Flexible energy systems Leveraging the Optimal integration of EVs deployment Wave

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Author(s): Fabiano Pallonetto
Maynooth University (NUIM)

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List of Acronyms

Acronym	Meaning
EV	Electric Vehicle
DC	Direct Current
AC	Alternate Current
M	Month
WP	Work Package
ICE	Internal Combustion Engine
BMS	Battery Management System
SOC	State of Charge
T	Task
API	Application Programming Interface

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Executive Summary

T6.4 develops a testing framework validated at Maynooth University campus in Ireland to engage and promote the integration at the district level of demand response using aggregated controllable EV charging; it engages with communities and participants such as staff, students, and building managers, as well as a broader network of stakeholders through the Sustainable Energy Communities programme; and advance research in intelligent energy systems and user engagement. The motivation of setting up this testbed is to understand the challenges faced by EV owners on utilizing the charger infrastructure and the importance of a slot-based scheduling application at the workplace to address these challenges. The data acquired from the EV charging station can be used to nudge the behaviour of EV owners to consume more sustainable energy for EV charging and reducing the range anxiety to make EV a preferred choice for daily commute. Maximising the usage of available EV chargers and reducing the congestion at public charger by enabling more organizational EV chargers is also a goal of this testbed. The FLOW application developed for this testbed can be used as a benchmark for setting up organizational EV chargers for promoting EV adoption across the nation.

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1. Introduction

The automobile industry has seen a drastic change in the last decade with the adoption of EVs across all sectors. With improved battery packs and better vehicles that could compete and even outsmart the performance of ICE vehicles, EVs have become a preferred choice for many buyers. The concerns over depleting fossil fuels, carbon emissions, and global climate change have also fuelled the adoption of EV as a cleaner and greener solution for transportation. Electric motors offering better efficiency than ICE counterparts, zero noise and zero tail pipe emissions, with support from government grants for purchase, also motivate more buyers to choose EV.

The motivation for choosing Ireland as the testbed of the Flow EV charging app is mainly due to the increase in EV adoption in recent times. The figures from the Society of the Irish Motor Industry (SIMI) show that, in 2025, 23,085 new electric cars have been sold so far till October 2025, up almost 40% on the same period last year (RTE, 2025). Out of 123,858 new cars that were sold in the first ten months of the year, 25% of new car sales were petrol versions, followed by hybrid petrol electric cars at 22.5%, electric at 18.6%, diesel at 17% and plug-in electric at almost 15%. The 40% growth in EV sales, along with the increase in hybrid vehicles, shows the growing demand for EV charging infrastructure across the nation as well as the increased load on the existing EV charging infrastructure.

The ease of using a gas station and the low waiting time are the important advantages of ICE vehicles, which are still hindering vehicle owners from migrating to EVs, as the charging time is still higher even with DC fast chargers. Greater charging time increases the queuing time at the charging stations, too. Increasing the charging stations exponentially to solve this problem will not be a viable solution, as the initial cost of chargers is expensive and requires finding more space for setting up new charging. This motivates us to conduct a detailed analysis of identifying the challenges of EV charging and to come up with a solution to overcome those challenges in the best possible way.

1.1. Identifying the Challenges in EV Charging

The primary concern of the regular owners of ICE vehicles to migrate to EV was about the tank-to-tank distance that can be covered by the vehicle, and also the mileage offered across different climatic conditions. Charging the EV battery is not as quick when compared to filling gas in an ICE vehicle, and the time needed to charge varies from vehicle, battery pack and on the available capacity of AC/DC chargers. For long journeys and continuous daily usage, juicing up the EV battery to the right levels was always a concern in the minds of EV owners. Finding the EV charger, range anxiety about the upcoming journey and effectively using the time of charging were some of the important challenges still on the mind of EV owners. For the larger adoption of EV across the world, we need more EV charging stations as frequent as gas stations, or even more, considering the time for a full charge.

With fewer moving parts, EVs are considered to be easier to service and maintain than the ICE counterparts; however, the higher initial cost, battery warranty and replacement cost urge EV owners to drive maximum distance under the warranty period, which again increases the demand for EV chargers.

Task 6.4 focuses on setting up a Testbed at Maynooth University that facilitates EV owners to leverage the FLOW Mobile application to ensure better scheduling of the EV charging at the campus. This will help the EV owners for efficient time management and reduce the range anxiety to make EV a perfect

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choice for daily drive. We expect to build better insights from analysing data from the chargers that can be used to nudge the behaviour of owners to reduce range anxiety and ensure sufficient battery SOC for their daily need. The scheduling mechanism also aims to promote usage of more green energy for EV charging and allow fair distribution of slots to all the EV users across the campus. The analytics built from this Testbed can also help to set up EV charging points at institutions and organisations, that can motivate the employees to switch to a greener daily commute

1.2. Background Studies

A detailed background study was conducted by the student group from Maynooth University among various categories of EV owners and users to understand the challenges and concerns of owning and using the EV. This study provided valuable insights right from choosing the perfect location for the EV charger to designing the mobile application and even building the insights for enhancing the user experience.

During the observations and subsequent data collection, the team found that the EV users lacked knowledge about the existing charging stations, congestion in the charging facilities during peak hours and also hesitancy in EV users to move out their vehicles due to limitations in charging stations pertaining to slow chargers. During peak hours, the shared parking spaces are all occupied, restricting the influx of vehicles due to which EV users are unable to locate any charging stations. Moreover, due to the slow chargers at the larger charging stations, the EV users were unable to take out the vehicles during the day.

To further understand these issues, our team conducted both quantitative and qualitative research by performing in-depth in-person interviews of EV users at selected EV charging facilities. We have utilised Microsoft Excel and Google Analytics tools to perform data analysis on the collected data. We chose to conduct in-person interviews as part of our qualitative study since it provided explanation, context, appropriateness and acceptability. Also, as a result of the requirement to incorporate the prevalence criterion, we added several cross-sectional survey questions (Bengtsson, 2016).

EV charging stations at Maynooth University and University College Dublin were chosen as test-beds owing to the congestion concerns these stations had, especially during peak hours. After estimating the approximate influx of EVs in these test-beds during our observations, we decided on a sample size of 10 for each test-bed.

