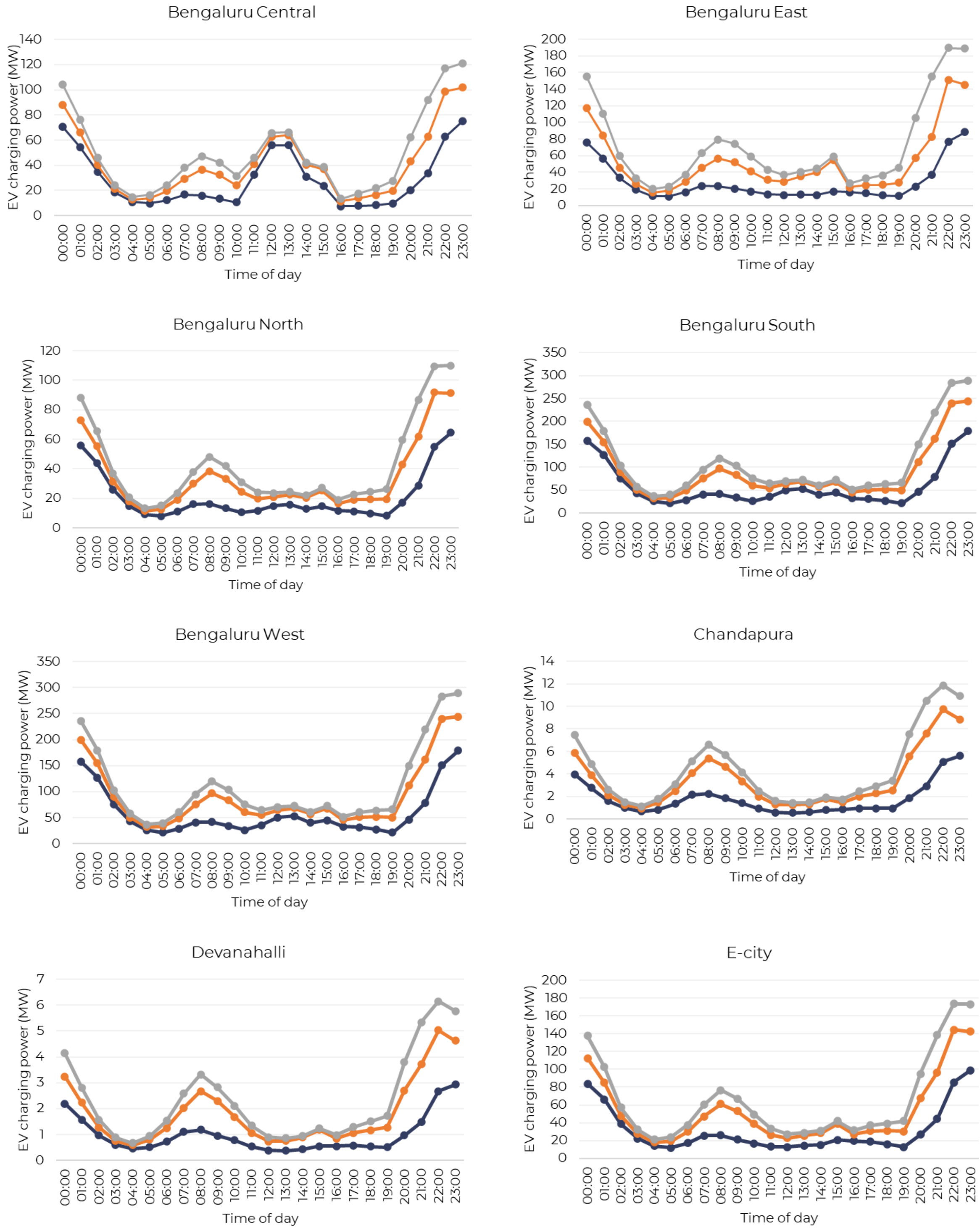
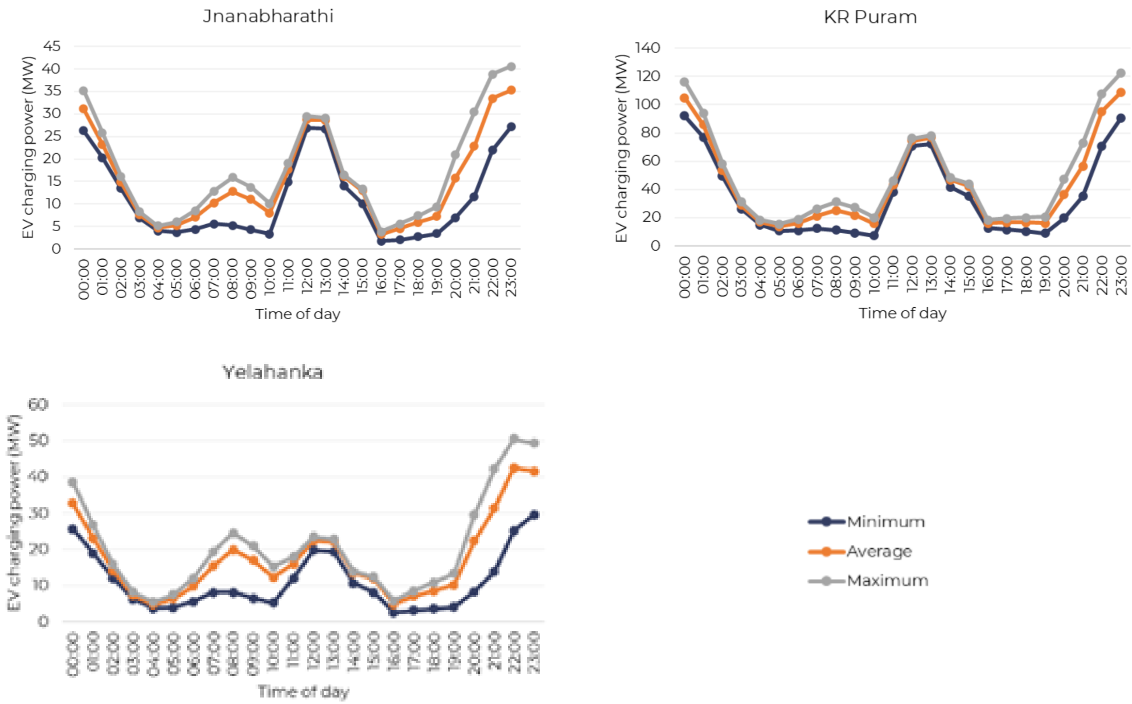


Figure 91: Minimum, average, and maximum power demand due to EV charging in each RTO zone





Details of charging scenarios

To develop insights into the power demand due to EV charging in the near future, the following two extreme scenarios for EV charging were modelled:

1) 90% of the vehicles are charged at home and the remaining 10% at public charging stations (90% home charging)
2) 10% of the vehicles are charged at home and 90% at public charging stations (90% public charging)

In addition to the assumptions used for the main analysis, it was assumed that slow charging occurs only at home and that all public charging stations offer fast charging services only. The charging patterns, i.e. charging location and frequency, were adjusted to reflect these scenarios. Based on this, the hourly distribution of vehicles being charged was computed. The demand for charger guns and power demand due to EV charging (load profile) were calculated (Figure 92, Figure 93, Figure 94, and Figure 95).

