Innovations in Computing and Emerging Technologies

ISSN: 3106-6518 (Print) 3106-6526 (Online) | Issue: 01

Peer-Reviewed Academic Journal

Research Article

Cloud-Enabled Electric Vehicle Charging and Management: A Prototype Model for Pakistan

Muhammad Waqas

Email: 203149@students.au.edu.pk, ORCID: 0009-0008-3515-2203

Submitted	Accepted	Published	Article No.
20-Oct-25	26-Nov-25	19-Dec-25	ICET0125-274

Affiliations:

Department of Computer Science, Air University, Islamabad, Pakistan

Abstract

The increase in the adoption of electric vehicles (EV) in Pakistan has led electric vehicle owners to face many issues. These issues include searching for the nearest charging station, long waiting in queues at charging stations, difficulty in making payments of charging sessions and trip planning for long drives on electric vehicles. Due to all these, electric vehicle owners in Pakistan face frustration and become hesitant in the daily use of electric vehicles. Although there are some global EV platforms available to address these issues, but they do not provide a solution in the context of Pakistan. To address these issues, this study presents ChargeEase, a cloud-based prototype that allows users to find the nearest charging station according to their location using Open Street Maps API, see reviews of charging stations left by other users, remotely book a charging slot at station with a simulated local gateway of payment and leave a review of charging station after charging session. The application is developed using HTML, CSS and JavaScript for frontend and backend services like user authentication, real-time slot booking, etc., are powered by Firebase. The mobile version of the application is a web wrapper in Flutter using WebView to access its services. When the application was tested by users, the results showed that users consistently accomplished simple tasks like charging station discovery and reservation of a charging slot, while the trip planning feature faced limitations of greedy routing strategy in sparse regions and revealed slot booking release time issues in session lifecycle management. Quantitatively, urban areas showed a high success percentage, whereas long-distance trip plans showed a significant decrease in success and increase in stops in the route of the trip, which indicated sensitivity to the number of charging stations available in an area. These results show the feasibility of a localized electric vehicle charging stations ecosystem and highlight practical implications for improvement, such the integration of a real local payment gateway, and automatic slot-expiry mechanisms. Currently, this application only aims to show as proof-of-concept of these discussed features and their performance with limitations.

Keywords: : Electric Vehicles, Charging Station, Digital Cloud-based Platform

---

1 Introduction

The increase in use of electric vehicles has been the main key policy goal of Pakistan. The government had introduced Electric Vehicle Policy [1] 2020-2025 to encourage the use of electric vehicles by offering incentives for manufacturers and consumers, like reducing taxes and import and customs duties on electric batteries, equipment for charging and investment in infrastructure of charging. The regulations regarding electric vehicles were also done under Pakistan Electric Vehicles Charging Infrastructure and Battery Swapping Regulations [2] 2024 to support electric vehicles adoption by encouraging partnerships, cost-efficient tariffs of electricity and one-window operations for business. Despite these encouraging policies and regulations, the real-time experience of users remains indecisive. The charging stations are located irregularly in geographical locations. Due to this, many electric vehicle owners don't have accurate information about charging slot availability/ Thus, there is no digital platform available for finding the nearest charging station, booking a slot and planning long-trips on an electric vehicle. Therefore, practically, the problem that electric vehicle owners face in Pakistan is divided into two parts as follows,

1. Infrastructural issues like an irregular and scarce number of charging stations.
2. Lack of a digital platforms to simplify the charging and related management of electric vehicles.

The existing global electric vehicle digital solutions cannot be used by electric vehicle owners in Pakistan due to a lack of official support by major electric vehicle brands, a small number of charging stations, no compatibility with foreign payment systems, and most applications are company-oriented only, which means they only work with certain brands of electric vehicles. Considering all this, this study makes 3 novel contributions as follows.

1. The design and implementation of a local cloud-based electric vehicle management application prototype specially developed for electric vehicle owners in Pakistan.
2. The implementation of a trip planning algorithm tailored for an area with sparse charging stations.
3. User testing of the application to evaluate its performance in real-time and highlight its limitations

The objectives of this research paper are:

1. To develop an electric vehicle management cloud based application that helps in locating nearest charging station according to user's location, allowing user to remotely book charging slot of station upon confirmation of payment, provide feedback system to user to improve charging experience, plan trip of long drives for electric vehicles according to their available battery percentage, speed and mileage, and lastly provide a platform to build an online community of electric vehicle owners where they can chat with each other.