1	Reference Number I	How often do you us	How do you monitor	How long do you typ	How long does your	Do you pay for getti	If Yes, how much do	If No, how much are	How important are t	How important are t	How important are t
2	M001	A few times a month	3 hours	2 to 4 hours	2 to 4 hours	No	N/A	N/A	important	important	very important
3	M003	Several times a week	Just plug it in to charge	More than 4 hours	More than 4 hours	No	N/A	Half the price of petrol	neutral	less important	very important
4	M007	Once a week	2.5 Hours (Hybrid) - Sc	2 to 4 hours	2 to 4 hours	No	N/A	No idea about the cost	neutral	neutral	very important
5	U001	Several times a week	App	More than 4 hours	More than 4 hours	No	N/A	8 cents per kwh (Home	very important	important	important
6	M004	Several times a week	App	2 to 4 hours	More than 4 hours	No	N/A	Standard Rate, less is	neutral	very important	very important
7	U004	Rarely	Charge it for 15-20 min	Less than 30 minutes	Less than 30 minutes	No	N/A	N/A	very important	very important	important
8	U005	Several times a week	Through Phone App	More than 4 hours	More than 4 hours	No	N/A	0.59 Euro per KW (For	important	important	very important
9	U021	Almost every day	Do my work and come	More than 4 hours	More than 4 hours	No	NA	NA	important	important	important
10	M006	Several times a week	No Monitoring	More than 4 hours	More than 4 hours	No	N/A	ESB Rates	important	less important	very important
11	M002	Once a week	App on phone	2 to 4 hours	More than 4 hours	No	N/A	Not more than the dom	neutral	less important	very important
12	M005	Several times a week	Manually Check	2 to 4 hours	2 to 4 hours	No	N/A	No Idea	important	neutral	very important
13	U008	Several times a week	I do not	2 to 4 hours	More than 4 hours	No	n/a	Would prefer free charg	very important	important	important
14	U011	Once a week	App	More than 4 hours	More than 4 hours	No	N/A	N/A	important	least important	less important
15	U012	Almost every day	App	More than 4 hours	More than 4 hours	No	N/A	50 cents	less important	very important	very important
16	U013	Several times a week	Physically	More than 4 hours	More than 4 hours	No	N/A	60 cents /KWH	very important	very important	important
17	U016	Almost every day	no monitor	More than 4 hours	More than 4 hours	No	free	standard rate	very important	important	very important
18	U017	Rarely	app in phone	Less than 30 minutes	Less than 30 minutes	No	free	market rate	important	important	very important
19	U018	A few times a month	app on phone	2 to 4 hours	2 to 4 hours	No	free	market rate	least important	important	very important

Figure 1 : Snapshot of Data Collected

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1.2.1. Quantitative Analyses

Some of the key findings from the quantitative analysis are included below with the infographics. The sample size consisted of 59% Males and 41% Females, which indicates the EV users are equally distributed among both genders.

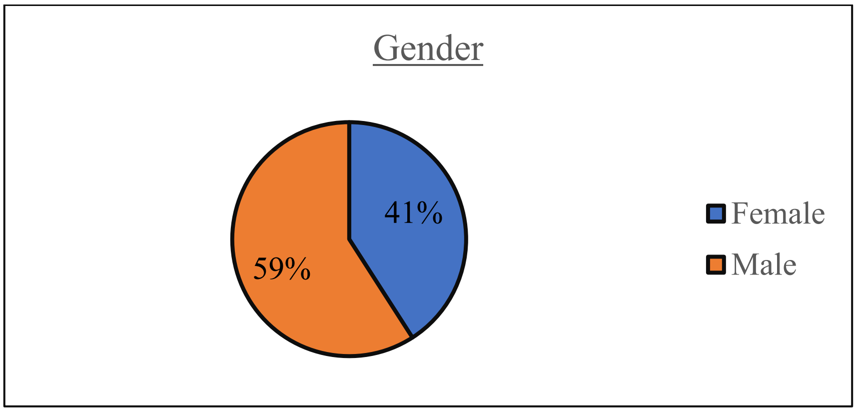

Figure 2 : Sample size

The age of the EV users was almost evenly distributed in the four ranges that were considered for the study, with roughly one-third of users under 30, indicating the interest of young drivers to adopt the EVs. This also shows a positive trend for the long-term adoption of EVs.

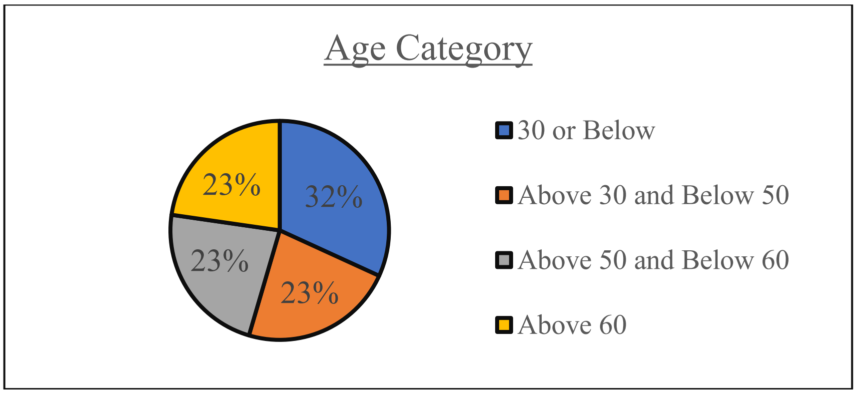

Figure 3 : Age of EV users from sampling data

The next parameter on the analysis was the education level of the EV users. • Majority of people using EVs are having a university degree which indicated that education plays an important role in encouraging EV usage.

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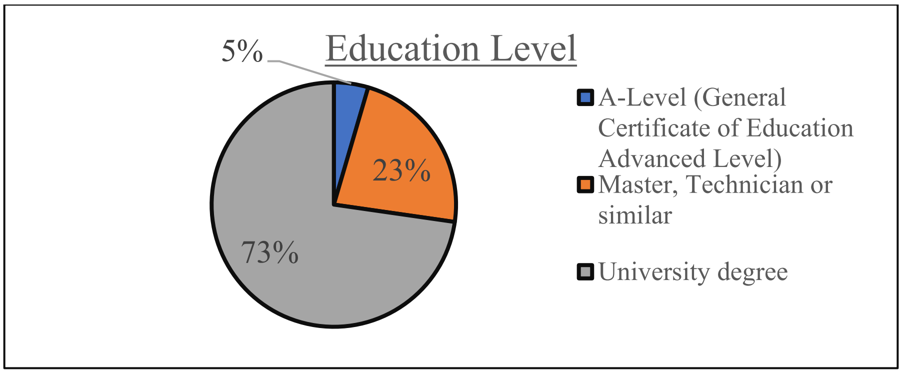

Figure 4 : Education Level of EV Users

Since EV adoption is in its nascent phase, most of the EV users have used their vehicle for less than 4 years. However, it's a good indication of the growing demand of EVs across the country.