Table 15: Demand for EV charger guns in different scenarios

e-2W commercial	90% home charging	90% public charging
SC gun	3,28,282	4,054
FC gun	10,839	97,542
e-2W personal		
SC gun	2,37,111	2,928
FC gun	1,285	1,32,630
e-3W commercial		
SC gun	81,542	1,009
e-4W personal		
SC gun	24,694	310
FC gun	83	7,336
e-4W commercial		
SC gun	20,582	371
FC gun	518	4,659
e-bus		
SC gun	3,414	3,414
FC gun	1,707	1,707

Figure 92: Load profile of average power demand in the scenario of 90% home charging in 2030

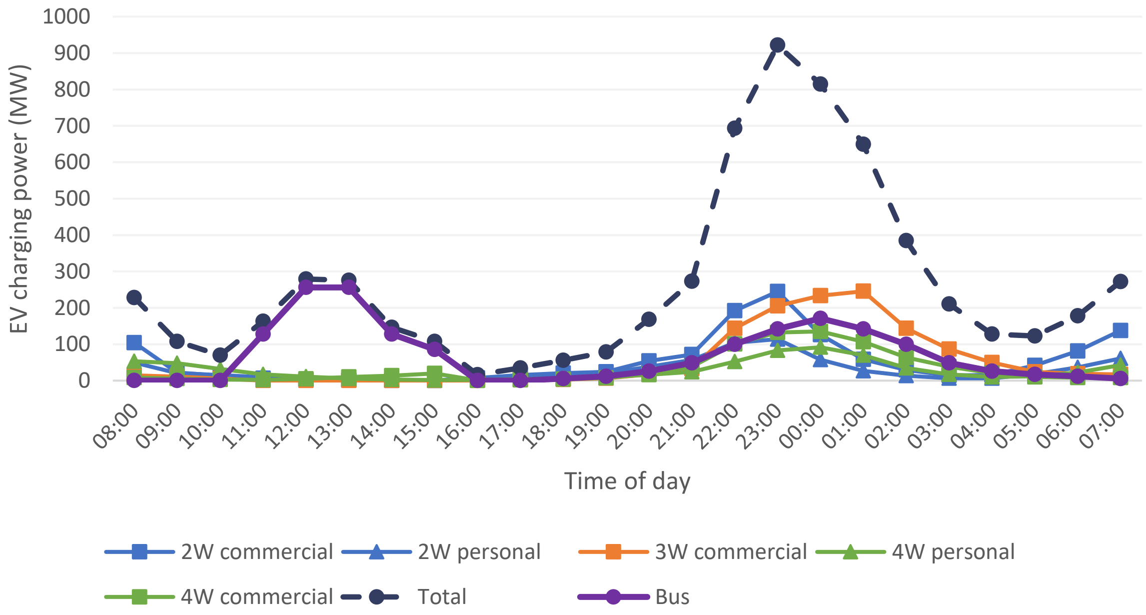


Figure 93: Load profile of the maximum power demand in the scenario of 90% home charging in 2030

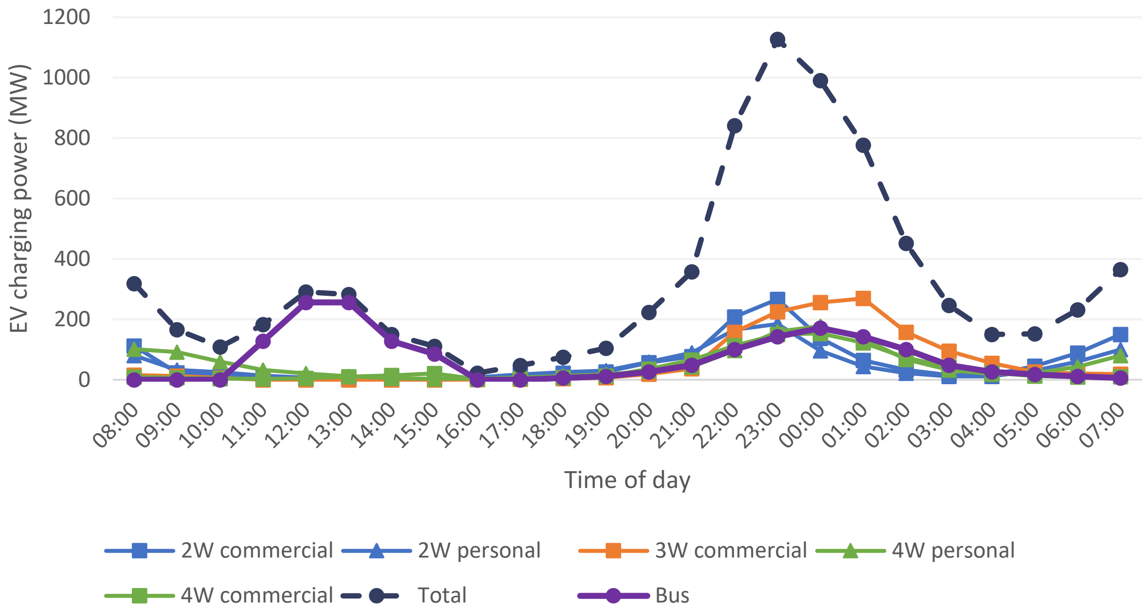


Figure 94: Load profile of average power demand due to 90% public charging in 2030

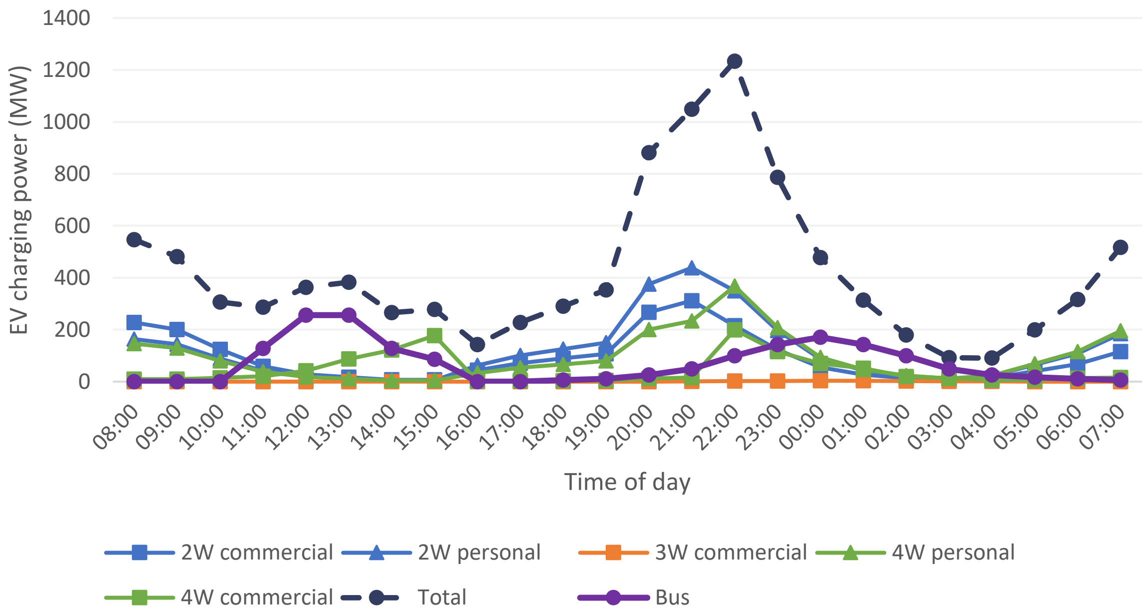
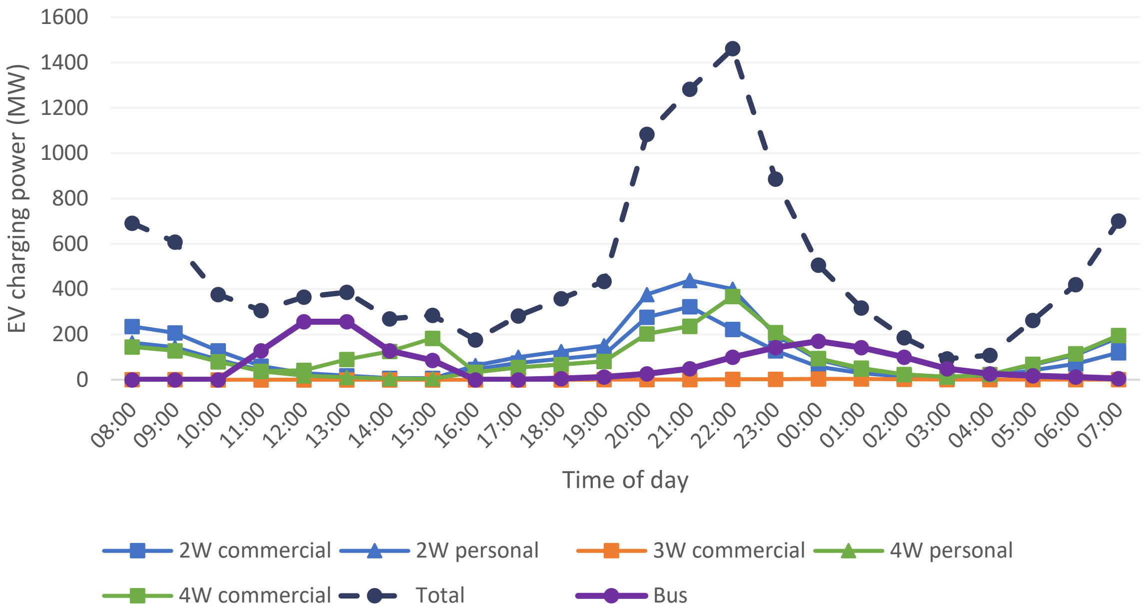


Figure 95: Load profile of the maximum power demand due to 90% public charging in 2030



Estimation of utilisation of EV chargers

Utilisation is a measure of the extent of usage of an EV charger gun in a day. To compute the same, two key parameters are required: i) the number of guns and ii) duration of their usage in a day.

