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The impact of electric vehicle charging infrastructure on the energy demand of a city

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Abstract

With the increased market penetration of electric vehicles (EVs), energy consumption is growing at a quicker rate. Electric vehicles are slowly but surely gaining a foothold in India's rapidly expanding market. With more EVs on the road, there will be more demand for charging and more energy use in some places, which can put a lot of stress on the power grid. In the absence of sufficient planning, there is a risk of power system interruption and failure. Therefore, the need for energy in cities will shift in light of the advent of EVs in the next decade or two. Accordingly, Surat has been chosen as the research region for the planning of charging infrastructure in the current study. After reviewing the literature, primary data was acquired to estimate citizen travel demands. Vehicle registration statistics were compiled from the Regional Transport Office (RTO) for the purpose of EV forecasting. After collecting data, the EV population and demand for public charging stations by 2025 and 2030 were calculated. This study aims to meet the public charging demand in the city of Surat by analyzing the electric vehicle growth rate and vehicle forecast. This anticipated data was then utilized to compute the energy demand consumption for Surat city by calculating vehicle kilometers traveled. The demand for public charging comes out to be 42.4 MWh/day in 2025 and 358.05 MWh/day in 2030, respectively. The study's objective is to determine energy demand per region in order to better understand grid planning due to the imbalance in electricity demand.

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Keywords: Electric vehicle; Energy demand; Charging infrastructure; Charging demand; Logistic growth model; Public charging requirement

1. Introduction

Greenhouse gas (GHG) emissions increased by 50% between 1990 and 2018 and are now rising at a faster rate. As reported in 2018, the transportation sector accounted for 14.2% of all GHG emissions, making it one of the top contributors. Road transportation accounts for 12.5% of total emissions, making it the most prevalent mode of transportation. As a result of these rising emissions, society has begun moving in the direction of sustainable energy,

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with EVs as the primary option [1,2]. Charging demand is rising with shifting EV policies in India, leading to an increase in energy consumption. The integrity of the grid is at risk if energy demands are miscalculated. Sustainable development goals (SDGs) also prioritize clean, renewable energy. E-mobility is gaining widespread acceptance at an accelerated rate around the globe in various countries. According to the International Energy Agency (IEA), global sales of electric vehicles increased 360 times between 2010 and 2020, from 8289 to 29,86,659.

It is anticipated that the need for public charging stations will increase as the EV population grows. With increased electrification of mobility, many industry experts anticipate that the domestic market will develop in the next 1–2 years. Presently, relatively few public charging facilities are accessible for electric vehicles. This dearth of public charging stations in the nation hinders the adoption of e-mobility. Therefore, it is vital to provide charging stations as soon as possible. However, charging stations should be deployed wisely to optimize the scarce resources, particularly in developing nations like India. Therefore, charging stations must be considered and built as infrastructure. The infrastructure for charging should be developed at the city and regional levels. Currently, the use of electric vehicles is primarily restricted to big cities.

The Ministry of Power (MOP), Government of India (GOI), has shortlisted cities with more than 4 million populations for the first phase of implementing charging infrastructure. Surat is one of the cities that were chosen for the first phase. The purpose of this study is to find out the public charging demand considering one of the fast-growing cities of India, Surat, as a case study. The relevant literature was taken out, and primary data collection was conducted to determine the daily travel needs of citizens. From the RTO, inventory data collection for vehicle population data has been acquired. After collecting data, the EV population in the research region and the need for public charging stations between 2025 and 2030 have been projected, and daily energy needs and public charging demand have been found. According to the Ministry of Power, Surat's energy demand in 2018–19 was 9849 million units (MU), and it is expected to reach 13 362 MU by 2024–25 with a 5.23% compound annual growth rate (CAGR) and 16 761 MU by 2029–30 with a 4.64% CAGR. As the number of EVs grows, more energy will be needed. This means that charging stations will need to be planned ahead of time. The present study's findings can be utilized to plan the charging infrastructure in a balanced way so that the energy demand can be calculated and proper power supply planning can be done. Furthermore, this study emphasizes the additional demand generated by EVs.