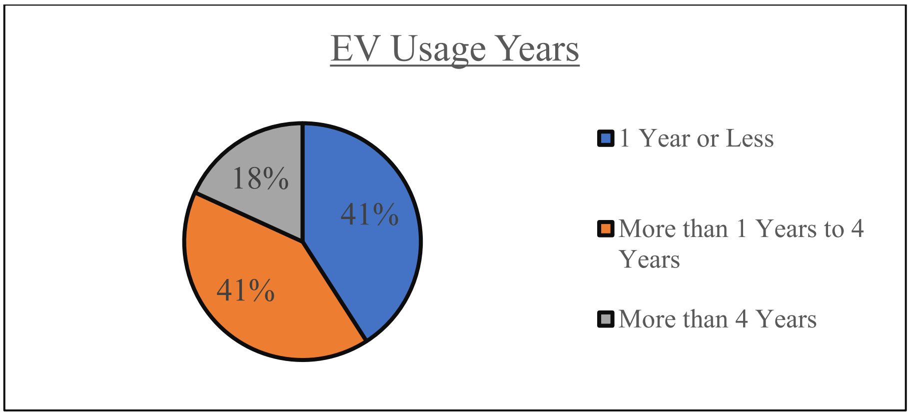

Figure 5: EV Usage Years

68% of the EV users we analysed for sampling were using the charging station at least once a week. Hence, it is crucial to effectively manage the influx of the vehicles.

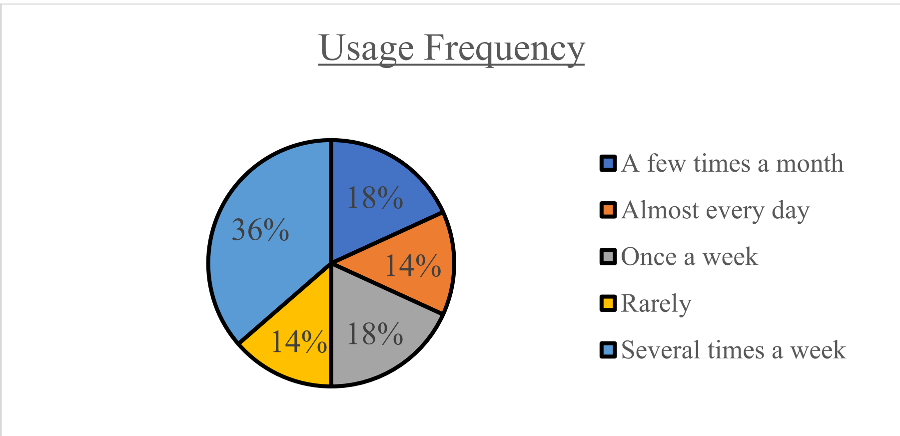

Figure 6 : Usage Frequency

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45% of the EV users charge their cars for more than 4 hours. However, 65% EV users park their cars in the EV charging space more than 4 hours. This shows that almost 20% users had parked their cars even after getting full charge, not allowing other EV users to use the charging station.

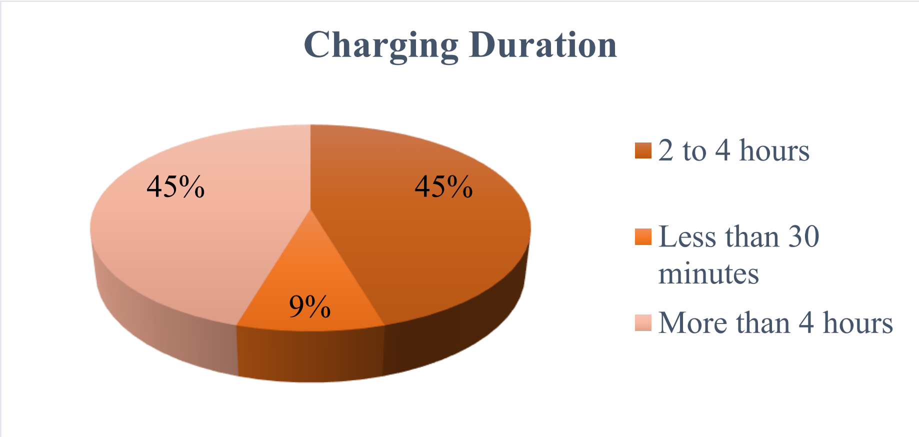

Figure 7 : Charging Duration

We also found that majority of the users used the charging station for more than 4 hours which is a key insight regarding the time spend on the station when compared to ICE vehicles.

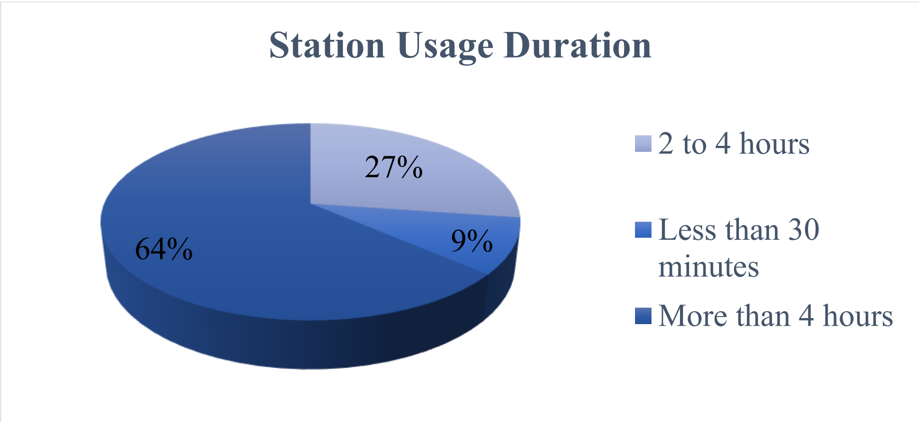

Figure 8 : Charging Station Usage

1.2.2. Qualitative Analyses

As per the feedback from the EV users, there is no authentic platform available in which reliable shared EV charging facility locations can be checked. Most of the times users have faced difficulty in finding shared EV charging station. There is no service in place with updated database of shared EV charging stations with their accurate locations and working conditions.

The EV users were of the opinion that Availability at the charging station and Charging Speed are the most important factors for them while using a shared EV charging facility. Relatively, charging price was of lesser importance for the users if they are being provided with better service in terms of availability and superchargers in future.