The step-by-step procedure adopted to estimate the utilisation of EV FC guns is described below.

Step 1: Hourly demand

Let n_{t1}, n_{t2}, n_{t3},… n_{tn} represent the demand* for FC guns during a day's different hours t_1, t_2, t_3, …t_n.

* Demand: After accounting for those plugging out and plugging in and charging durations.

Step 2: Sorting

n_{t1}, n_{t2}, n_{t3},… n_{tn} are sorted in ascending order.

Let n_1, n_2, n_3,… n_n represent the sorted hourly number of guns such that $n_2 > n_1$, $n_3 > n_2$, and so on.

Step 3: Distinct number of guns

We calculated $N_1 = n_1$, $N_2 = n_2 - n_1$, $N_3 = n_3 - n_2$, and so on.

Where, N_1, N_2, N_3, and so on represent the distinct number of guns per hour.

Note: N_1, N_2, N_3 and so on are essential because n_{t1}, n_{t2}, n_{t3} may be such that $n_{t3} \leq n_{t1}$, hour t_3 requiring no additional guns, and those in hour t_1 satisfying demand during hour t_3 as well.

Step 4: Duration of usage of FC guns

n_1, n_2,… n_n (step 2) were compared with n_{t1}, n_{t2}, n_{t3},… n_{tn} (step 1) to determine the number of hours the FC guns were engaged/used.

Let T_1, T_2, and so on represent the number of hours of usage of guns N_1, N_2, and so on.

Step 5: Weighted average

T_e in hours was computed as per the formula below.

$$T_e = \frac{\sum_1^n (N_i T_i)}{\sum_1^n N_i}$$

Step 6: Utilisation

Utilisation E in % was computed using the formula $E = \frac{T_e}{24} \times 100$

***

Appendix 3: Potential Charging Station Locations

RTO zone: Bengaluru Central

The potential charging locations in this RTO zone are presented in Figure 96 and Figure 97, while the break-up of different locations is listed in Table 16.

Figure 96: Potential charging station locations in the Bengaluru Central RTO zone

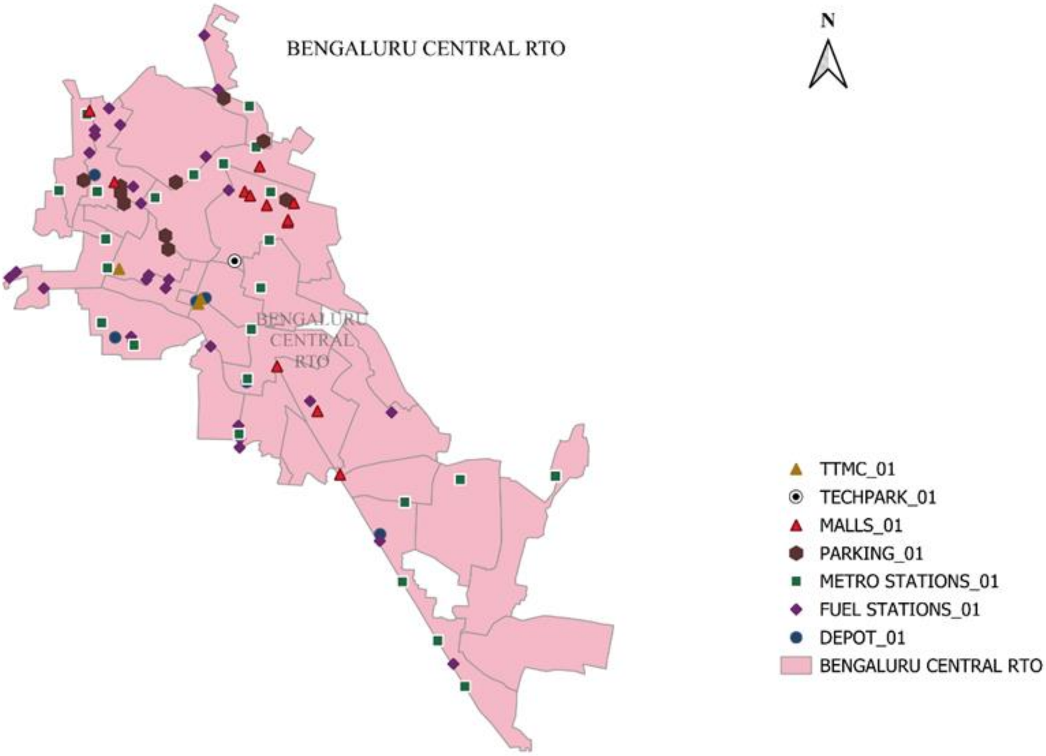
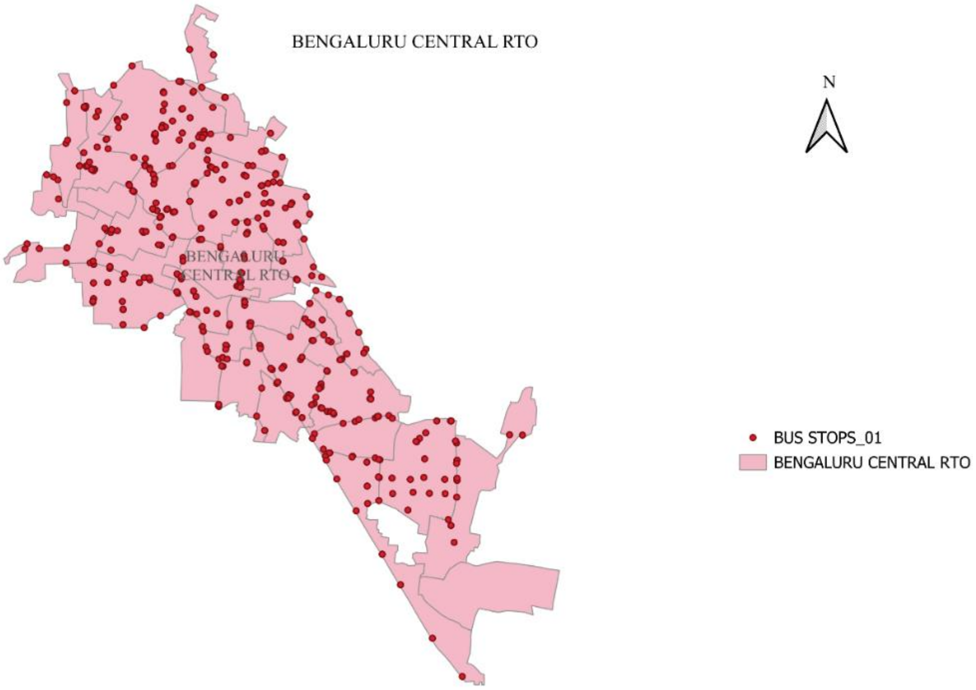


Table 16: Break-up of potential charging station locations within the Bengaluru Central RTO zone

	Potential location	Count
1	TTMC	3
2	Bus depot	6
3	Metro station	24
4	Fuel station	28
5	Tech park	1
6	Mall	10
7	Off-street parking	10
8	Total	82

Figure 97: Potential bus stop locations for EV charging in the Bengaluru Central RTO zone



RTO zone: Bengaluru West

The potential charging locations in this RTO zone are presented in Figure 98 and Figure 99. Moreover, the break-up of different locations is listed in Table 17.