2. To implement and conclude performance-based results of the algorithm for trip planning

3. To conduct user testing, identify limitations and derive conclusions for future development of such a similar application.

The remaining part of this paper is structured as follow: the literature review of existing similar digital solutions with their limitations is discussed in Section 2. Section 3 mainly discusses the methodology and architecture of the application to explain its working along with its algorithm. The results and discussion about the performance of this application prototype are presented in Section 4. Finally, Section 5 contains the conclusion from this study and the work of this application, and its limitations, with a light on future scope.

2 Literature Review

2.1 Charging Systems

Location-oriented platforms provide only general information about charging stations, not real-time slot availability or user reviews. However, Kim et al. proposed a study in which the route of the user is directly influenced by the availability of a charging slot at a charging station [3]. In the same way, Dastpak et al. discussed in their paper the real-time enroute of users according to slot availability to solve queue problems at charging stations [4]. These studies emphasize IoT-system architecture at charging stations to address issues like queue management and efficient route selection. Nonetheless, these studies assume dense charging station availability in an area and reliable conditions of charging stations, which are unpredictable in the context of Pakistan.

2.2 Trip-planning Algorithms

The trip planning in case of electric vehicles is different from traditional trip planning due to distance coverage, charging station availability, and battery percentage available. Martinelli's study presents that nonlinear charging patterns and the shortest-path strategy usually fail in actual battery models [5]. Abid et al.'s paper reviews algorithms and their performance with trade-offs in real-time implementations [6]. These papers show that the effectiveness of route discovery is dependent on number of charging stations available in an area. The complex optimized algorithms may not be efficient in areas with a smaller number of charging stations. Due to this reason, range-effective greedy algorithm is more effective even with its limitations in areas with a smaller number of charging stations.

2.3 EV platforms in developing regions

The proposed solutions from developed countries usually assume fast internet speed, large datasets, and integrated payment gateways, while these hypotheses fail when taken in the context of less developed regions. Zulfiqar et al. presented a study showing that electric vehicles adoption in Pakistan faces not only finance but infrastructural problems too which causes frustration among potential electric vehicle owners [7]. Durmus et al. presented that public electric vehicle digital platforms need to have feedback from users and involvement from the government to attain users' confidence [8]. These papers show that the proposed digital platform must be compatible with local charging stations, and community-based to increase adoption among users in the market.

2.4 Theoretical Framework

From all this discussion, we can say that in these emerging electric vehicles market, the unavailability of reliable information causes hesitation and range anxiety, which ultimately decreases intercity use of electric vehicles. So, a cloud-based digital platform can decrease anxiety by simplifying the process of finding the nearest charging station, booking a charging slot remote and trip planning according to available battery percentage, speed and vehicle mileage on long drives, thus decreasing adoption constraints.

2.5 Research Questions

In light of these studies, we examine 1) Can a local cloud-based platform help users in finding the nearest charging station and booking slot in comparison with informal methods? 2) Will range-efficient greedy algorithm be more effective in trip planning in an area with a smaller number of charging stations? 3) What limitations can be faced when such digital platform is developed and implemented in Pakistan?

2.6 Research Gap

The previous studies have focused on optimization of the algorithm in areas with many charging stations, and IoT-enabled charging stations. These do not study the following type of scenarios: 1) digital cloud-based platform specialized to deal with areas with a smaller number of charging stations 2) local technological issues faced by electric vehicle owners of Pakistan There is not a single digital simplified platform available for electric vehicle owners that facilitates them with features like searching for the nearest charging station, remotely booking a charging slot, seeing reviews of charging stations, community features like chat with other electric vehicle owners and range-aware algorithmic routing for a region like Pakistan. ChargeEase aims to address all these issues by providing a prototype application developed in the local context of Pakistan as proof-of-concept.

3 Methodology

3.1 Application Architecture

The ChargeEase consists of a cloud-based client-server architecture usingBackend as a Service(BaaS) to provide services including searching for the nearest charging station, remotely booking a charging slot, and a range-aware algorithm for routing on long drivers for electric vehicles in Pakistan. The architecture of ChargeEase mainly consists of 4 components as follows.

3.1.1 Routing Service

OpenStreetMap (OSM) [9] and Open-Source Routing Machine (OSRM) [10] APIs are used for routing of users and to calculate distance to a charging station. The main reasons for the selection of these as they are free to use, have higher accuracy in Pakistan and open access to the geometry of routes.

