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ADDRESSING INFRASTRUCTURE GAPS IN MUMBAI'S 2-WHEELER EV CHARGING NETWORK: A FOCUS ON ACCESSIBILITY, USABILITY, AND USER FEEDBACK

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ABSTRACT

Electric vehicles (EVs) are transforming transportation in Mumbai, with 2-wheeler EVs gaining significant traction among commuters. However, the insufficient availability and accessibility of charging infrastructure remain critical challenges. This study investigates the experiences of 2- wheeler EV users in Mumbai, focusing on the barriers they encounter when charging their vehicles. Given Mumbai's dense traffic and urban complexities, limited charging points, long waiting times, and infrastructural constraints can hinder the user experience and discourage further adoption of EVs. The findings provide key insights into optimal charging station locations based on a comprehensive analysis of population density, traffic flow, and urban planning frameworks. Additionally, the study addresses the need for standardized charging protocols, advanced technologies, and user-friendly interfaces to enhance the usability of charging stations. The study emphasizes that addressing these challenges is crucial not only for the user experience but also for policymakers, urban planners, and stakeholders aiming to expand Mumbai's EV infrastructure. Moreover, the environmental benefits of 2-wheeler EV adoption are examined, including reductions in energy consumption, carbon emissions, and overall environmental impact. By analyzing these factors, the research highlights the positive environmental outcomes of investing in robust charging infrastructure. Key challenges, such as high costs, feasibility concerns, and policy limitations, are also explored, offering a holistic understanding of the practical barriers to improving the EV charging network. The study concludes with actionable recommendations aimed at overcoming these challenges, fostering sustainable growth, and ensuring the efficient deployment of 2-wheeler EV charging infrastructure across Mumbai.

Keywords: Electric Vehicle Usability, 2-Wheeler EV Charging Infrastructure, Spatial Distribution of Charging Stations, Sustainable Transportation in Mumbai, Urban Mobility and EV Adoption, Urban Planning

1. INTRODUCTION

A 2-wheeler EV is a bicycle equipped with an electric motor that may be activated to assist with or replace pedaling. In the bustling city of Mumbai, "2-wheeler EVs" are gaining popularity due to their eco-friendly nature and efficient mode of transportation. Unlike traditional two-wheelers that run on fossil fuels, 2 wheeler EVs rely on electricity as their primary source of power. This shift towards

electric vehicles is driven by the need to reduce carbon emissions and combat the adverse effects of climate change. Mumbai, being a densely populated city with heavy traffic congestion, is an ideal environment for the adoption of 2-wheeler EVs. These vehicles offer numerous advantages over their conventional counterparts Niti Aayog, G. (2024). Firstly, they produce zero tailpipe emissions, contributing to cleaner air quality and reducing the city's overall carbon footprint. Secondly, 2-wheeler EVs are quieter, resulting in reduced noise pollution in the bustling streets of Mumbai. Additionally, the cost of operating an electric vehicle is significantly lower compared to traditional

petrol or diesel-powered two-wheelers, as electricity is generally cheaper than fossil fuels. The adoption of 2-wheeler EVs in Mumbai is also supported by the government's initiatives and policies Alanazi, F. (2023). The Maharashtra state government has introduced various incentives and subsidies to promote the use of electric vehicles, including 2 wheelers. These incentives aim to make electric vehicles more affordable and accessible to the general public. Furthermore, the government has been investing in the development of charging infrastructure across the city, ensuring that EV owners have convenient access to charging stations. This infrastructure expansion is crucial for the widespread adoption of 2-wheeler EVs, as it addresses the concern of range anxiety and encourages more individuals to switch to electric vehicles Suman et al. (2024).Overall, the concept of 2-wheeler EVs in Mumbai represents a significant step towards a greener and more sustainable future for urban transportation. The rise of 2-wheeler EVs in Mumbai has also sparked a wave of innovation and entrepreneurship in the city. Start-ups and companies are now focusing on designing and manufacturing electric two-wheelers that cater specifically to the needs of the urban population. These vehicles are compact, lightweight, and agile, making them ideal for navigating through the city's narrow streets and congested traffic. Additionally, many of these electric two-wheelers come equipped with advanced features such as regenerative braking, smart connectivity, and long-lasting batteries, further enhancing their appeal to consumers. The popularity of 2-wheeler EVs in Mumbai has also led to the emergence of new business models and services. For instance, there are now electric scooter rental services available in the city, allowing individuals to rent an electric scooter for short commutes or leisure rides. These rental services not only provide a convenient and affordable transportation option but also contribute to reducing the number of privately owned vehicles on the road, thereby easing traffic congestion. The adoption of 2-wheeler EVs in Mumbai has not only had environmental and economic benefits but has also positively impacted public health. The reduction in air and noise pollution resulting from the use of electric vehicles has led to improved respiratory health for the city's residents. Additionally, the shift towards electric two-wheelers has encouraged more people to choose active modes of transportation, such as cycling or walking, for shorter distances, promoting a healthier and more active lifestyle Roopa et al. (2024)