Figure 98: Potential charging station locations in the Bengaluru West RTO zone

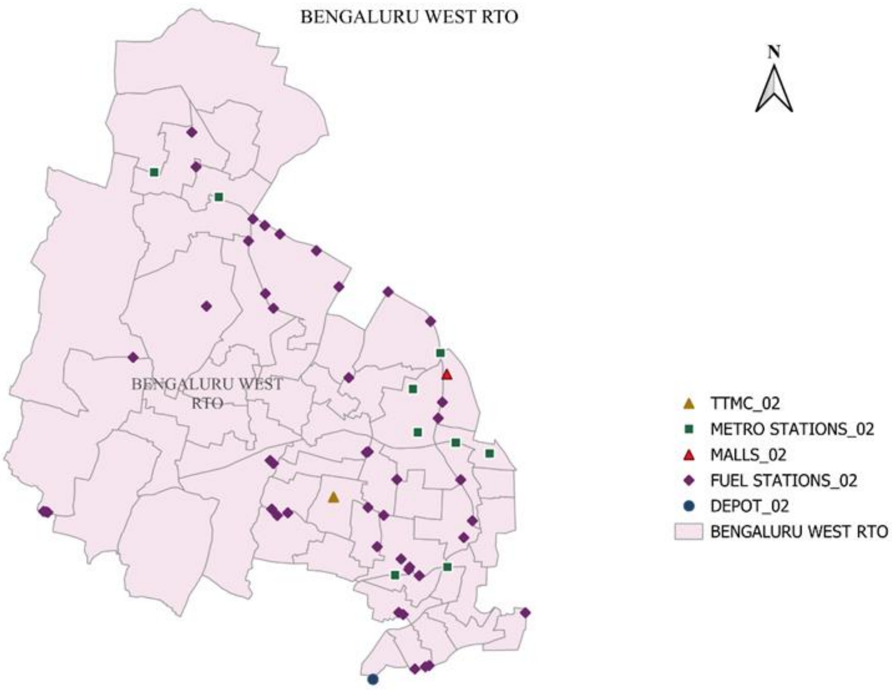
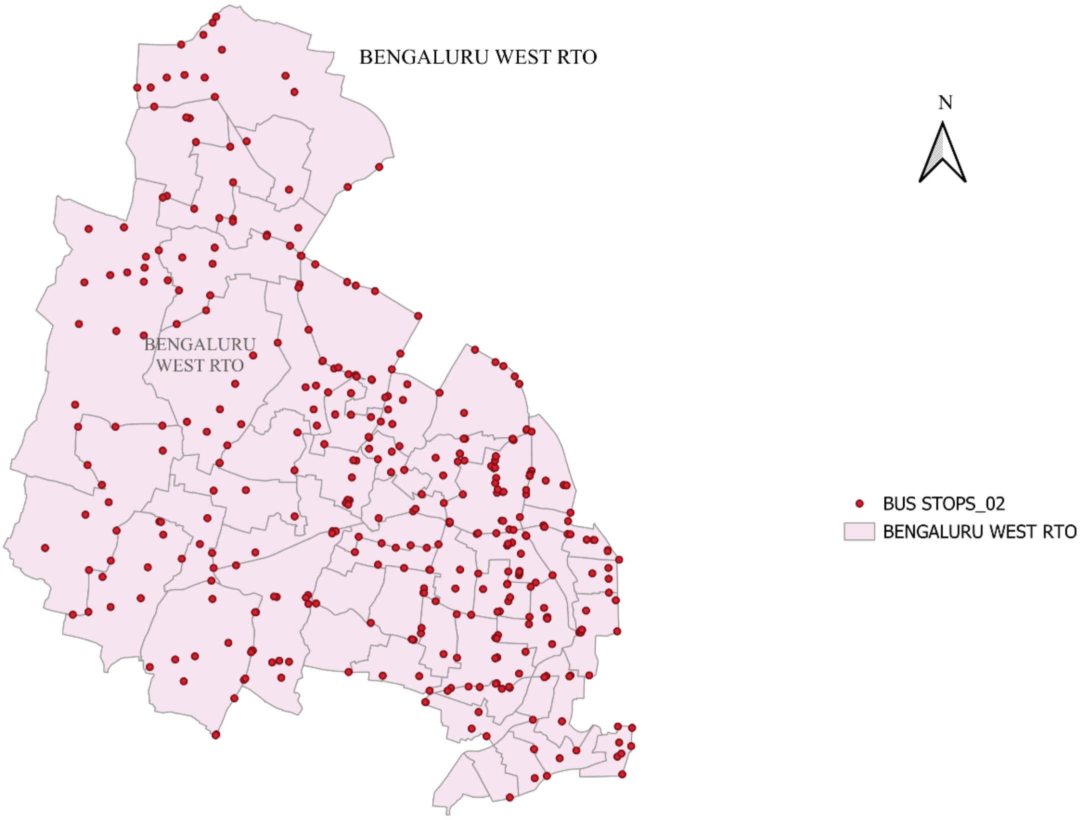


Table 17: Break-up of potential charging station locations within the Bengaluru West RTO zone

	Potential location	Count
1	TTMC	1
2	Bus depot	1
3	Metro station	9
4	Fuel station	44
5	Tech park	0
6	Mall	1
7	Off-street parking	0
8	Total	56

Figure 99: Potential bus stop locations for EV charging in the Bengaluru West RTO zone



RTO zone: Bengaluru East

The potential charging locations in this RTO zone are presented in Figure 100 and Figure 101, while the break-up of different locations is listed in Table 18.

Figure 100: Potential charging station locations in the Bengaluru East RTO zone

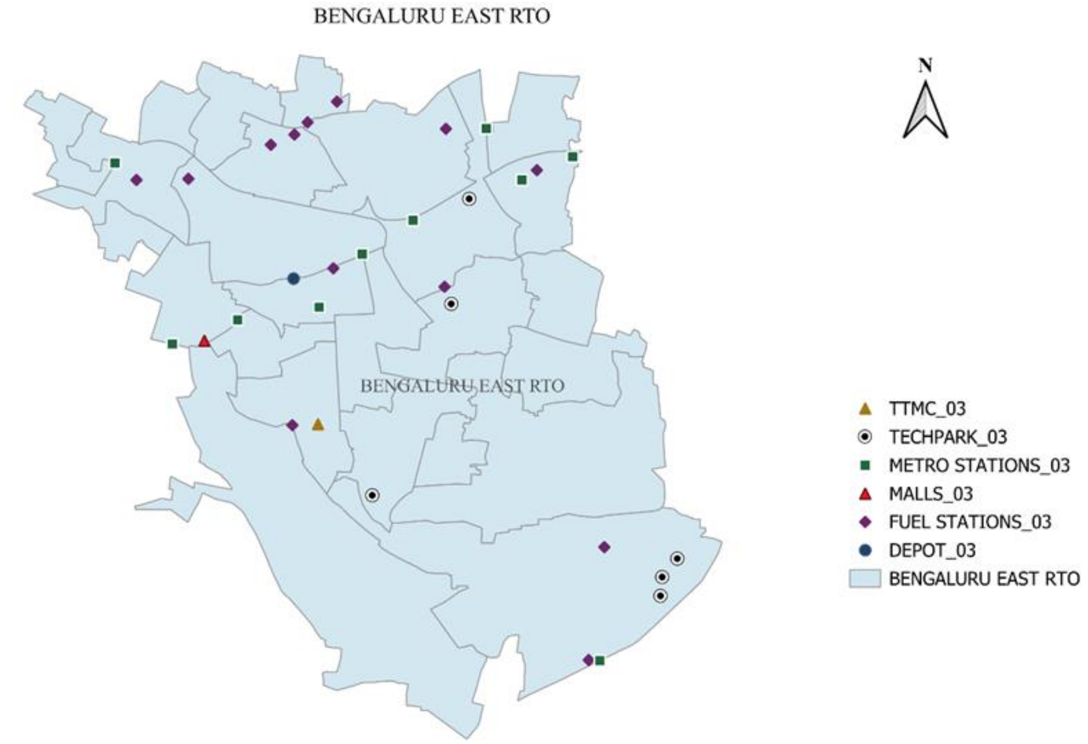
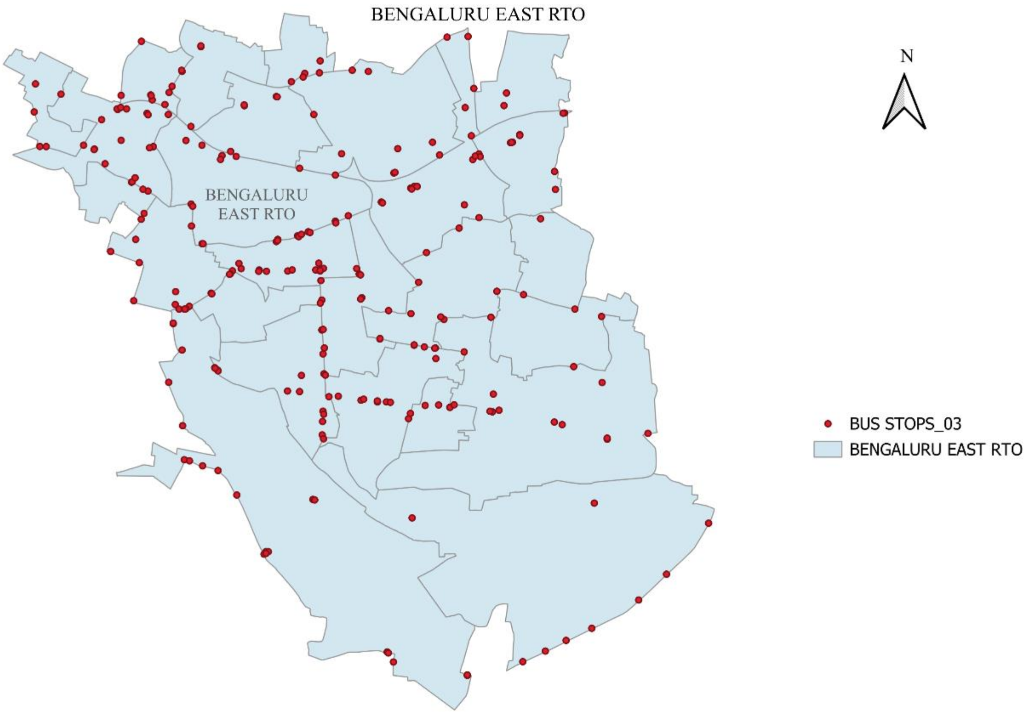