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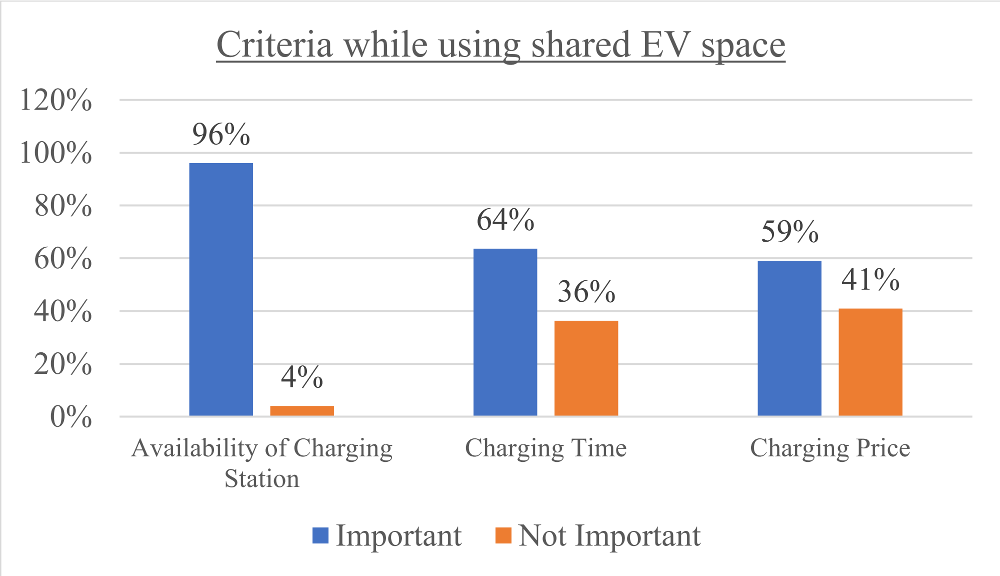

Figure 9 : Criteria while using shared EV Space

Most of the EV users wanted to have a penalty system in place to check on the habit of parking EVs at the charging station by the users even when they are not actually charging their vehicle. We asked users about incentives that can help motivate users to take their cars out of the charging station after getting the required charge in their car but they were of the opinion that rather than incentives, there should be penalty system to address this issue.

The majority of EV users expressed their happiness at the prospect of a shared EV charging facility app, which would enable them to communicate with other EV users and manage congestion at the station in real time.

We also received several recommendations for improvements in infrastructure that may be made at the shared EV charging station to enhance the service. One of them was to increase the number of superchargers so users wouldn't have to wait around for a long time to charge their vehicles. Another idea was to provide an equal number of waiting parking spaces at each shared EV charging station in order to inform all users of the need and encourage them to swap parking spaces in order to improve the turnover for charging stations.

1.3. Key Observations from the Analyses

1.3.1. Solution to Ensure Availability of Chargers

It is unanimously accepted that we need more EV chargers across the country, like the gas stations to ensure EVs can be taken across the country on any routes, irrespective of the geographical constraints. This is the basic requirement of all the participants of the survey so that they can consider EV as a perfect replacement of the ICE vehicle rather than a second car or a city-only car. Even though home chargers are becoming increasingly common day by day, a work charger at the organisation or place of work dedicated to the employees can be a great advantage for the employees and a big relief for the range anxiety. This will also ensure better utilisation of green energy sources like solar energy as

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the organisational chargers will be used the majority during the daytime of weekdays. This can also reduce the load on energy grids during the peak hours, which can be caused if EVs are charged from home during the night once the person reaches home after work.

1.3.2. Fair Usage of Charging Slots

Finding the charger and waiting for the next available slot is a big concern for most of the EV owners. As majority of EV owners use the vehicle for daily use, a convenient charging location at the workplace with a booking mechanism can help majority of EV owners to plan their charging well in advance based on the travel. This will also reduce long waiting times at charging stations and maximize the usage of EV chargers. For designing the testbed in Maynooth university, the division of charging slots was much needed as majority of the EV owners can find a suitable slot based on their work schedule.

1.3.3. Convenient Location

For designing the Testbed at the Maynooth University, our first aim was to find a suitable location within the campus that is feasible from the technical perspective as well as convenient for the EV users. We aimed at finding locations that were close to the university car parking lots so that it's easily accessible to the EV owners. Also, the new charging station should be as close as possible to the electrical room so that the electrical and earth work can be minimal and cost effective.

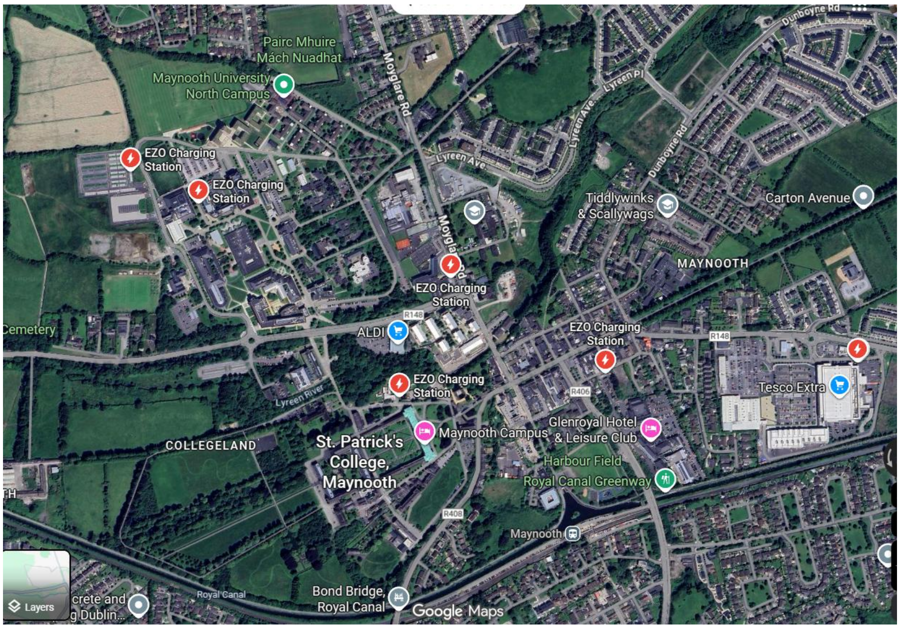

Figure 10 : Current EV Chargers close to Maynooth University

We have analysed the available EV chargers within an approximate radius of 5 kilometres around the campus. Out of that only one charging station is on the premises. This clearly defines the need for a

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charging station within the campus premises and make Maynooth university one of the perfect testbed for the Flow Project.

Figure 11 : Car Parking slots within and close to Maynooth University

Next, we analysed the car and coach parking slots in and around the campus to choose the best location for setting up the charger for the Flow app. We found approximately 9 parking lots and need to find a location which is equally accessible to all those who are using the parking lots. As the South Campus already has an EV charger, we focused on setting up the charger in the North campus. The coordinates of the new charging station are (53.384899,-6.600339).