2. Literature review

2.1. Public charging requirement

According to Hardman et al. [3], home charging meets the majority of an EV's charging needs. Home charging accounts for approximately 50–80 percent [3]. After home charging, the preferred charging location is the workplace, which accounts for about 15–25 percent of charging needs [3]. During the early stages of deployment of EVs, public charging stations account for less than 10% of charging events [3]. Also, the article by Funke et al. [4] concludes that home charging is sufficient during early stages of EV deployment in most countries. However, in the future, public charging infrastructure will be required for mass diffusion [4]. According to Funke et al. [4], public charging infrastructure will be critical in areas where home charging is limited. In contrast, countries with abundant parking spaces can rely on home charging [5]. Furthermore, public charging infrastructure promotes EV adoption [6]. Table 1 below summarizes public charging requirements in various countries from literature.

Based on the preceding discussion, it can be concluded that the need for public charging varies by country. According to the article by Nicholas and Hall [11], the need for public charging varies by region. According to Funke et al. [4], the proportion of public charging is determined by factors such as the proportion of detached houses, population density, the proportion of the urban population, and the proportion of private charging. When designing a city's charging infrastructure, factors such as the availability of private parking should be considered. In the absence of data on the availability of private parking, factors such as housing typology in the city should be studied to indirectly assess the availability of home charging.

2.2. Experienced driving range and electric energy consumption

The values mentioned in Table 3 for claimed range and electric energy consumption are according to standard test conditions specified by International Centre for Automotive Technology (ICAT). These tests are performed according to Automotive Industry Standards (AIS). For measuring the range of an EV, AIS-040(Rev.1):2015 is

Table 1. Literature for public charging requirement.

Sr. No.	Author	Country	Remarks
1	Baresch and Moser [7]	Austria	Share of public charging less than 5%.
2	Gnann et al. [8]	Worldwide	The utilization of public charging infrastructure will depend on the accessibility of other charging alternatives.
3	Hardman et al. [3]	Countries from North America and Europe	Public charging infrastructure is critical for long-distance travel and areas with limited access to home charging.
4	Helmus et al. [5]	Netherlands	In heavily populated locations where home charging is not viable, public charging infrastructure might act as an alternative to home charging.
5	Liu et al. [9]	China	Users are shifting to direct current (DC) fast charging due to a lack of parking spaces at their homes and workplaces.
6	Hall and Lutsy [10]	Worldwide	The availability of private charging facilities is one of the most critical variables affecting public charging demands.

Table 2. Literature support factors affecting energy consumption of EV.

Sr. No.	Factor	Literature support
1	Temperature	[12–15]
2	State of charge	[12,16]
3	Vehicle mass and loading	[13,14,17]
4	System Efficiency	[13,15–17]
5	Tyre pressure	[17]
6	Road condition	[13,14,17,18]
7	Driving pattern	[13–16]
8	Use of auxiliaries	[15]

Table 3. Claimed vs. actual driving range.

Sr. No.	Vehicle category	Claimed Avg. energy consumption (a)	Experienced Avg. energy consumption (b) = 1.3(a)	Claimed Avg. driving range (c)	Experienced Avg. driving range (d) = 0.75(c)
1	2-Wheeler	3.19 kWh/100 km	4.15 kWh/100 km	109.20 km	81.9 km
2	3-Wheeler	6.22 kWh/100 km	8.09 kWh/100 km	120.24 km	90.18 km
3	4-Wheeler	12.77 kWh/100 km	16.60 kWh/100 km	209.30 km	156.98 km

used. AIS-039(Rev.1):2015 is used to measure electrical energy consumption. According to these codes, the test is conducted at a temperature between 20 °C to 30 °C after charging the vehicle overnight. Also, iterations of specific driving cycles are performed according to vehicle category during tests. These conditions may not hold true when the vehicles are traveling on the road, affecting the vehicle's performance. Other than these, several factors affect EVs' performance, as mentioned in Table 2.