3.1.2 Charging Station

The information about charging stations is stored in Firebase Realtime Database [11], which includes the type of charger, slots available and reviews of the charging station. Slot booking is also done through Firebase Realtime Database to ensure the resolution of concurrency conflicts and failures of booking.

3.1.3 User Authentication

The users of the application are authenticated using Firebase Auth, as this prevents unauthorised users from using the application and ensures only registered users are able to use the application.

3.1.4 Payment API

The simulated dummy system is currently being used to mimic a transaction to book a slot. But as far as architecture is discussed, the interface for the actual local payment gateway API exists, which can be implemented when the API is available. However, this architecture is designed for prototype application to evaluate the performance and feasibility of the algorithm in areas with a smaller number of charging stations, and this architecture may not be the best choice for implementation at the commercial level. The architecture of ChargeEase can better be understood by looking at the following Figure 1:

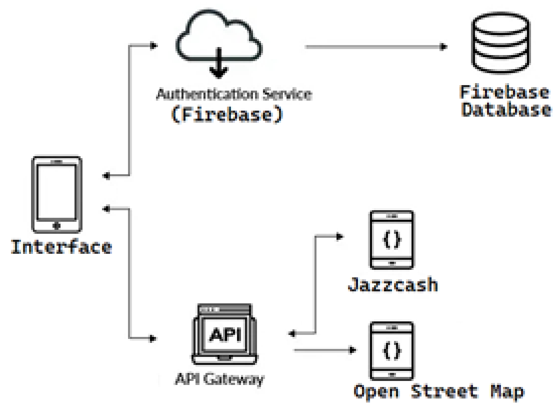

Figure 1: Application Architecture

3.2 Application Modules

The application ChargeEase consists of two main modules

1. User Module: For registration of users, login of registered users, search for nearest charging station, view station details, book a charging slot at station, view own booking history, chat with other users and plan trips for long drives

2. Admin Module: For adding new charging stations, deleting any existing charging stations, view all users and their booking history, viewing all reviews left by a user, deleting any review left by a user, and deleting any user profile

3.3 Use Case Diagrams

In a role-wise, the actors are expressed in figures 2 and 3.

3.3.1 User

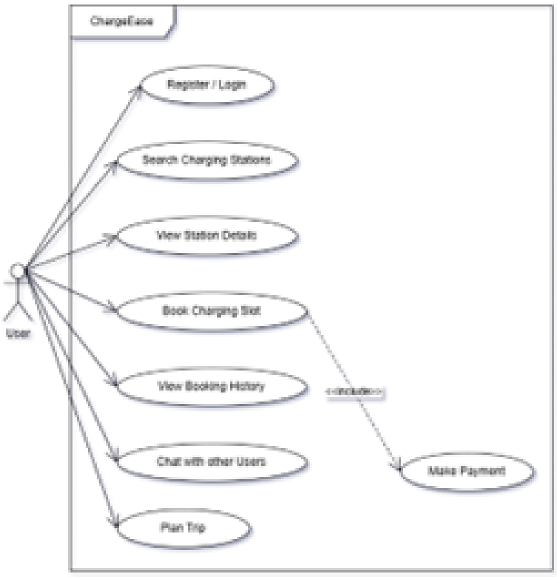

Figure 2: Use Case Diagram of User

3.3.2 Admin

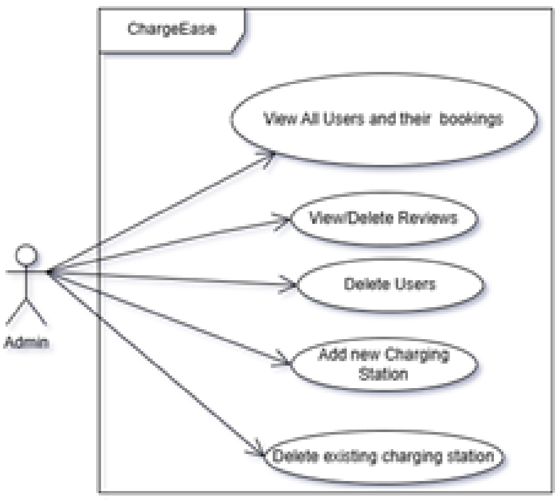

Figure 3: Use Case Diagram for Admin

3.4 Implementation

The ChargeEase application is already hosted and is available for use. As a new user, the site map of the application is represented in Figure 4.