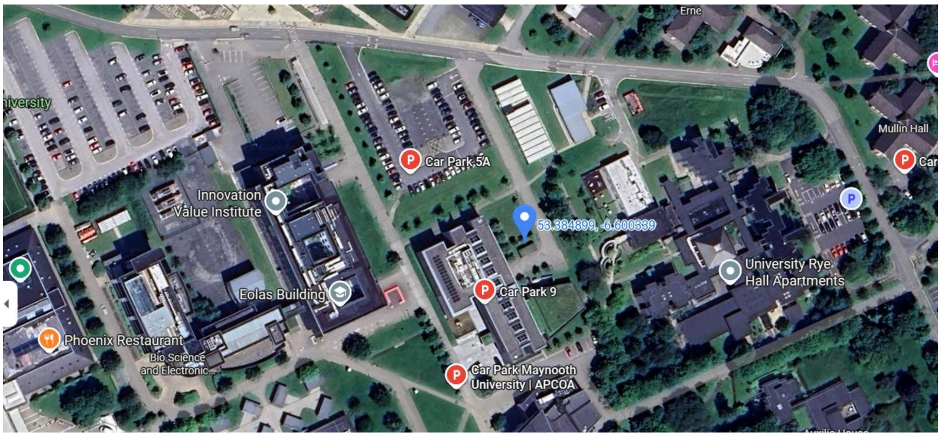

Figure 12 : Preferred choice of Testbed charger

This led us to zero in on the current location for the testbed, which is close to three of the large car parking slots and also near the electric circuit room. This space can accommodate two cars for charging in parallel and a queue of two other cars without affecting the campus traffic.

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2. Codesign and development of a shared solution

2.1. Stakeholder Communication

Based on the above qualitative and quantitative analyses, the first step in the codesign and development of the shared solution for the FLOW project is stakeholder communication. Considering the feedback from the EV owners, the concerns and challenges listed in the survey and the fundamental literature, we listed the important stakeholders to get in touch for setting up the testbed in Maynooth University. The primary stakeholders include EV users (staff and students) on the campus, the Grounds Department, the Electrical Department, the Sustainability Office and the security team of the University. We also prepared the list of secondary stakeholders: the IT department, for internet connection at the charging station, the finance department, for discussing disbursement of funds relating to the installation, the procurement division, for tender process and finalising vendors for cabling and charger installation, and finally, the potential external vendors who can provide chargers to Maynooth University.

Individual discussions and stakeholder meetings were organised by the project manager to understand the regulations and policies of the university and to ensure that all the processes are carried out as per the same. The ways of communication to the stakeholders, including mail communications to the EV user groups in the university and documentation of the process, were also discussed during the stakeholder communication.

We conducted interviews of EV owners across two universities in Dublin, UCD and Maynooth University, to collect data on their current pain points and understand their needs that can be incorporated into the application. The interviews were conducted in support of TUC, Germany. The collected data were used to finalise the features of the application and supported us in developing the prototype in Figma. We also conducted the focus group interviews with people from specific demographics from Ireland and India, again with support from TUC, Germany. The focus group interview was focused to get insights for gamification elements and user preferences for the created prototype. We collected the data and used it to refine the user flow and features.

2.2. Need Assessment and Design of Pre-survey

Our student team have conducted multiple levels of need assessments from the data collected from EV users, as well as analysing the car parking grounds in and around the university and accessibility of the EV chargers. As discussed in the section1.3.3 , the location of the charging station was crucial during the need assessment, as the charging spot should be equally accessible for EV owners working in multiple buildings across the university. The team also gathered the site-related constraints like power availability and the cabling requirements, impact on flora and fauna, parking space for vehicles in queue, lighting, marking of the charging space, security, etc.

2.3. Concept Design and FLOW App Blueprint

The Project Manager drafted the initial layout of charger placement, including the charging pole placement, digging and concrete requirements for the charger pole, vehicle parking lots, ensuring distance between vehicles, driveway for entering and returning the charging lot, considering the

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incoming traffic to the university, speed restrictions, crash barriers and fire and safety precautions. After subsequent discussions with stakeholders and analysing the budgetary constraints, we decided to install 22KW AC charger with 2 charging guns for a parallel charging facility. A high-level electrical infrastructure plan was also discussed with the Electrical department regarding distribution, metering, earthing and protection of the charging docks.

2.4. User Experience Design

To understand how the user experience has to be designed for the main application, we have created a mock-up of the user interface before building the live app.

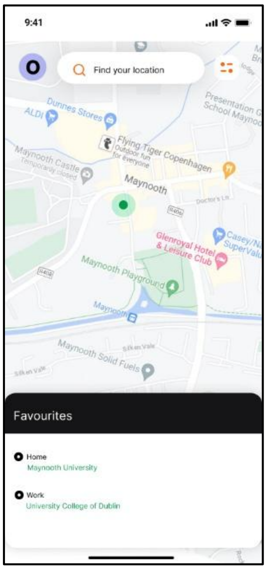

Figure 13 : Mock-up Home up

User Profile Section: In the Profile section user can enter his/her basic details. The left toggle bar of the home page will allow users to edit his/her profile, set up a wallet, notification (which will allow users to check payment status and previous booking details, etc.), help (which will be an AI-powered bot), membership details, choose between dark and light theme and finally a log out option.

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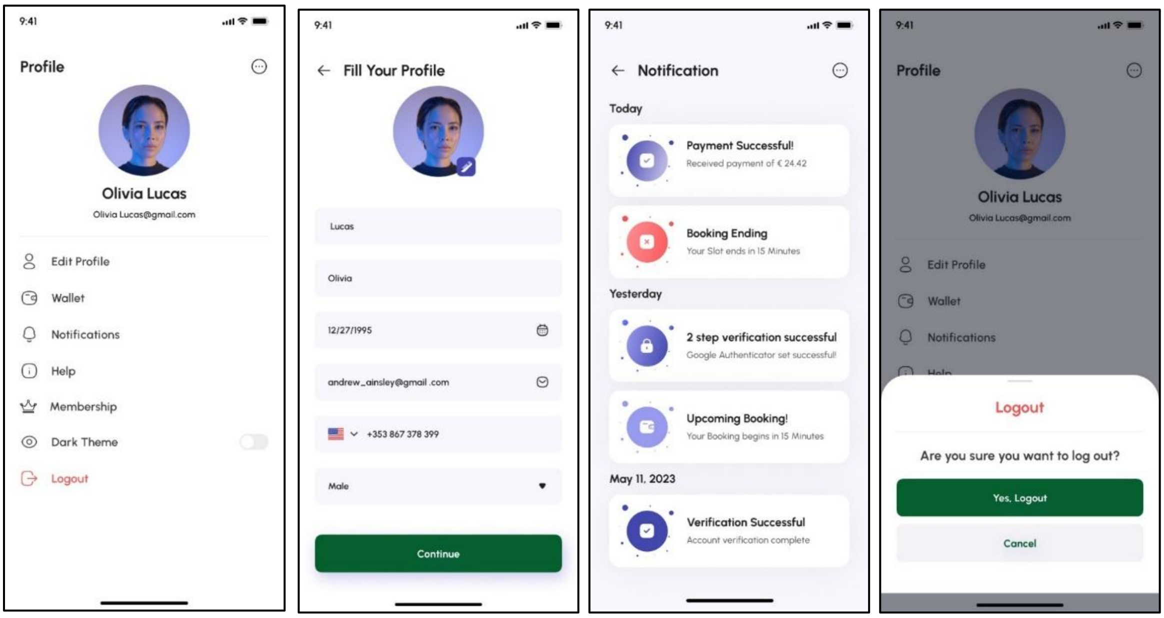

Figure 14 : Mock-up UI designed by the student group

Slot Selection: Once the user searches for the desired location, the app will show the authenticated shared EV charging facilities in and around that area, and the user can choose his/her preferred charging station. Using the right toggle bar present at the home page, users can also filter the results for a particular shared EV facility by selecting the preferred date, time and type of chargers.