Because of the factors mentioned above, experienced electric energy consumption is more than claimed by the manufacturer, which results in a less experienced driving range than claimed. A survey of dealers has been carried out to understand the difference in experienced and claimed range and consumption. The survey was conducted by interacting with the dealer.

According to the survey, experienced electric consumption is, on average, 30% higher for all categories of vehicles, which results in the reduction of experienced range by about 25%, as shown in Table 3. These driving ranges will be further used to calculate daily energy demand needs.

3. Methodology

The present study assesses the public charging demand for the study area. The first step for public charging demand assessment is identifying factors indicating public charging demand. In the following step collection of required data on vehicle registrations, penetration rates, and specifications of EV models has been done. After this, forecasting the vehicular population with a growth rate-based method and penetration rate with the logistic curve method is carried out. A survey has also been conducted to find daily Vehicle Kilometers Travelled (VKT) for various categories of vehicles. From the collected data, at first daily charging demand is calculated for the study area. Public charging need for different vehicle categories has been calculated based on the share of public charging.

4. Data collection & analysis

Surat, a city in the western part of India, has been selected to assess the public charging demand. Transportation in Surat is predominantly road based. Surat has Bus Rapid Transit System (BRTS), city buses, and unorganized auto rickshaws for public transport. The Metro rail project is under construction in Surat. Compared to detached and semi-detached homes, the percentage of residents living in group housing in Surat is significantly higher.

The inventory data collected from the RTO is used to access the number of vehicles. The data used for the study is from 2013 to 2021. The types of vehicles included in different category groups are mentioned in Table 4. According to estimates of ministry of power for 2018–19, the current energy demand for the study area is 9849 million units (MU). Electric vehicle charging requirements will undoubtedly increase in tandem with the anticipated increase in market demand for EVs and subsequent increases in energy demand. The energy demand is calculated further in the study paper. To avoid power grid collapse, the overall energy consumption of EVs must be accurately estimated.

Table 4. Vehicle categories.

Sr. No.	Vehicle category	Vehicle class
1	4-Wheeler	Motor Car, Motor Cab, Maxi Cab, Omnibus, etc.
2	3-Wheeler	E-Rickshaw, E-Rickshaw with Cart, 3W Personal, 3W Passenger, etc.
3	2-Wheeler	M-Cycle/Scooter, M-Cycle/Scooter with sidecar, Moped, Motorized Cycle (>25CC), etc.

4.1. Vehicular growth

The chart given in Fig. 1 shows the number of vehicles registered in Surat from 2013 to 2021, as it can be seen that vehicle registration has been almost increasing from 2013 to 2018 and has decreased from 2019 to 2021. In Surat, 2W has the highest share of more than 75% of the total sales.

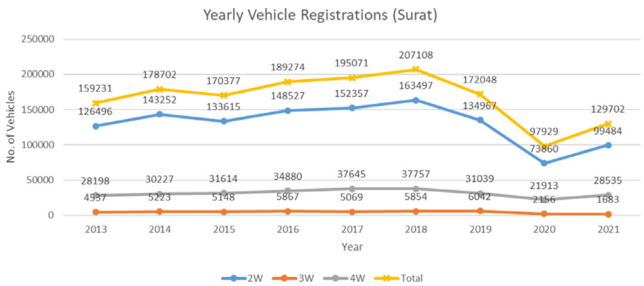

Fig. 1. Vehicle registrations — Surat.

According to the president of the Society of Indian Automobile Manufacturers (SIAM), the decline in vehicle registrations in 2019 is due to various reasons like the higher cost of acquisition due to new emissions norms, including Bharat Stage Emission Standards, BS IV to BS VI transition, liquidity crisis, poor consumer sentiments, slower economic growth of the country, etc. Because of the reasons mentioned above, sales of vehicles in 2019 in Surat have observed a drop of 16.93%. Another higher decline in vehicle registration of 43.08% was seen in 2020 as an impact of the nationwide lockdown due to COVID-19. After a consecutive decline in vehicle registrations for two years, in 2021, vehicle registrations saw an increase of 32.44%.