The success of 2-wheeler EVs in Mumbai has inspired other cities in India and around the world to follow suit. Governments and policymakers are now looking to replicate the initiatives and policies implemented in Mumbai to promote the adoption of electric vehicles in their cities. This global shift towards electric mobility is seen as a crucial step in reducing greenhouse gas emissions and combating climate change on a larger scale. However, challenges remain in the widespread adoption of 2- wheeler EVs in Mumbai. One of the main challenges is the limited availability of charging infrastructure, especially in residential areas and public spaces. To address this issue, the government and private companies are working together to install more charging stations across the city, ensuring that EV owners

have convenient access to charging facilities. Additionally, there is a need for increased awareness and education about the benefits of electric vehicles among the general public, as well as the availability of financial incentives and subsidies to make electric two-wheelers more affordable for all segments of society.

2. RATIONALE

The shift toward electric vehicles (EVs) represents a transformative moment in addressing climate change and advancing sustainable urban transportation. As metropolitan areas such as Mumbai struggle with rising carbon emissions and the negative consequences of fossil fuel reliance, the development of a robust EV charging infrastructure is crucial. This paper aims to bridge a significant gap in understanding the current state and future needs of 2-wheeler EV charging infrastructure in Mumbai by synthesizing existing research and providing localized insights.

Sulabh Sachan, P. S. (2022).provides a comprehensive analysis of the status and future challenges of EV charging infrastructure planning in India. The study highlights the considerable obstacles India faces due to environmental degradation and increasing emissions, emphasizing the necessity for a sustainable transportation ecosystem. Despite the Indian central and state governments' efforts since 2013 to promote EV development, fragmented policy landscapes and frequent strategy shifts have hampered progress. Maharashtra's leadership in EV sales in 2022 indicates regional success, yet the inconsistent policy landscape across the country undermines broader adoption. This paper builds on these findings by focusing specifically on Mumbai, offering a detailed examination of its unique urban environment and infrastructural challenges. By understanding Mumbai's specific context, the paper aims to identify key areas for improvement in policy and implementation, providing actionable insights that can be scaled across India Sulabh Sachan, P. S. (2022).

The study by Kchaou-Boujelben, M. (2021) on the charging station location problem in the United Arab Emirates (UAE) emphasizes the complexity of optimal site selection and the significant investment required for public EV chargers Kchaou-Boujelben, M. (2021)The research highlights the necessity of strategic planning to efficiently meet recharging demand while staying within budget constraints. This study's insights are particularly relevant for Mumbai, a densely populated city where land and financial resources are at a premium. By mapping the spatial distribution of existing charging stations and identifying areas with limited access, this paper will propose optimal locations for new installations. These recommendations will be based on demand patterns and urban dynamics, ensuring that new infrastructure is both effective and sustainable Anil Khurana, V. V. (2019).