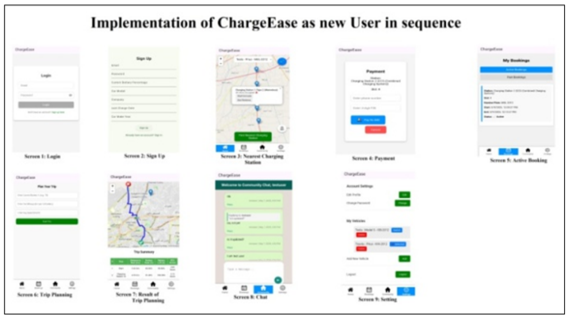

Figure 4: Screens of ChargeEase Application

Screen 1 shows Screen which appears when we launch the application on a phone or visit the URL in web browser (https://chargeease-a46b8.web.app/).
Screen 2 shows Sign-up screen asking for details.
Screen 3 shows First screen that you see when you log in as a new user after input of basic details of the vehicle.
Screen 4 shows Payment screen when we want to book an available slot at the charging station.
Screen 5 shows Booking screen showing active booking, which appears only if payment is confirmed.
Screen 6 shows Trip planning screen asking for details.
Screen 7 shows Showing the total route after selecting the starting and ending points in trip planning.
Screen 8 shows Chat screen showing all users' chatScreen
9 shows Showing setting options.

3.5 Trip Planning Routing

When trip planning routing is being done by an algorithm, it assumes the following and chooses route according to it.If the current battery percentage is B0 and the range of full charge is Rfull in which distance that can be covered from point of origin O to destination D, where C = {c1,c2,c3,. . . . . . ,cn} are the number of available charging stations in the route. It will route the user according to:

$$distance(x, y) \leq (B/100).R_{f}ull \tag{1}$$

Although this routing process is not the most optimal, it is a better choice for areas with or limited number of charging stations, which matches the context of Pakistan.

3.6 Pseudocode of Algorithm

see Algorithm [1]

3.6.1 Discussion

Complexity of Algorithm: ()
Deterministic: route plans will be the same on the same input values
Assumptions: recharge fully at every charging station,

Algorithm 1 Route Planning with Charging Stations

Require:

O, D ▷ start and destination coordinates on the map
B_0 ▷ current battery percentage available (0-100)
R_{full} ▷ maximum vehicle range in one full charge
C ▷ set of charging station coordinates available in that area

Ensure:

Complete the Route Plan or Fail to do so
Initialize:
RemRange $\leftarrow (B_0/100) \times R_{\text{full}}$
plan $\leftarrow [O]$
if distance$(O, D) \leq$ RemRange **then**
    plan.append(D)
    return plan
end if
cur $\leftarrow O$
while TRUE **do**
    if distance(cur, D) $\leq$ RemRange **then**
        plan.append(D)
        return plan
    end if
    Reachable $\leftarrow \{c \in C \mid \text{distance}(\text{cur}, c) \leq \text{RemRange}\}$
    if Reachable $= \emptyset$ **then**
        return FAILURE
    end if
    $c^* \leftarrow \arg\min_{c \in \text{Reachable}} \text{distance}(c, D)$
    plan.append(c^*)
    cur $\leftarrow c^*$
    RemRange $\leftarrow R_{\text{full}}$ ▷ assuming full recharge at every stop
end while

no queue assumed
This algorithm is efficient at prototype level testing for areas with a smaller number of charging stations

3.7 Evaluation Methodology

An arranged evaluation test was conducted to test the usability and performance of the prototype application.

1. Participants

   A sample of n = 24 users was selected for testing, with all having:

   - own smartphone
   - knowing using Google Maps and similar applications

   The demographics of users were as follows:
   EV owners = 8
   Hybrid Vehicle owners = 7
   Petrol Vehicle owners = 9
   Out of these 24, 9 were female, and 15 were male. All participants were from Multan.

2. User Testing Protocol

   Participants were asked to perform five main tasks without any given hint in this developed prototype application:

   Task 1: Search for the nearest charging station
   Task 2- Book any available charging slot
   Task 3- Plan a trip of a small distance (less than 20 km)
   Task 4- Plan an intercity trip
   Task 5- Write a review of the charging station

3. Metrics Measured

   - usability Metrics
     see Table 1.
   - Performance of the Routing Algorithm
     see Table [2].