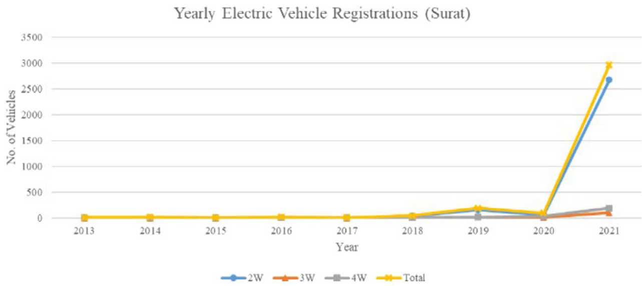

Fig. 2. EV registrations — Surat.

4.2. EV growth

The electric vehicle registration statistics have been taken from RTO for 2013 to 2021. For the present study, only Battery Electric Vehicles (BEVs) are considered for further analysis. Fig. 2 shows the chart for EV registrations. The EV registrations were almost negligible till 2018; after that, there can be seen slight growth in registration in the 2W category group. Significant growth in EV registrations happened after 2020. This increase is because of several factors, including financial incentives by state and central govt., rising prices of conventional fuel, recent advancements in EV technology reducing battery prices, awareness, and acceptance of EVs, and the introduction of various manufacturers and models in the EV marketplace.

4.3. EV penetration rate

Section 4.2 shows growth in EV registrations but cannot accurately represent their market share. Hence, for the present study, the penetration rate of EVs is considered to understand the growth of EVs. This penetration rate can provide EVs with a proportional registration share for a given year. The equation of penetration rate is given by,

Eq. (1) Penetration Rate

$$Penetration\ Rate_n\ (\%) = \frac{No.\ of\ EVs\ registered\ in\ year\ n}{No.\ of\ vehicles\ registered\ in\ year\ n} \times 100 \tag{1}$$

Fig. 3 represents Surat's penetration rates for different category groups of vehicles from 2013 to 2021. Surat also has the highest penetration rate for electric 3W, followed by 2W. Penetration rate of electric 3W, 2W and 4W is 5.88%, 2.69% and 0.65% respectively. The penetration rate of electric 2W, 3W, and 4W combined is just 2.28%.

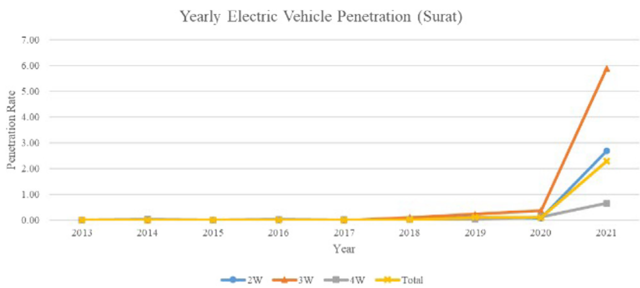

Fig. 3. EV penetration rate — Surat.

As seen from Fig. 3, despite the drops in registrations for years 2019 and 2020 for several reasons, the penetration rate for all the category groups has continuously been increasing. Hence it can be said that the growth of EVs has not been much affected by the drops in registration. Also, 3W has the highest penetration because most conventional 3W are primarily low speed; hence the drawback of EV being low speed does not hamper this category group. The other reason for this growth can also be the high price of conventional fuel.

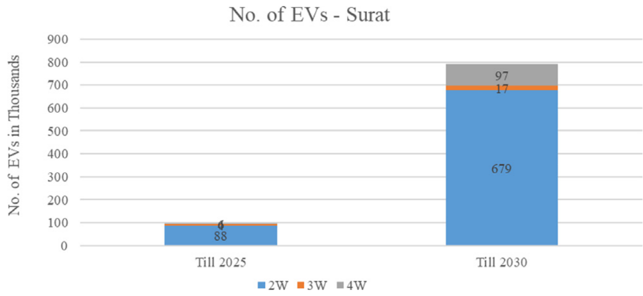

Fig. 4. EVs in 2025 and 2030 — Surat.