Table 18: Break-up of potential charging station locations within the Bengaluru East RTO zone

	Potential location	Count
1	TTMC	1
2	Bus depot	1
3	Metro station	10
4	Fuel station	13
5	Tech park	6
6	Mall	1
7	Off-street parking	0
8	Total	32

Figure 101: Potential bus stop locations for EV charging in the Bengaluru East RTO zone



RTO zone: Bengaluru North

The potential charging locations in this RTO zone are presented in Figure 102 and Figure 103. Moreover, the break-up of different locations is listed in Table 19.

Figure 102: Potential charging station locations in the Bengaluru North RTO zone

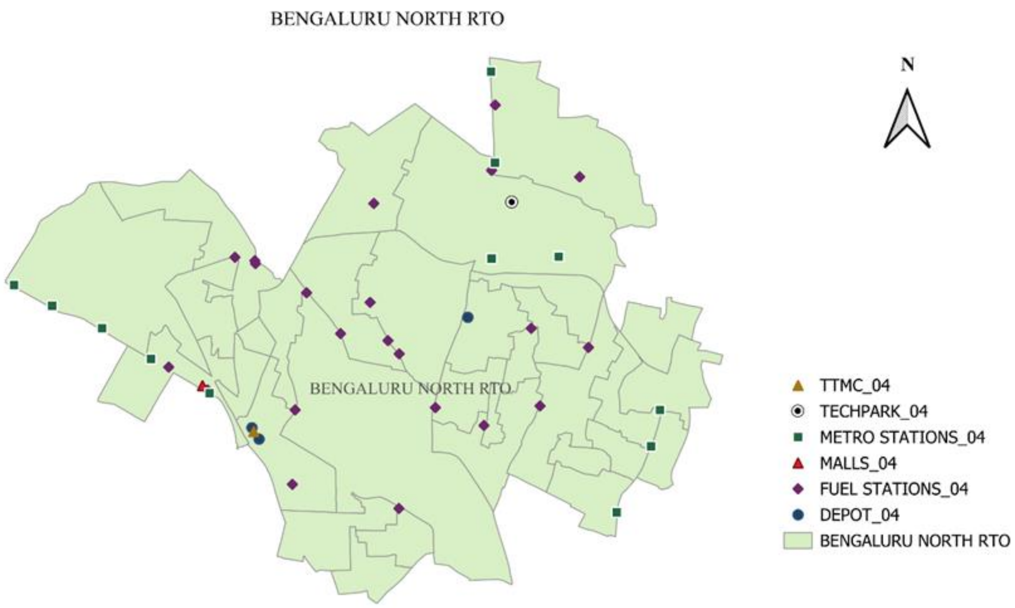
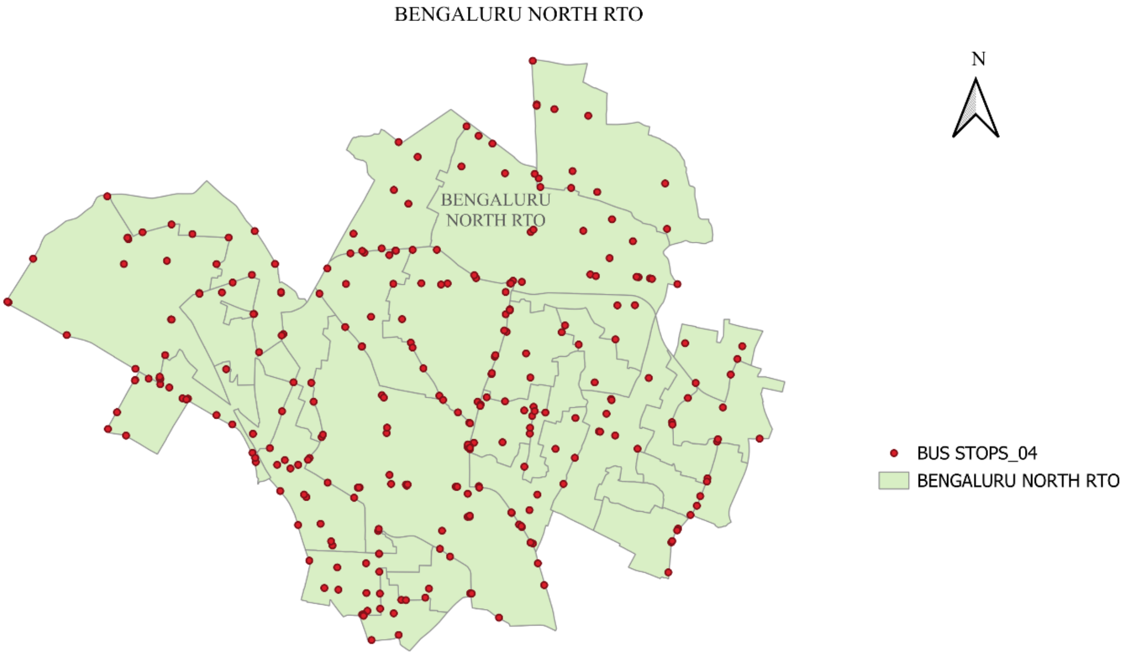


Table 19: Break-up of potential charging station locations within the Bengaluru North RTO zone

	Potential location	Count
1	TTMC	1
2	Bus depot	3
3	Metro station	12
4	Fuel station	22
5	Tech park	1
6	Mall	1
7	Off-street parking	0
8	Total	40

Figure 103: Potential bus stop locations for EV charging in the Bengaluru North RTO zone



RTO zone: E-city

The potential charging locations in this RTO zone are presented in Figure 104 and Figure 105, while the break-up of different locations is listed in Table 20.