Muhammad Shahid Mastoi, Z. S. (2022)provide an extensive analysis of EV charging station infrastructure, policy implications, and future trends in Korea. Their study underscores the environmental benefits of EVs, the efficiency of charging infrastructure, and the critical role of strategic station placement and grid integration Muhammad Shahid Mastoi, Z. S. (2022)The analysis of EV categorization, charging modes, and optimization techniques to reduce range anxiety is particularly relevant for Mumbai. By integrating global perspectives from this study, the paper will highlight the importance of smart grid integration, bidirectional charging, and the potential of Vehicle-to-Grid (V2G) technology. These advanced technologies can play a crucial role in Mumbai's transition to a more sustainable transportation system, offering solutions to some of the most pressing challenges faced by 2-wheeler EV users.

By synthesizing insights from these studies, this paper will not only map the current landscape of 2- wheeler EV charging infrastructure in Mumbai but also evaluate user experiences and identify practical solutions to enhance accessibility and usability. The comprehensive survey and data collection methodology will ensure that the findings are robust and representative of the user base. The insights gained will contribute to formulating policy recommendations and strategic planning, aimed at fostering a sustainable and efficient EV ecosystem in Mumbai.

Additionally, the study will address the diverse economic, social, and political conditions influencing infrastructure planning, as highlighted by Sulabh Sachan, P. S. (2022) . By focusing on the unique challenges and opportunities within Mumbai, the study aims to provide a blueprint that can be adapted to other urban

areas in India and beyond. The recommendations will focus on creating a balanced charging infrastructure plan that caters to specific charging requirements, encourages competition among service providers, and fosters regulatory measures to promote innovation and competition.

The rationale for this study is grounded in the urgent need to develop a comprehensive understanding of the 2-wheeler EV charging infrastructure in Mumbai. By drawing on the latest research and providing localized insights, this paper aims to contribute significantly to the body of knowledge on sustainable urban mobility. The findings will not only benefit policymakers and urban planners in Mumbai but also serve as a model for other cities aiming to transition to eco-friendly transportation solutions.

3. AIM AND OBJECTIVES

This study aims to assess and address the challenges related to the charging infrastructure for 2- wheeler electric vehicles (EVs) in Mumbai City and its nearby suburbs.

The specific objectives of the study are to:

1) analyze the spatial distribution of charging ports for 2-wheeler EVs across Mumbai, identifying gaps and areas with limited access to inform strategic infrastructure planning.
2) assess the design and accessibility of 2-wheeler EV charging stations, examining factors such as usability, location, layout, and user interface to improve the user experience.
3) provide actionable recommendations based on the study findings to enhance the availability and efficiency of charging infrastructure for 2-wheeler EVs in Mumbai.

4. METHODOLOGY

The study was conducted in Mumbai, utilizing a self-validated questionnaire as the primary tool for data collection. Through one-on-one interviews with 160 EV users, this study aims to comprehensively investigate, analyze, and propose improvements to the existing EV charging infrastructure in Mumbai, with a specific emphasis on enhancing the experience of 2-wheeler users. The research methodology employed a random sampling technique with specific inclusion and exclusion criteria to ensure the selection of a diverse and representative sample of 2-wheeler EV users in Mumbai. The main objective of this study is to evaluate the

design and accessibility of 2-wheeler EV charging stations, taking into consideration factors such as usability, location, layout, and user interface to improve the overall user experience. Additionally, the study aims to map the geographical distribution of charging ports in Mumbai, identifying potential gaps and areas with limited access to charging infrastructure, which will contribute to a comprehensive understanding of spatial patterns in the charging infrastructure landscape. By conducting an in-depth analysis of the challenges faced by 2-wheeler EV users in Mumbai regarding charging locations and infrastructure, this study aims to provide valuable insights and recommendations for enhancing the existing EV charging infrastructure. With a focus on improving user experience and addressing issues related to accessibility and design of charging stations, this research seeks to contribute to the sustainable development of electric mobility in Mumbai.

An exploratory research design was adopted to gain preliminary insights into the experiences, challenges, and perspectives of EV users. This approach was selected due to the relatively nascent stage of EV adoption within urban mobility contexts and the need to develop a broad understanding of user experiences. The research design facilitated the collection of both quantitative and qualitative data, thereby providing a comprehensive overview of the subject matter.