4.4. Vehicle growth forecasting- Logistics growth model

To comprehend future energy demand, it is necessary to anticipate the number of EVs. Vehicle growth forecasting can be done by growth rate-based forecasting, for which the growth rate for each year is worked out. However, the average growth rate from 2014 to 2021 is shown to be relatively low, and in certain datasets, it is even negative; because of exceptional behavior in vehicle growth from 2019 to 2021. For this reason, growth rate-based forecasts with an average growth rate from 2014 to 2018 have been considered for further computation. The results of which are used for forecasting the EV population in the study area.

The Logistic growth model is the method majorly dependent on the previous data. Logistic growth is characterized by a slow start, then an almost exponential increase to reach near the carrying capacity, and then a decline in growth to reach the carrying capacity. The logistic growth model is best suited for assessing EV growth because the initial slow start of the logistic curve denotes the early adaptors; the exponential increase signifies the imitators influenced by the early adaptors. In the end, the slow growth indicates the fully grown EV market with a constant market share. The equation of the Logistic curve used for the present study is referred to as Verhulst or Verhulst-Pearl equation [19]. The general logistic equation is given by

Eq. (2) Logistic Growth Model for Penetration Rate

$$P_{(t)} = \frac{M\,P_0}{P_0 + (M - P_0)\,e^{-rt}} \tag{2}$$

where, P_0 = Penetration Rate at time t = 0, $P_{(t)}$ = Penetration Rate at time t = t, M = Carrying Capacity, and r = Intrinsic Growth Rate.

Here, P_0 is taken as the first non-zero penetration rate after 2013. Carrying capacity (M) is taken as 100%, with an assumption that, with advancements in EV technology, the penetration rate will reach 100% in the absence of any other alternative fuel technology. The above two parameters are fixed for every model. The variable parameters include intrinsic growth rate (r) and time (t). The variable t being dependent on the horizon year and base year; r is the only variable parameter left. For the present study, a logistic growth model is developed to fit the actual penetration rate till 2021, with various values of r by trial-and-error method for all category groups. The summary of all the models developed, with all variable and fixed-parameter is provided in Table 5.

The results of vehicular growth forecasting and penetration rate forecasting are used to arrive at EV forecasts for the study area. The chart given in Fig. 4 provides the category-wise cumulative number of EVs registered till

Table 5. Logistic growth models for forecasting penetration rates.

Series	Base year	Base penetration rate (P_0)	Intrinsic growth rate (r)	Logistic growth model
Surat – 2W	2013	0.006324%	0.75991076%	$P_{(t)} = \frac{100 \times 0.006324}{0.006324 + (100 - 0.006324)\,e^{-0.75991076 \times t}}\%$
Surat – 3W	2016	0.017044%	1.1808679%	$P_{(t)} = \frac{100 \times 0.017044}{0.017044 + (100 - 0.017044)\,e^{-1.1808679 \times t}}\%$
Surat – 4W	2013	0.003546%	0.6525463%	$P_{(t)} = \frac{100 \times 0.003546}{0.003546 + (100 - 0.003546)\,e^{-0.6525463 \times t}}\%$

2025 and 2030 for Surat. According to this, Surat is expected to have 88,231 2W, 4275 3W, and 5607 4W by 2025. These figures will increase to 6,78,920 2W, 16,754 3W and 96,975 4W till 2030. Here, the penetration rates are derived using a logistic growth model based on the available past penetration rates. Hence it can be inferred that projections made by the logistics growth model are more reliable and can be used for energy demand estimation and planning of charging infrastructure.

5. Energy demand assessment

The public charging requirement is assessed to calculate the daily energy demand for Surat city. For which characteristics of EV models available in India and the travel needs of the residents is studied.