Figure 104: Potential charging station locations in the E-city RTO zone

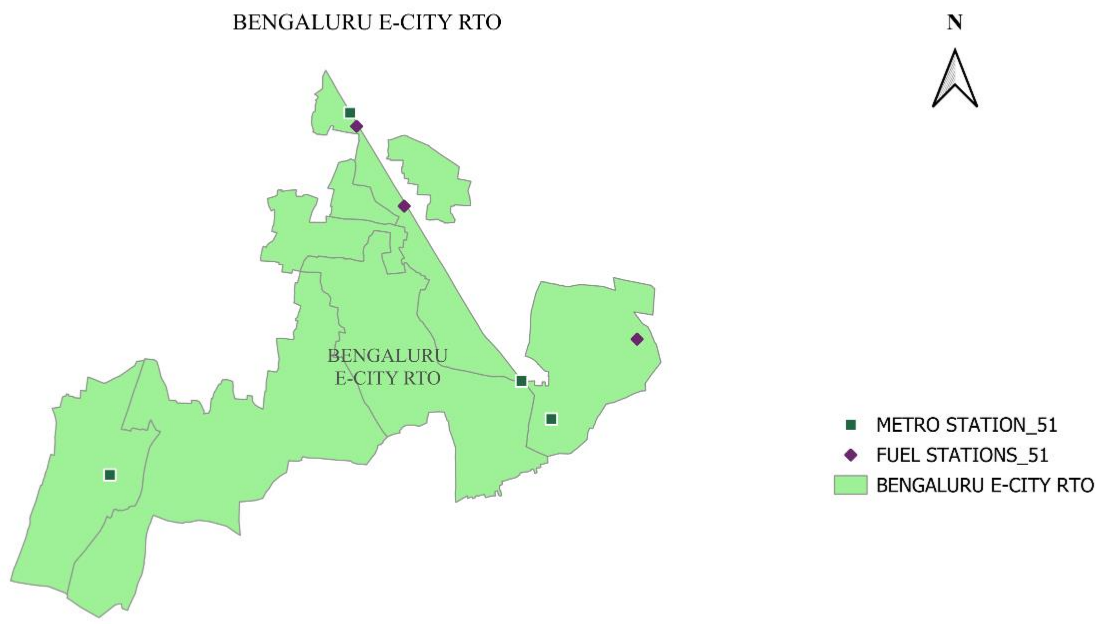
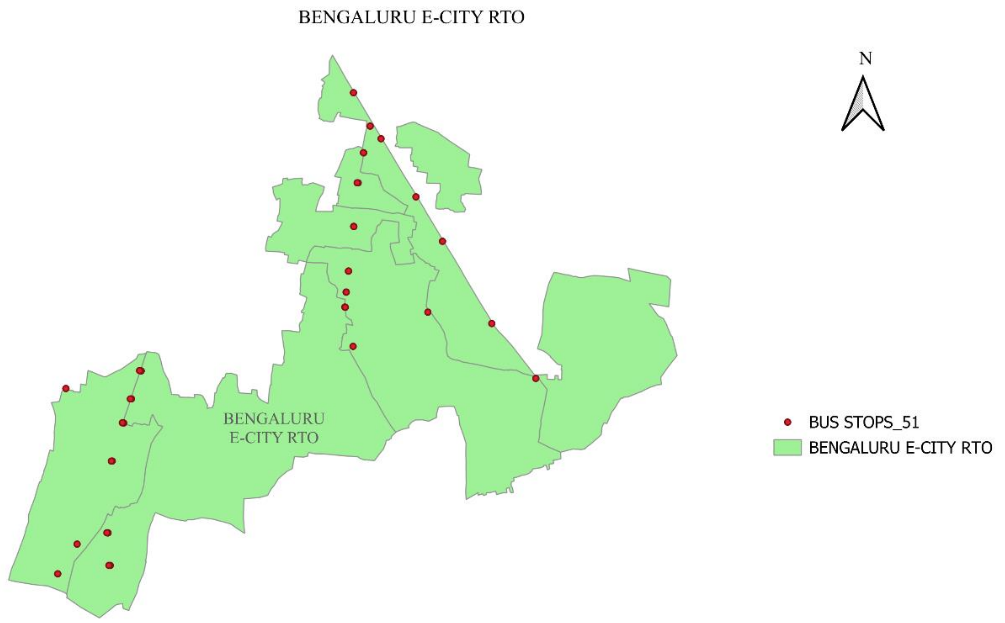


Table 20: Break-up of potential charging station locations within the E-city RTO zone

	Potential location	Count
1	TTMC	0
2	Bus depot	0
3	Metro station	4
4	Fuel station	3
5	Tech park	0
6	Mall	0
7	Off-street parking	0
8	Total	7

Figure 105: Potential bus stop locations for EV charging in the E-city RTO zone



RTO zone: Jnanabharathi

The potential charging locations in this RTO zone are presented in Figure 106 and Figure 107, while the break-up of different locations is listed in Table 21.

Figure 106: Potential charging station locations in the Jnanabharathi RTO zone

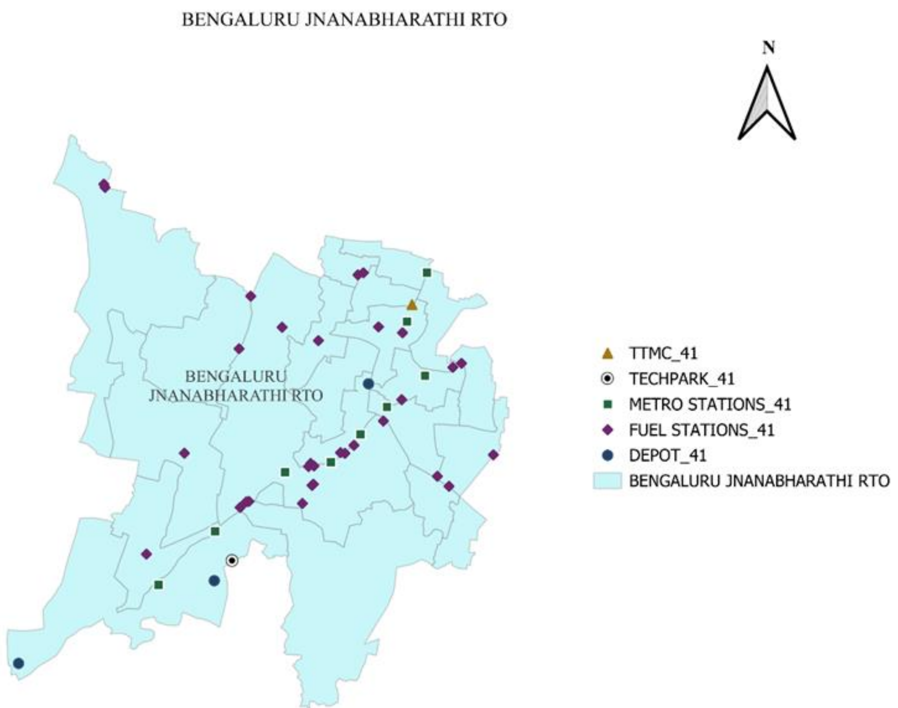
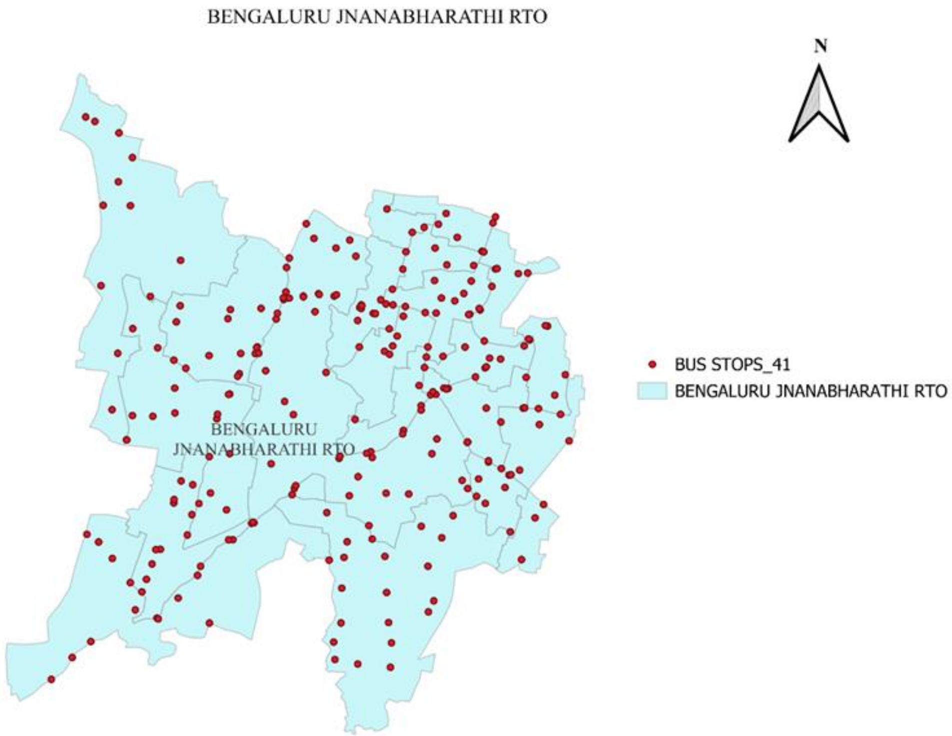


Table 21: Break-up of potential charging station locations within the Jnanabharathi RTO zone

	Potential location	Count
1	TTMC	1
2	Bus depot	3
3	Metro station	9
4	Fuel station	31
5	Tech park	1
6	Mall	0
7	Off-street parking	0
8	**Total**	45

Figure 107: Potential bus stop locations for EV charging in the Jnanabharathi RTO zone



RTO zone: KR Puram

The potential charging locations in this RTO zone are presented in Figure 108 and Figure 109. Moreover, the break-up of different locations is listed in Table 22.