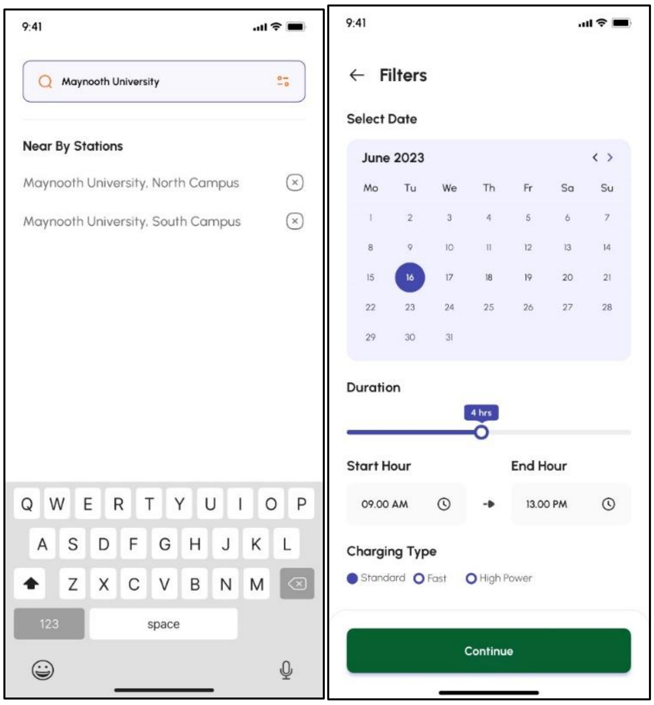

Figure 15: Mock-up for Charging Slot selection

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Parking Layout Selection: Once the user selects a charging facility with all the desired filters, he/she will be directed to the booking page, where the exact layout of the facility, along with the status (available, booked and faulty), will be shown. If he/she taps a booked parking slot, the app will provide the user with a pop-up with two options. The first option would be to request the user who has booked the slot for the charging space, i.e., through the communication platform. In the second option, he/she can choose to get notified when that facility is available again.

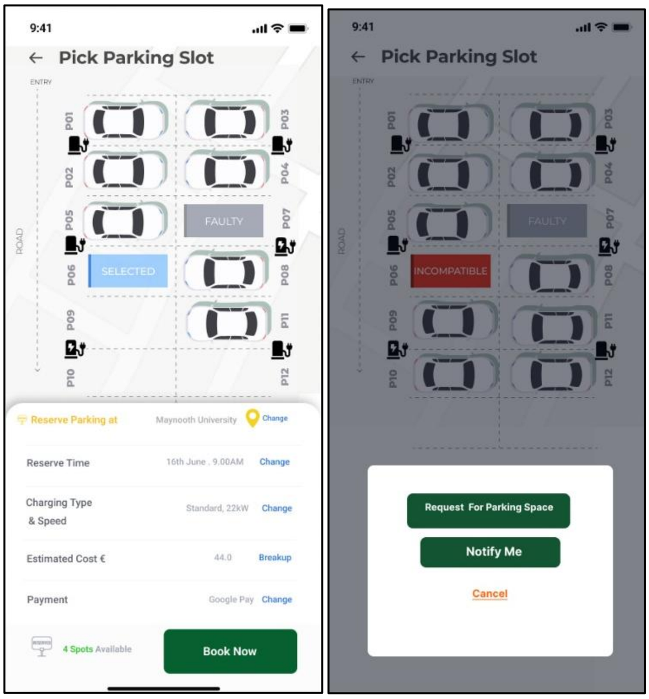

Figure 16: Mock-up for choosing the parking slot

2.5. Technical and Business Feasibility Analysis

The team also conducted a technical feasibility analysis for the long-term sustainability of the chargers even after their usage as a testbed. After finalising the specification of the EV charger, the team contacted the electrical department for electrical load analysis and future load projection and gained the approvals to proceed with the testbed. The team also analysed the integration with existing electrical and IT infrastructure, including the panels, conduits, and the communication network (campus WiFi). Together with the grounds department, the team conducted a meeting for risk assessment, including overloading, outages, and any other environmental hazards and gained approvals to proceed with the tender.

The team also formulated a business plan for the charging station and also to scale this model to other locations.

2.5.1. Easee chargers

Easee is a manufacturer of **smart electric vehicle (EV) charging systems**, primarily deployed in residential, workplace, and semi-public environments. **Easee** chargers are designed to support

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connected, software-driven charging, enabling remote monitoring, configuration, and data exchange through cloud-based services.

The chargers support features such as:

- Continuous reporting of charging status (plugged-in, charging, idle)
- Measurement of electrical parameters
- Secure remote access via APIs and cloud integrations

These capabilities make Easee chargers suitable for integration into energy management and monitoring platforms.

2.5.2. About Enode

Enode is a **device-integration platform** that provides a **single, standardised API** to connect with energy-related hardware such as EV chargers, electric vehicles, batteries, and other smart energy devices, regardless of manufacturer.

Instead of integrating separately with each vendor's proprietary API, Enode acts as a **unified abstraction layer**, normalising data formats, authentication, and device status across multiple brands.

In practical terms, Enode allows Flow to:

- Discover connected devices
- Retrieve device status and operational data (e.g. charging state, power draw)
- Receive event-based updates when a device changes state

All through **one API**, without the need to go through every vendor API where it's present.

2.5.3. Delayed Charger State Synchronisation

During the initial testing phase, a significant delay was observed between the real-time charger state reported by Easee and the status reflected in Enode. Although Easee updated the "plugged-in" state instantly, the corresponding update in Enode appeared only after a considerable delay. This discrepancy affected how accurately and promptly the application could represent charging activity to users.

After the issue was escalated, Enode's engineering team confirmed that the delay originated from their new event-based integration with Easee. Certain events were being processed slowly or intermittently missed, resulting in inconsistent synchronisation. Enode has since resolved this defect, and real-time events are now being delivered reliably, with further optimisation efforts ongoing on their end.

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Although temporary, this synchronisation issue impacted the system's responsiveness to real charger state changes during the testing period. With the fix implemented, the integration is now stable and functioning as expected.