Some ethical standards that were followed during this testing include no personal data collection of any user, a payment feature was a dummy simulation to avoid financial loss, and users were made aware that this data would be used for testing purposes.

3.8 Reason for Selection of Firebase and OpenStreetMap

OpenStreetMap and Open-Source Routing Machine were selected because they work with higher accuracy in the context of Pakistan, support raw geometry of routing, are totally free to use, and easily integrate into systems to simplify the route calculating process. Firebase was selected because it has a pre-built user authentication system, real-time database synchronization, allows hosting of webpages, has low maintenance overhead and is free to use.

Due to all these reasons, these were selected as they are a perfect fit for small-scale proof-of-concept prototype application and can easily be used to show proper functioning of intended features in a controlled testing environment with room to experiment.

3.9 Simulated Payment System

The prototype application uses a simulated dummy gateway of payment for transactions to book a charging slot remotely. This is done deliberately as the focus of this study is on routing users to charging stations, accurately booking charging slots and management related to electric vehicles, which could have been distracted due to its implementation. Secondly, using the actual payment transactional API would have introduced regulatory, cybersecurity and legal constraints and obligations according to the requirements of related ordinances of Pakistan. Also, using such an actual API would have brought its own connectivity and server connection issues, like bank user authentication and OTP OTP-based transactions and related issues. Lastly, the unavailability of a local payment API for testing purposes at this level also became one of reasons of the simulated system.

This is the reason for not using the actual API of the payment gateway.

Although the performance of applications may become different in real-time when the actual API is implemented. Due to this reason, the performance of the simulated dummy payment system is not measured in testing.

4 Results and Discussion

4.1 Results of usability testing

The data is already available in Table 1 on the previous page. The tasks that are specified for short distances have a high success rate of more than 90% representing effective routing and trip planning. But as soon as the distance is increased to intercity level, performance decreases significantly due to the low number of available charging stations. The overall average of success percentage of task completion is more than 80% in usability testing.

Table 1: Usability Metrics of ChargeEase

Task	Success Percentage	Average Time in seconds	Average Errors (incorrect clicks/re-tries)
Search for the nearest charging station	0.96	10s	2
Book any charging slot	0.85	28s	1
Plan a trip of a small distance	0.92	49s	4
Plan an intercity trip	0.61	137s	7
Write a review of the charging station	0.78	34s	2
Total Average	0.824	51.6s	3.2

Table 2: Performance of the Routing Algorithm of Trip Planning

Metric	Value
Mean Latency of Routing	27s
Maximum Latency of Routing	120s
Feasibility of Route	0.87

4.2 Results of the performance of the routing algorithm

The data is already available in Table 2 on the previous page. The performance of the routing algorithm is also within the interaction threshold, with a mean latency of 27s. However, its feasibility degrades strongly in long-range routes as performance decreases in the greedy routing algorithm [3]. Overall, it has a feasibility of the route at 87%.

4.3 System Limitations

1. Performance of the Routing Algorithm
   The implementation of the greedy heuristic routing algorithm adds unnecessary stops and increases detours and ends the route if no charging station is reachable with energy available at that stop. This is also supported by the greedy algorithm limitations in the study [6].
   Results: Implement multiple goals search while routing or forced A* for long trip planning.

2. Session Management Challenges
   The application is intended to work in a way that a slot booked by a user becomes available to other users after 15 minutes if they fail to reach the charging station or start charging their electric vehicle, but in actual implementation, it remains booked for an indefinite time. Client-side timers failed to reliably enforce TTL, a known limitation of front-end-driven state transitions [12].
   Results: Implementation of server-controlled system with timestamps and access to the user's booking data to validate or invalidate the status of a charging slot.

3. Payment workflow hurdles Since payment is a simulated dummy process to mimic the behaviour of actual transactions to protect participants in usability testing from financial loss, its absence may have significantly increased the success rate of tasks in usability testing. The previous Human Computer Interaction paper presents that financial friction significantly impacts perceived trust and completion time [13] Results- Implementation of the actual payment gateway API, and again, usability testing must be conducted to get actual performance results.