The study involved a total of 160 EV users, chosen through purposive sampling to ensure the relevance and reliability of the data collected. The sample was diverse in terms of age, gender, and socio-economic background to ensure a comprehensive representation of the EV user population.

Ethical considerations were paramount in the design and implementation of this study. Participants were thoroughly informed about the study's purpose, their role, and their right to withdraw at any time without repercussions. Informed consent was obtained from all participants before their inclusion in the study. The researchers ensured that all collected data remained confidential and anonymized to protect participant privacy. Ethical approval was obtained from the relevant institutional review board before commencing the study.

The data collection process employed a combination of quantitative and qualitative methods to gather comprehensive information on EV users' experiences and perspectives. The primary tool used was – A self-constructed questionnaire administered to gather quantitative data on EV usage patterns, preferences, and challenges. The questionnaire included both closed and open-ended questions to capture a wide range of information; Direct observation methods were utilized to study the behaviours and interactions of EV users in real-world settings. This approach provided contextual insights that complemented the questionnaire data; semi-structured interviews were conducted with a subset of EV users and petrol pump owners to gain in-depth qualitative insights. The interviews explored participants' experiences, challenges, and perceptions of the EV ecosystem in Mumbai.

Random sampling techniques were employed to ensure the representativeness of the sample. This method helped mitigate selection bias and ensured that the findings could be generalized to a broader population of EV users in Mumbai. Data analysis was conducted using simple statistical methods. To enhance the validity and reliability of the findings, triangulation was used by comparing and cross-verifying data from multiple sources (questionnaires, observations, and interviews).

5. RESULTS AND DISCUSSION

Demographic Profile: Figure 1 provides an overview of the EV user's demographic profile. It reveals that among females, the highest percentage is in the 15-20 age group (12%), while among males, the 21-30 age group has the highest percentage (24%). The group has diverse riding backgrounds, with 27.5% having less than 1 year, 4.5% less than 10.1 years, 51% having 1.1-5 years, and 17% having 5.1-10 years of experience. Among 160 people, 81% have a driving license, while 19% do not, highlighting that most in the survey own a license but a notable portion does not. The service sector has the most graduates (27.5%) and HSC passed (11.9%), while the student sector has (23.8%) HSC passed, with other sectors having lower proportions of various educational qualifications.

Figure 2 provides an overview of the EV user's knowledge regarding the whereabouts of charging infrastructure. It reveals that among the participants, 31% are informed about charging infrastructure locations through petrol pumps, while 24% acquire this information from retailers. Additionally, 21% of respondents rely on word of mouth, 9% receive information from friends, and 5% obtain it from family members. These percentages are based on the total population that was interviewed for this specific question, highlighting the various sources through which individuals become aware of charging infrastructure locations.

To assess the design and accessibility of 2-wheeler EV charging stations, factors such as usability, location, layout, and user interface were evaluated to improve the user experience. The study revealed