Figure 108: Potential charging station locations in the KR Puram RTO zone

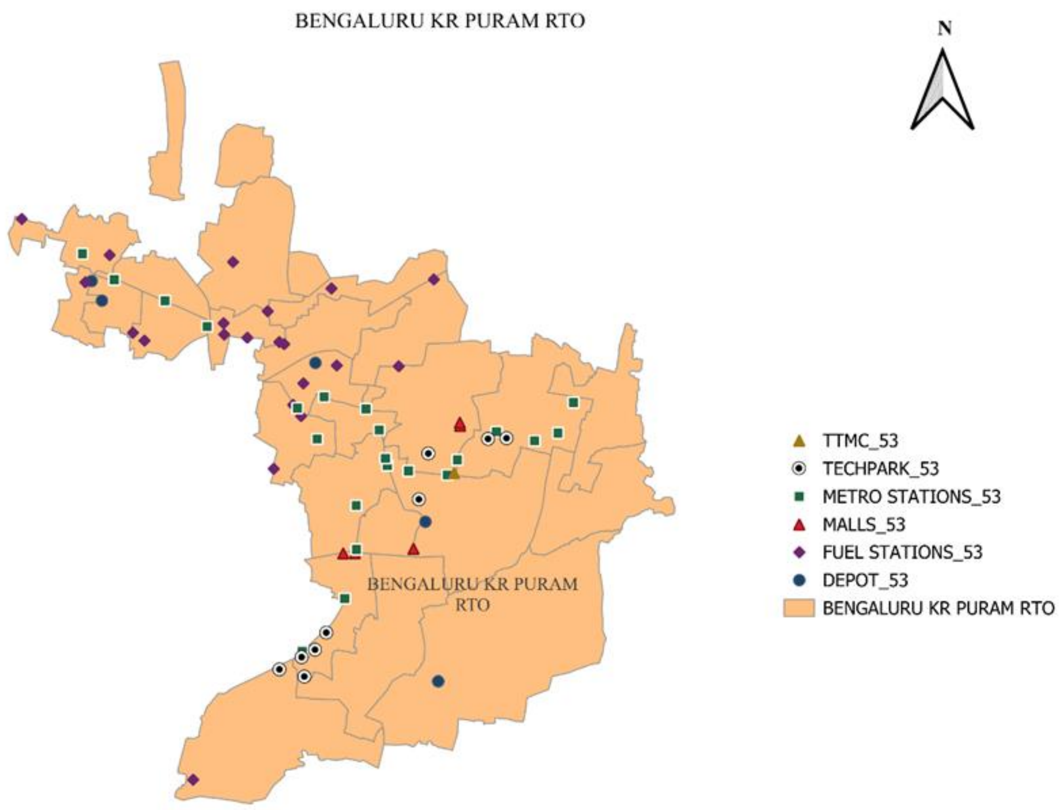
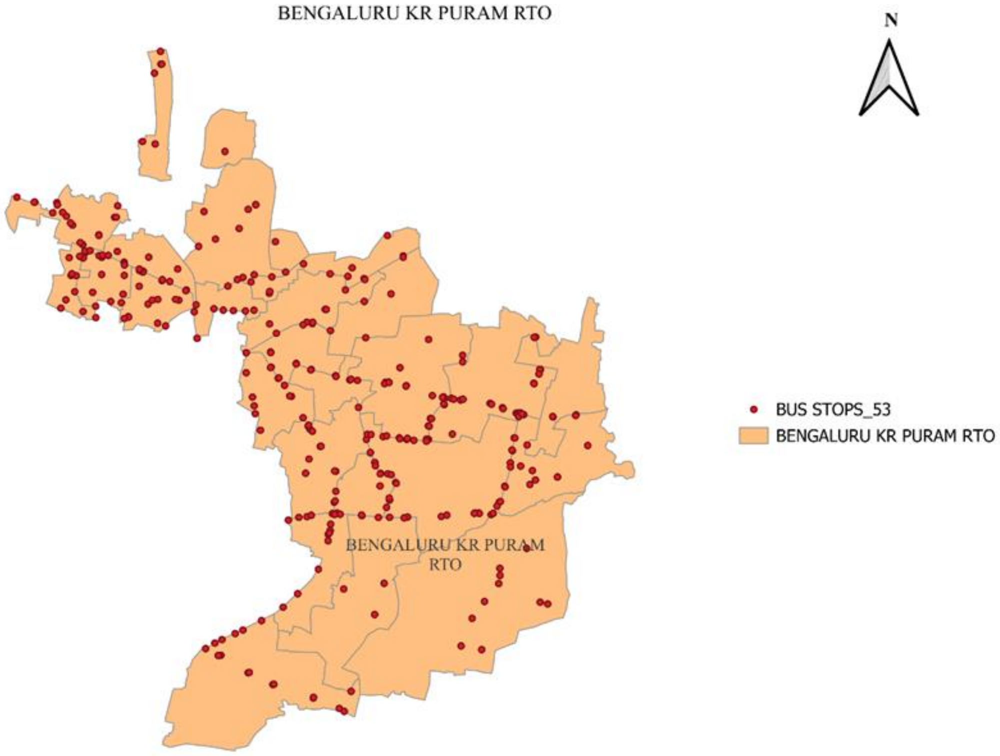


Table 22: Break-up of potential charging station locations within the KR Puram RTO zone

	Potential location	Count
1	TTMC	1
2	Bus depot	5
3	Metro station	22
4	Fuel station	21
5	Tech park	9
6	Mall	4
7	Off-street parking	0
8	Total	62

Figure 109: Potential bus stop locations for EV charging in the Bengaluru KR Puram RTO zone



RTO zone: Yelahanka

The potential charging locations in this RTO zone are presented in Figure 110 and Figure 111, while the break-up of different locations is listed in Table 23.