5.1. EV models available in the Indian market

Under Faster Adoption and Manufacturing of Electric and Hybrid Vehicles in India (FAME-II), the government of India has approved various models of EVs under different categories. A total of 170 models of EVs are registered. Out of which 3W has the highest, 89 models available in the market. After 3W, 2W has the second highest, 57 models registered under FAME-II. 4W has the lowest 24 models available in the Indian market. The characteristics of FAME-II electric vehicles are listed in Table 6.

Table 6. Summary of characteristics of FAME - 2.

Sr. No.	Characteristic	Measure (Approved 2W)	Measure (Approved 3W)	Measure (Approved 4W)
1	Average driving range	109.20 km	120.24 km	209.30 km
2	Average battery capacity	2.5 kWh	6.14 kWh	21.29 kWh
3	Average electric energy consumption	3.19 kWh/100 km	6.22 kWh/100 km	12.77 kWh/100 km

The average driving range, battery capacity, and electric energy consumption for52 approved 2W models are 109.20 km, 2.5 kWh, and 3.19 kWh/100 km, respectively. In terms of 3W, the scheme has approved 86 models with an average driving range, battery capacity, and electric energy consumption of 120.24 km, 6.14 kWh, and 6.22 kWh/100 km, respectively. With 4W, 23 models are approved with an average driving range of 209.30 km, an average battery capacity of 21.29 kWh, and average electric energy consumption of 12.77 kWh/100 km, respectively.

5.2. Vehicle kilometer traveled

Vehicle kilometers traveled per day have been worked out in two ways, by conducting a survey and from existing reports. The method used for deriving kilometers traveled per vehicle per day from existing reports is mentioned below. The formula used for this purpose is

Eq. (3) *Vehicle Kilometers Traveled per day*

$$\begin{array}{c} Kilometers\ traveled \\ per\ vehicle\ per\ day_x \end{array} = \frac{Per\ capita\ trip\ generation\ rate \times Modal\ Split_x \times Avg.trip\ length_x}{Vehicle\ ownership\ ratio_x} \tag{3}$$

Population statistics from the Surat Urban Development Authority (SUDA) development plan report 2035 and other data from the Comprehensive mobility plan (CMP) 2018 were used to determine VKT.

Category-wise daily VKT: Daily VKT/vehicle obtained from CMP 2018 and survey, along with adopted VKT for further analysis, is shown in Table 7. This adopted VKT/vehicle is then multiplied with EV forecasts to arrive at the total daily VKT for 2025 and 2030. The results of which are shown in Table 7.

5.3. Daily energy need

To calculate daily energy demand, multiply average energy consumption by daily kilometers traveled. Table 8 shows that daily energy requirements for Surat in 2025 and 2030 will be 183 MWh and 1564 MWh, respectively.

The majority of public charging requirements in the initial stage are anticipated to be fulfilled by home and workplace charging. But for mass diffusion, public charging infrastructure will be required to fulfill the demand.

Table 7. Summary of EV forecasts.

Sr. No.	Vehicle category group	Daily VKT/Vehicle from CMP-2018	Daily VKT/Vehicle from Survey	Adopted daily VKT/Vehicle	Forecasted total daily VKT in 2025	Forecasted total daily VKT in 2030
1	2-Wheeler	12.10	30.03	30	26,46,930	2,03,67,600
2	3-Wheeler	101.97	108.70	115	4,91,625	19,26,710
3	4-Wheeler	10.99	33.83	35	1,96,245	33,94,125

Table 8. Daily energy requirement — 2025 & 2030.