Figure 1

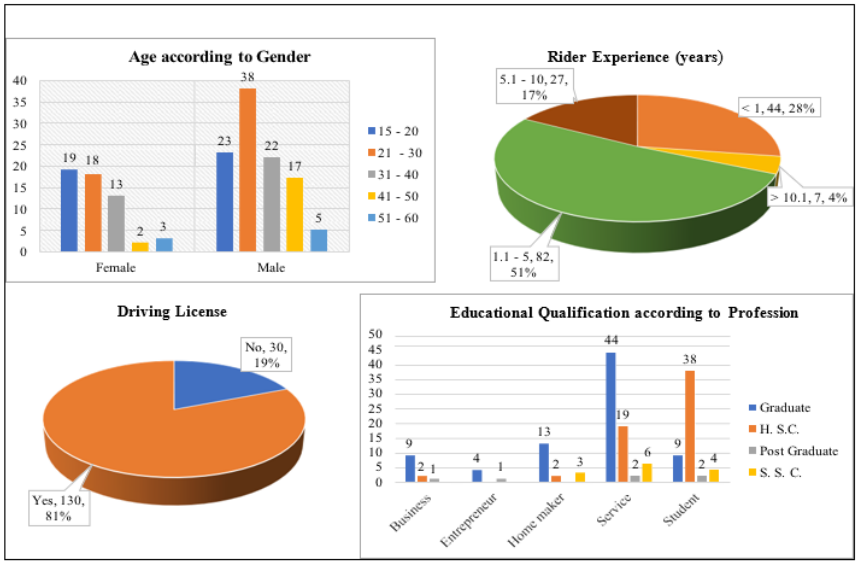


Figure 1 Demographic Profile of 2-Wheeler EV Users

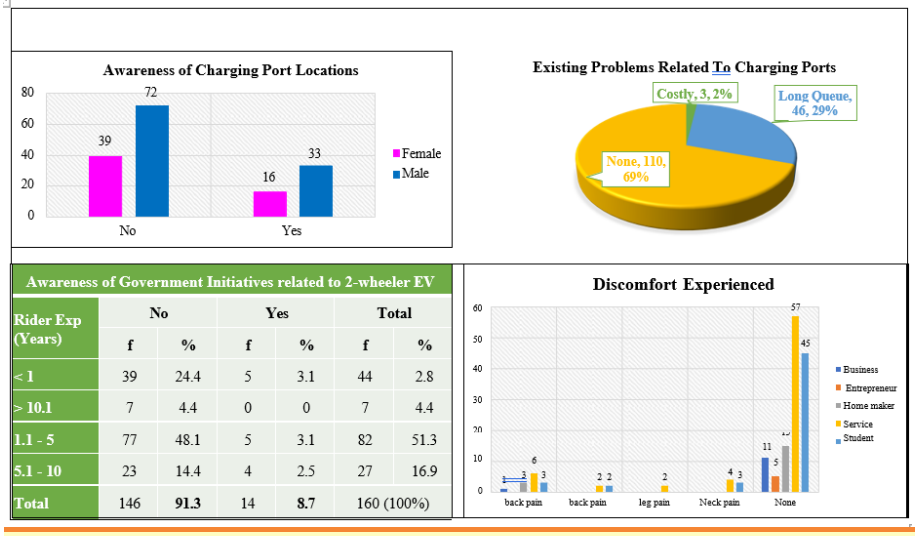
diverse sources of information influencing user knowledge about charging infrastructure. Among the participants, 31% reported that petrol pumps were their primary source of information about charging station locations, while 24% relied on retailers for this knowledge. Additionally, 21% of the respondents depended on word of mouth to learn about charging locations, 9% received information from friends, and 5% obtained it from family members.

These findings underscore the importance of having easily accessible and well-publicized information channels. The reliance on multiple sources suggests a need

for a more centralized and user-friendly approach to disseminating information about charging stations. Improved signage at petrol pumps, comprehensive listings by retailers, and enhanced digital platforms can play crucial roles in addressing these needs. Moreover, integrating user-friendly interfaces at charging stations, ensuring strategic placement in easily accessible locations, and optimizing the layout for convenient use can significantly enhance the overall user experience and encourage broader adoption of 2- wheeler EVs.

The data indicates that Ola currently manages a total of 8 electric two-wheeler charging stations across Mumbai and Thane districts, underscoring a deficiency in charging infrastructure. This underscores the urgency for increased funding and growth in charging amenities to cater to the rising

Figure 2



Awareness of Government Initiatives related to 2-wheeler EV						
Rider Exp (Years)	No		Yes		Total	
	f	%	f	%	f	%
< 1	39	24.4	5	3.1	44	2.8
> 10.1	7	4.4	0	0	7	4.4
1.1 - 5	77	48.1	5	3.1	82	51.3
5.1 - 10	23	14.4	4	2.5	27	16.9
Total	146	91.3	14	8.7	160 (100%)	