Figure 110: Potential charging station locations in the Yelahanka RTO zone

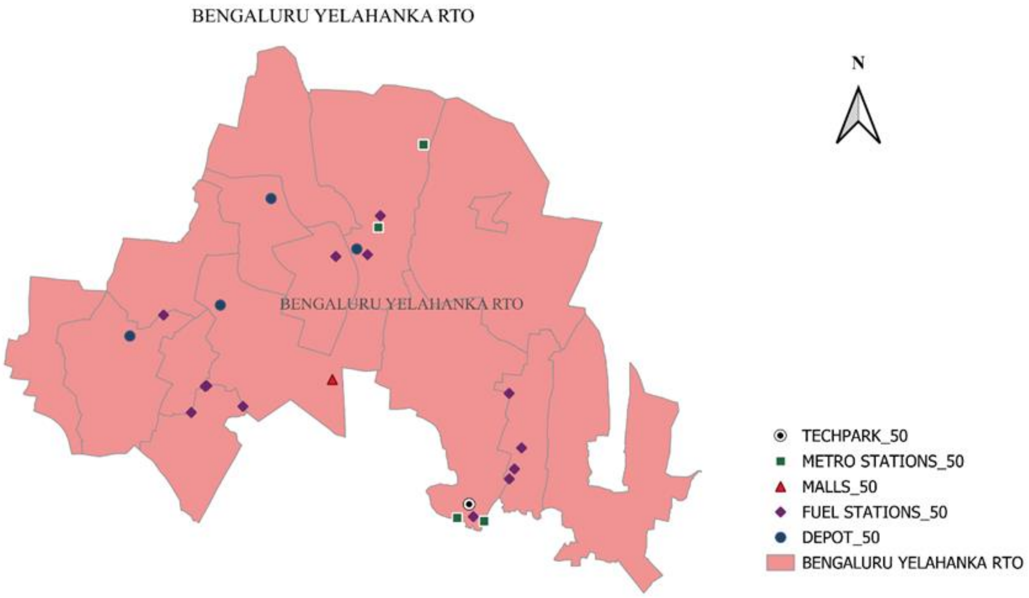
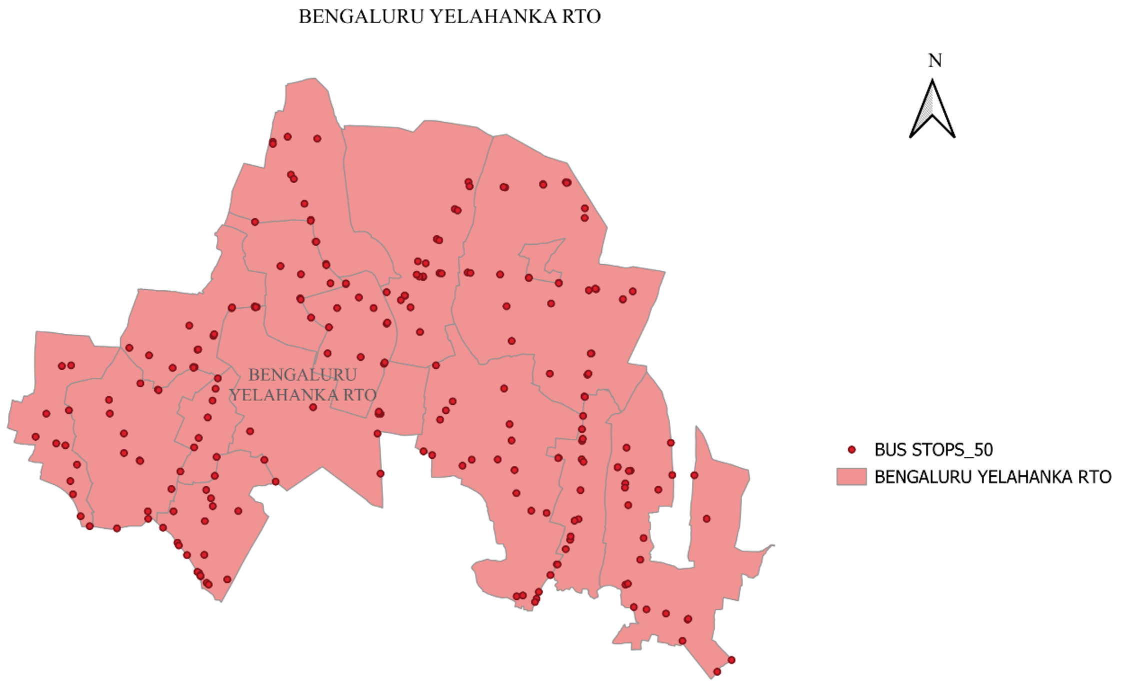


Table 23: Break-up of potential charging station locations within the Yelahanka RTO zone

	Potential location	Count
1	TTMC	0
2	Bus depot	4
3	Metro station	4
4	Fuel station	13
5	Tech park	1
6	Mall	1
7	Off-street parking	0
8	Total	23

Figure 111: Potential bus stop locations for EV charging in the Yelahanka RTO zone



Appendix 4: Commercial Feasibility of Charging Stations

The charging tariffs at 10% and 20% IRR are presented in Figure 112 and Figure 113, respectively.

Figure 112: Charging tariff vs utilisation at 10% IRR

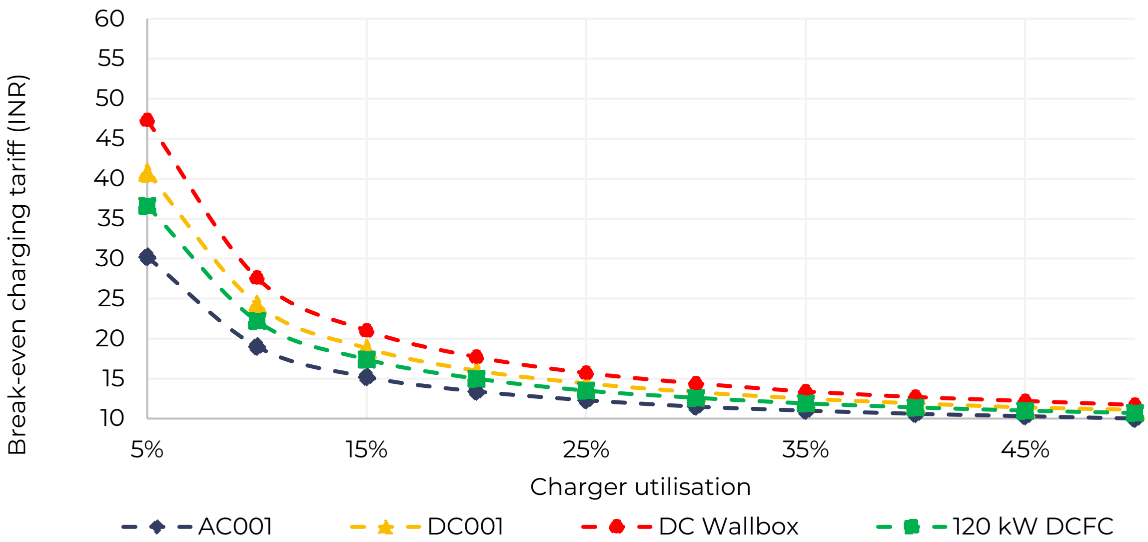
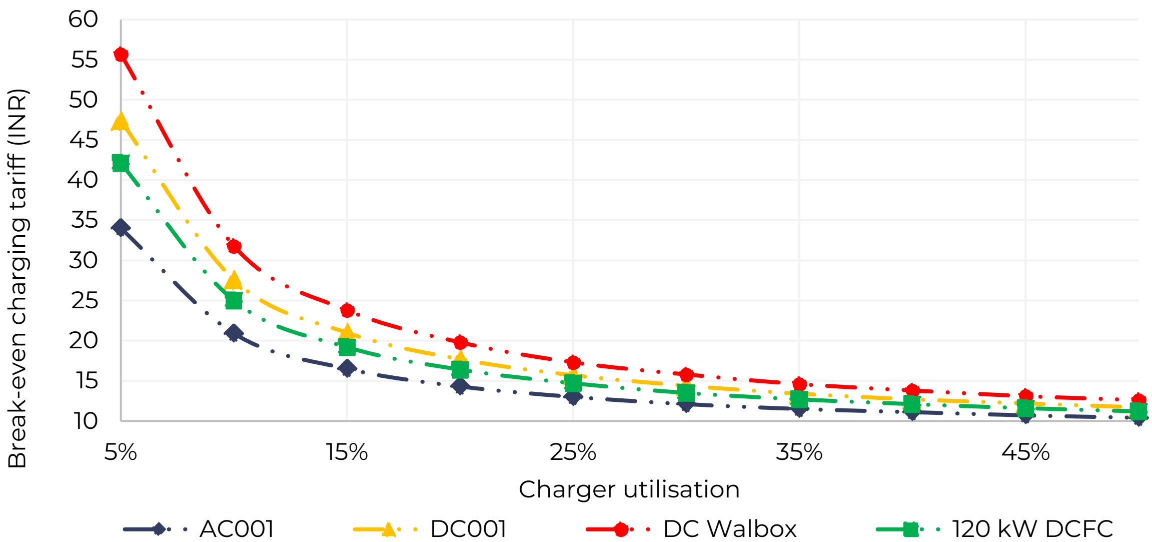
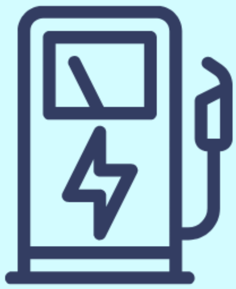


Figure 113: Charging tariff vs utilisation at 20% IRR





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