4. EV infrastructural gap in local context
   All these results help understand Pakistan's electric vehicle infrastructure, which has a smaller number of charging stations, non-consistent internet connectivity and a lack of publicly available APIs for local implementation of services. However, ChargeEase performs well in areas of dense charging stations and better internet connectivity but significantly loses performance in intercity travelling, as it is noted trend before in development electric vehicle platforms in other developing areas [14]. This all shows that digital solutions cannot be a replacement for infrastructural gaps, however can leverage along with the development and growth of infrastructure.

5 Conclusion and Future Work

This paper discussed ChargeEase, a cloud-based prototype application to facilitate electric vehicle owners in Pakistan in searching for the nearest charging station, booking a charging slot remotely, community features and range-aware trip route planning according to available battery percentage, mileage and speed. The testing of the performance of the application shows strong usability, real-time route algorithm performance and accurate management. However, the platform has limitations when planning a trip on long route due to a limited number of charging stations, greedy heuristic algorithm issues, impractical assumption of full charge at every stop and client-based slot release.This all concludes to directly connect with goals of study that ChargeEase significantly improves the experience of management of electric vehicle owners, but also highlights that any digital solution cannot substitute for the actual lack of infrastructure. ChargeEase contributes directly as a realistic part of the solution to the electric vehicle ecosystem of Pakistan and highlights that development must be equally done in digital solutions as well as in the infrastructure of electric vehicle charging to facilitate users.

5.1 Future Work

1. Implementation of capacity-aware, energy optimized routing algorithms to decrease the number of detours and increase efficiency
2. Directly connect chargers with the application to show users real-time information like power rating, queue capacity and charging availability to resolve assumptions of full charging at every stop
3. Implement server-based slot-releasing system
4. Implement an actual local payment API to make the application more practical at the commercial level

By addressing all these enhancements, ChargeEase or any other similar digital platform can evolve from a functional prototype to a working, actual, meaningful solution to increase electric vehicle adoption in Pakistan by simplifying the charging process and management.

References

[1] Government of Pakistan, NEW ENERGY VEHICLES POLICY 2025-30 Ministry of Industries and Production, Islamabad, Pakistan.

[2] NEPRA, Electric Vehicle Charging Infrastructure Regulations,? National Electric Power Regulatory Authority, Islamabad, 2021. [Online].
URL: https://www.nepra.org.pk

[3] G. Kim, Electric Vehicle Routing Problem with States of Charging Stations,Sustainability, vol. 16, no. 8, Art. 3439, Apr. 2024.

[4] M. Dastpak, F. Errico, O. Jabali and F. Malucelli, ?Dynamic Routing for the Electric Vehicle Shortest Path Problem with Charging Station Occupancy Information,arXiv, May 2023.

[5] L. E. C. Monteiro and R. Martinelli, The Electric Location-Routing Problem: Improved Formulations and Effects of Nonlinear Charging, arXiv, Feb. 2025.

[6] M. Abid, M. Tabaa, A. Chakir and H. Hachimi, Routing and charging of electric vehicles: Literature review,Energy Reports, vol. 8, pp. 556-578, 2022.

[7] M. Zulfiqar et al., Pakistanies Electric Vehicle Market: Challenges, Opportunities, and Future Pathways,? Journal of Clean Energy & Sustainability, vol. 75, no. 1, 2024.

[8] H. N. enyapar and U. Durmu, Importance of Charging Infrastructure for Public Adoption of Electric Vehicles: Recommendations for Turkey,Proc. Int. Conf. Smart Grid and Clean Energy, 2023.

[9] OpenStreetMap, OpenStreetMap, OpenStreetMap, 2024.
URL: https://www.openstreetmap.org/

[10] Project OSRM, project-osrm.org.
URL: https://project-osrm.org/

[11] Firebase,Firebase,Firebase, 2025.
URL: https://firebase.google.com/

[12] Z. K. Zhou, L. Cheng, L. Wen, X. Lu, and T. Ding, "A coordinated charging scheduling method for electric vehicles considering different charging demands," Energy, vol. 213, p. 118882, 2020.

[13] Kaewkitipong, L.; Chen, C.; Han, J.; Ractham, P. Human-Computer Interaction (HCI) and Trust Factors for the Continuance Intention of Mobile Payment Services.Sustainability?2022,?14,14546.

[14] V. Kumar, T. Panhale, P. Kale, and A. Gedam, Electric Vehicle Charging Station Finder And Slot Booking Mobile Application Using Flutter,International Research Journal of Engineering and Technology (IRJET), vol. 10, no. 03, pp. 827-831, Mar. 2023.