Figure 2 Awareness and Accessibility of 2-wheeler EV Charging Stations Awareness of Charging Port Locations

need for electric two-wheelers in the area. The lack of sufficient charging stations for electric two- wheelers in the Mumbai and Thane districts is a pressing issue that needs to be addressed promptly. With the increasing popularity of electric vehicles, companies like Ola must expand their charging infrastructure to meet the growing demand. This data highlights the need for increased investment in charging amenities to support the transition towards sustainable transportation options in the region. As Ola continues to expand its fleet of electric two-wheelers in Mumbai and Thane, the limited number of charging stations poses a significant challenge for both the company and its customers. To encourage more people to switch to electric vehicles and reduce carbon emissions, it is imperative to invest in the development of a robust charging infrastructure. The data indicates the need for immediate action to address this deficiency and ensure the successful adoption of electric two-wheelers in the area.

6. DISCUSSION

Figure 1 provides valuable insights into the knowledge of EV users regarding the locations of charging infrastructure. The data reveals that among the participants, 31% acquire information about charging infrastructure locations through petrol pumps, while 24% rely on retailers for this information, 21% of respondents depend on word of mouth, 9% receive information from friends, and

5% obtain it from family members. These percentages are based on the total population interviewed for this specific question, highlighting the diverse sources through which individuals become aware of charging infrastructure locations. This information underscores the importance of disseminating information through multiple channels to ensure widespread awareness and accessibility to charging amenities.

Results report a critical shortfall in the charging infrastructure for electric two-wheelers in the Mumbai and Thane districts, as indicated by Ola's current management of only eight charging stations across these regions. This inadequacy poses significant challenges to the growth and adoption of electric vehicles (EVs), particularly given the rising demand for sustainable transportation solutions.

The limited number of charging stations underscores an urgent need for enhanced investment and strategic expansion of charging infrastructure (Finding EV Charging Stations for Two-Wheelers Near You, 2024). As the popularity of electric two-wheelers continues to surge, the existing infrastructure is insufficient to support the increasing number of users. This inadequacy not only hampers the convenience for current EV users but also serves as a deterrent for potential users who may be considering a switch to electric vehicles.

For companies like Ola, which are spearheading the transition to electric mobility, the expansion of charging infrastructure is vital. Without adequate charging facilities, the company's efforts to increase its fleet of electric two-wheelers could face significant operational challenges, including longer wait times for charging and reduced availability of fully charged vehicles. This scenario could lead to customer dissatisfaction and ultimately slow down the adoption rate of electric two-wheelers.

The data calls for immediate and substantial investment in charging amenities. A robust charging infrastructure would facilitate seamless and convenient charging for users, thereby enhancing the overall user experience and encouraging more people to opt for electric vehicles. This, in turn, would contribute to reducing carbon emissions and fostering a more sustainable urban environment.

Moreover, addressing this deficiency requires a multi-stakeholder approach. Government policies and incentives could play a crucial role in accelerating the development of charging infrastructure. Public- private partnerships could be leveraged to pool resources and expertise, ensuring the deployment of charging stations in strategic locations that maximize accessibility and convenience for users.

The analysis highlights a pressing need for increased investment and strategic planning in developing a comprehensive charging infrastructure for electric two-wheelers in Mumbai and Thane. Such efforts are crucial to support the growing demand for electric vehicles, reduce carbon emissions, and promote sustainable transportation solutions in the region. The data serves as a clear indicator that immediate action is required to address the current infrastructure gaps and ensure the successful adoption and long-term viability of electric two-wheelers.

7. RECOMMENDATIONS

Based on the analysis of the current inadequacies in charging infrastructure for electric two-wheelers in Mumbai and Thane, the following suggestions are made to multiple stakeholders to improve charging infrastructure and accessibility. These recommendations are crucial if the metro city aims to successfully transition to green electric vehicles (EVs):

Government and Policy Makers

1) Policy Incentives and Support:

- Providing financial incentives such as subsidies, grants, or tax breaks to companies and individuals investing in charging infrastructure.
- Developing a comprehensive regulatory framework that mandates the inclusion of EV charging stations in new commercial and residential projects.
- Encouraging PPP (Public–private – Partnership) models to pool resources and expertise for the rapid deployment of charging stations.
- Simplifying the permitting process for setting up charging stations to reduce bureaucratic delays.