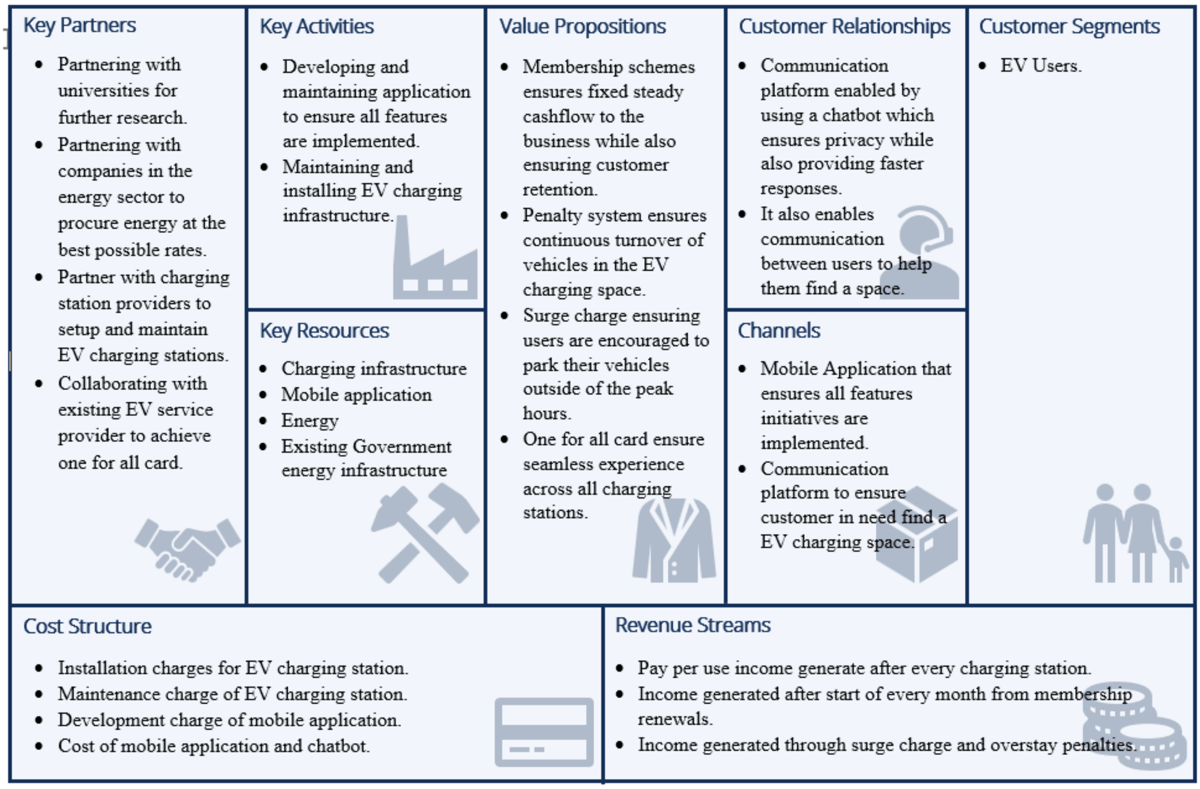

Figure 17: Business Plan for the scalability of the Testbed

2.6. Design of Post Survey

After consultation with the TUC Germany, we have designed the Post Survey questionnaire to be shared with the EV users once they attend the pilot testing and contribute. The survey will be shared with the EV users once they finish at least 2 months of testing at the testbed.

We can include here that the post-survey is focused on collecting user insights on their feedback on the usability of the application and also their experience with the system implemented in the application. We can also add that the questionnaire also involve open ended questions to get suggestions and ideas that we can implement in future for better usability and accessibility.

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3. Intermediate User Testing

The FLOW EV Charging App, which is designed to be rolled out among the testbed in Maynooth University, underwent a preliminary evaluation of the mobile app with the potential users and business analytics students of the university. The template for the Business Evaluation Report was carefully designed, keeping in mind the features and functionality of the mobile app and considering the practical usage of the app at the Maynooth University testbed. 17 participants attended the workshop, who were introduced to the features of the FLOW app in an introductory session. Most of the participants understood EV and the charging and were familiar with evaluating a mobile app. However, it was the first-of-its-kind experience for the participants to try and test out a scheduling application for the EVs. The primary business objective of this EV charging application is to optimise the availability and management of Electric Vehicle charging stations for the Maynooth University community. Its core function is to solve the significant user frustration of charging spots being occupied longer than necessary, a practice commonly referred to as "hogging." This document provides a consolidated synthesis of qualitative feedback from multiple user evaluation reports, presenting a clear and comprehensive view of the application's current strengths, its critical deficiencies, and a strategic path forward for product improvement and user adoption. The analysis confirms that while the application is built on a strong conceptual foundation, users expect a more feature-rich experience at the testbed.

3.1. Validated Strengths and Value Proposition

Despite a range of usability challenges identified during testing, user feedback consistently validates that the application is built on a strong and valuable core concept. Users clearly understand and appreciate the problem the app aims to solve, confirming a solid product-market fit within its initial target environment. The foundational value proposition is sound, providing a strong base for future development.

The key elements that users perceive as most valuable include:

- **Addresses a Clear Need:** The application effectively solves the problem of EV charging spot "hogging," which users identified as a significant source of "disappointment and frustration." By managing slot availability, the app provides a fair and optimised system for all users.
- **Advance Booking Capability:** The ability to book a charging slot in advance is a core strength. Users highlighted this feature as a key benefit, providing them with the certainty and convenience of a guaranteed charging session.
- **Efficient Core Performance:** Despite some feedback that load times could be improved, a more frequent theme was the application's strong fundamental performance. Multiple users described core functions like page loading and navigation as "perfect," "fast," and "smooth," indicating a solid technical foundation.
- **Unique Local Offering:** Within the Maynooth University campus context, the application is perceived as a unique and innovative solution. Users noted that there are "no known other competitors" in this specific area, giving the app a distinct first-mover advantage.

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While these strengths form a solid foundation, the positive user sentiment is significantly undermined by critical flaws in the user experience and system performance

3.2. Challenges in User Experience and Performance

To comprehend all the worst-case scenarios that can happen in reality, we split the participants into 2 groups and tested all possible combinations in an adversarial manner to understand the user behaviour in such scenarios. A gamified experience was provided to the users that mimics the real-world challenges which they could face in real-life scenarios and compile them for the business evaluation report.

Comprehensive user testing revealed challenges across the user interface, system reliability, and core communication architecture. The users expect that the issues can undermine the app's value proposition, create user frustration, and present some barriers or hindrances to adoption and sustained use. Rectifying these deficiencies is the non-negotiable prerequisite for achieving user retention and realising any future growth.

3.2.1. Enhanced User Interface (UI) and Usability Failures

User feedback was unanimous in identifying more upgrades in the application's user interface and overall usability. The design complicates simple tasks and creates some confusion, leading to user churn in the booking process.