Sr. No.	Vehicle category	Experienced Avg. energy consumption	Kilometers traveled per day in 2025	Energy requirement in 2025	Kilometers traveled per day in 2030	Energy requirement in 2030
1	2-Wheeler	4.15 kWh/100 km	26,46,930	110 MWh	2,03,67,600	845 MWh
2	3-Wheeler	8.09 kWh/100 km	4,91,625	40 MWh	19,26,710	156 MWh
3	4-Wheeler	16.60 kWh/100 km	1,96,245	33 MWh	33,94,125	563 MWh
	Total energy requirement			183 MWh		1564 MWh

Table 9. Daily public charging need — 2025 & 2030.

Sr. No.	Vehicle category	Assumed share of public charging	Daily energy need		Daily public charging need	
			2025	2030	2025	2030
1	2W	15%	110 MWh	845 MWh	16.5 MWh	126.75 MWh
2	3W	40%	40 MWh	156 MWh	16 MWh	62.4 MWh
3	4W	30%	33 MWh	563 MWh	9.9 MWh	168.9 MWh
Total			183 MWh	1564 MWh	42.4 MWh	358.05 MWh

The share of public charging will depend on several factors, including the availability of private parking facilities, which will further depend upon housing typology. Hence it can be said that the share of public charging will depend on housing typology. Now, dividing houses into three categories, namely detached, semi-detached, and group housing, on the basis of parking availability. The detached category includes bungalows and duplexes, considering private charging is available for 4W and 2W both. The semi-detached category includes row houses and gala-type constructions, considering private charging is available for 2W only. And the last category is group housing, which includes flat, apartments, and slums (Reinforced Cement Concrete (RCC) and Non-RCC), where private charging facility is unavailable. As discussed earlier, Surat has a higher group housing share than detached and semi-detached housing. Hence need for public charging will be higher than the public charging requirement of any average city. Thus, an assumption has been taken for the requirement of public charging for each category of vehicles, which is shown in Table 9.

5.4. Daily public charging need

The relation shown below has been used for deriving public charging needs from daily energy requirements and share of public charging.

Eq. (4) *Daily public charging need*

$$Daily\ public\ charging\ need = Daily\ energy\ need \times Share\ of\ public\ charging \tag{4}$$

The results obtained from the above relation are shown in Table 9, according to which daily public charging demand in 2025 and 2030 will be 42.4 MWh and 358.08 MWh, respectively.

6. Conclusion

The purpose of this study was to estimate the energy requirement due to the increase in the EV population and to plan for the charging infrastructure for the study area. With increased electrification of mobility, many industry experts anticipate that the domestic market will develop in the next 1–2 years. Accordingly, charging demand was assessed on the city's traffic characteristics. The charging demand assessment forecasts the daily energy demand for EV charging in the study area and demand for public charging for 2025 & 2030. The daily energy consumption is estimated to reach 183 MWh in 2025 and 1564 MWh in 2030, representing roughly 2% and 10% of Surat City's energy demand in 2025 and 2030, respectively. With the increased market penetration of electric vehicles, energy consumption is growing at a quicker rate. With more EVs on the road, there will be more demand for charging and more energy use in some places, which can put a lot of stress on the power grid. In the absence of proper management, there is a risk of power grid failure. So, there comes a need for a properly planned system. The emerging nations are focused on the metro, e-mobility, and public transit, which might increase energy consumption. The article focuses only on personalized vehicles, and the energy demand has not been determined for metro & public transport. This anticipated demand, however, applies to the entire city, and because of the unequal distribution of the city's population, the energy demand is also unevenly distributed. Hence, to tackle the unevenly distributed energy demand and prevent grid failure, charging infrastructure should be deployed systematically using technologies like Geographic Information System (GIS). This growing requirement for charging will need a huge number of chargers, making it difficult for Urban Local Bodies (ULBs) to offer public charging stations. As a result, battery-swapping infrastructure and related alternatives should be researched for future charging demands. In future studies, with the increase in the EV population, user perception can also be included to arrive at more accurate energy demand forecasts. Also, investigating users' need for public charging can help determine the actual share of public charging and, thus, increase energy demand. The EV population per grid can also be taken into consideration when calculating the actual energy demand of the micro-level grid.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

No data was used for the research described in the article.

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