2) Urban Planning and Zoning

- Implementing zoning regulations that allocate specific areas for the development of charging infrastructure.
- Integrating EV charging infrastructure into smart city projects to ensure cohesive urban planning and efficient resource allocation.

Municipal Corporations

1) Public Charging Stations:

- Identifying strategic locations and prioritizing high-traffic areas such as shopping malls, public parking lots, transportation hubs, and tourist attractions for the installation of charging stations.
- Upgrading existing public infrastructure to support the additional power load required for EV charging stations.
- Encouraging the use of renewable energy sources, such as solar power, for charging stations to further enhance environmental benefits.

Private Sector and Businesses

1) Corporate Responsibility and Investment

- Encouraging businesses to install charging stations at workplaces to facilitate employee use.
- Partnerships with retail chains, hotels, and restaurants to provide charging facilities to customers.
- Collaborating with utility companies to develop and manage an efficient and reliable power supply network for charging stations.

2) Technology and Innovation

- Investing in advanced technologies such as fast charging and wireless charging to reduce waiting times and improve user convenience.
- Developing smart grid solutions that optimize energy usage and manage demand fluctuations efficiently.

Electric Vehicle Manufacturers

1) User Education and Engagement

- Launching awareness campaigns to educate consumers about the benefits of EVs and the locations of charging stations.

- Developing mobile apps that provide real-time information on the availability and status of nearby charging stations.

2) Collaborative Efforts

- Working towards the standardization of charging plugs and systems to ensure compatibility across different EV models and charging stations.
- Joint ventures with other EV manufacturers and stakeholders to fund and expand the charging infrastructure network.

Citizens and EV Users

1) Community Engagement

- Participating in feedback mechanisms to report issues and suggest improvements for existing charging infrastructure.
- Demand for more charging stations in residential areas and public places through community groups and local governance meetings.

2) Sustainable Practices

- Encouraging off-peak charging alleviates pressure on the power grid and reduces charging costs.
- Promoting the use of shared EVs and communal charging solutions to maximize the use of available infrastructure.

Transitioning to green electric vehicles in a metro city like Mumbai requires a concerted effort from multiple stakeholders. The government needs to provide a supportive policy environment, municipal corporations must prioritize infrastructure upgrades, businesses, and private sectors should invest in advanced charging solutions, and EV manufacturers need to engage and educate users. Additionally, citizens must actively participate in advocacy and sustainable practices. By working collaboratively, these stakeholders can develop a robust and accessible EV charging infrastructure, paving the way for a greener, more sustainable urban mobility future.

8. SCOPE OF STUDY

Based on the results of the current study focusing on the charging infrastructure and accessibility for electric two-wheelers in Mumbai and Thane, several avenues for further research can be explored, such as a longitudinal study to assess the long-term impact of the implemented strategies and interventions aimed at improving charging infrastructure. This study could track changes in EV adoption rates, charging station usage patterns, and overall environmental outcomes over an extended period. User Satisfaction levels and overall experience of electric two-wheeler users with the charging infrastructure can be investigated. This research could delve deeper into factors influencing user satisfaction, such as charging station reliability, waiting times, ease of use, and payment methods.

Exploring emerging technologies and innovations in EV charging infrastructure, such as fast-charging solutions, wireless charging, and smart grid integration. Assess the feasibility and effectiveness of implementing these technologies to enhance charging accessibility and efficiency, is another possibility. These further studies would contribute to a deeper understanding of the challenges

and opportunities surrounding EV charging infrastructure and support ongoing efforts to promote sustainable urban mobility.

INFORMED CONSENT

Before their participation, all participants provided written informed consent, demonstrating their understanding of the study's objectives, procedures, and potential risks.

CONFLICT OF INTERESTS

None.

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