3.2.1.1. Confusing and Unintuitive Booking Process:

The process for selecting a time slot is a primary point of failure. Users are presented with multiple, unsynchronised options—including a timeline, pre-selected slots, and dropdown menus—which overcomplicates what should be a straightforward task. This leads to confusion, with one user describing the interface as "complicated and without prompts," creating some cognitive load that directly impedes successful bookings.

3.2.1.2. Misleading Availability Indicators:

A critical bug repeatedly displays a "no charger available" message on slots that are, in fact, free. This misinformation misleads users into abandoning the booking process. This was addressed immediately and notified with the UI team at the workshop itself.

3.2.1.3. Simple Visual Design and Hierarchy:

As the participants were mostly youngsters and aged under 25, they were expecting a production-ready and visually appealing interface rather than the functionality of the app. The application's visual design was described as "plain" and "not visually appealing." Key interactive elements, such as navigation arrows and location text, are disproportionately small and difficult to read on mobile devices, impeding basic navigation and affecting the ease of use for repeated bookings.

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3.2.1.4. Lack of Essential Confirmations

The system needs to provide essential user feedback after a key action is completed. Certain users reported not receiving booking confirmation emails or seeing an on-screen summary after making a reservation, creating confusions and affecting the future bookings.

3.2.2. Reliability Concerns

3.2.2.1. System Crashes

Certain users mentioned that the application crashes or freezes occasionally. This instability is most pronounced when a user attempts to change or rebook a time slot, often forcing a complete session restart and resulting in abandonment.

3.2.2.2. Lack of Real-Time Updates

The system does not update slot availability in real-time. Users reported that booked spots still appeared available, requiring them to manually refresh the page to get accurate information, leading to failed booking attempts and frustration.

3.2.2.3. Notification System Flaws

The notification system needs more accuracy. Critically, web users do not receive "vacate" requests, rendering a core feature ineffective for a portion of the user base. Additionally, the system sends multiple requests for a single user action, creating notification spam.

3.2.2. Dependency on an External Application (Telegram)

The strategic decision to rely on Telegram for user notifications is a major point of friction and a significant weakness. This dependency forces users to download and use a separate, third-party application, a requirement that users described as a "hassle" and a "deterrent to onboarding." Many suggested this be replaced with a more integrated solution, like in-app notifications, or more common platforms like WhatsApp or SMS. This approach also introduces data security concerns, with users noting that their personal information is being held by a third-party company.

The cumulative effect of these deficiencies is a user experience that is not merely inconvenient but actively hostile to the user's goal, directly contradicting the app's core purpose.

3.3. Strategic Opportunities for Enhancement

Beyond identifying critical flaws, user feedback has provided a clear and valuable roadmap for high-impact improvements. These suggestions not only offer solutions to existing problems but also highlight opportunities for significant feature enhancement and potential market expansion.

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3.3.1. High-Value Feature Enhancements

Users proposed several features that would dramatically improve the application's utility and user-friendliness:

- **Integrated Communication:** Develop in-app chat and native push notifications to completely replace the problematic dependency on Telegram.
- **Improved Mapping:** Integrate satellite or street views to help users precisely locate specific charging bays (e.g., "parking space is 1A or 2B"), removing ambiguity upon arrival.
- **Flexible Booking Management:** Allow users to amend active bookings (e.g., end a session early to free up the slot) or make multiple, non-contiguous bookings for different times.
- **Enhanced User Onboarding:** Add a welcome screen or tutorial prompts to guide new users through the app's functionality. Simplify the registration process by enabling Single Sign-On (SSO) with Google or Microsoft accounts.
- **Smart System Features:** Implement a waiting list for fully booked periods that automatically notifies users when a slot becomes available. Introduce a feature to automatically cancel a booking if a user is delayed by a set time (e.g., 30 minutes).

3.3.2. Potential Market Expansion

User feedback indicates that the app's core value proposition is highly scalable beyond the university campus. The following markets were identified as strong candidates for expansion:

- Hospitals
- Large Businesses with Car Parks
- Airports
- Shopping Centres
- Hotels

These opportunities demonstrate a clear path from stabilising the current product to achieving broader market growth.

3.4. Consolidated Strategic Recommendations

Distilling all user feedback into an actionable strategy, the following recommendations are prioritised to stabilise the application, enhance the user experience, and secure its business value.

3.4.1. Immediate Tactical Imperatives

These three items represent the most critical, high-impact fixes and should be treated as non-negotiable, short-term priorities to prevent user churn and repair the core experience.

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3.4.1.1. Overhaul the Booking Interface

The time selection process must be completely redesigned to be simple, singular, and intuitive. Concurrently, implement clear, universally understood visual indicators for slot availability, using colour-coding (e.g., green for available, red for booked) to eliminate ambiguity.

3.4.1.2. Restore System Credibility by Eliminating Critical Bugs

Prioritise engineering resources to fix the system crashes associated with rebooking and, most importantly, the trust-destroying bug that causes the misleading "no charger available" indicator to appear on free slots.

3.4.1.3. Implement Real-Time Status Updates

Re-engineer the application front-end to refresh slot availability automatically and in real-time across all user sessions. This removes the need for manual refreshes and ensures all users are acting on accurate information, preventing failed bookings.

3.4.2. Core Strategic Shift

The single most important strategic action required is to **remove the dependency on Telegram**. Developing a native, in-app notification and communication system is essential for creating a seamless user experience, ensuring reliability for all users (including those on the web), improving data security, and building foundational user trust in the platform.

3.5. Concluding Assessment

The EV charging app is founded on a strong and validated value proposition that directly addresses a clear and pressing need within its target market. However, its significant potential is critically undermined by severe UI/UX deficiencies, systemic instability, and a flawed strategic reliance on an external messaging platform. The current user experience is confusing and unreliable, creating a significant risk of user abandonment. Implementing the tactical and strategic recommendations outlined in this summary is essential to stabilising the product, retaining current users, attracting new ones, and ultimately realising the application's considerable market potential.

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4. Development, user engagement and rollout of a scheduling solution to the testbed premises

4.1. Requirement Analysis

In this phase, based on the feedback from section 3, we were primarily focusing on the need for a scheduling mechanism for EV charging to cater to the different requirements of EV owners, like daily commute, weekend drives, hybrid work, etc. In our scenario, the majority of users need EVs for daily commute, and if we provide an on-campus slot-based charging facility, more users are ready to switch from ICE vehicles to EVs, as their current concerns are on range anxiety due to the daily drive mileage on budget EVs. Scheduling mechanism should also take into consideration the different needs of the users, like slot booking, waiting list for charging, messaging request for urgent requirements, cancellations etc. Access-control mechanism was another important requirement to be analysed as the majority of the EV owners are not interested in installing a new application for charging the EV or carrying an RFID tag with the fear of losing it.

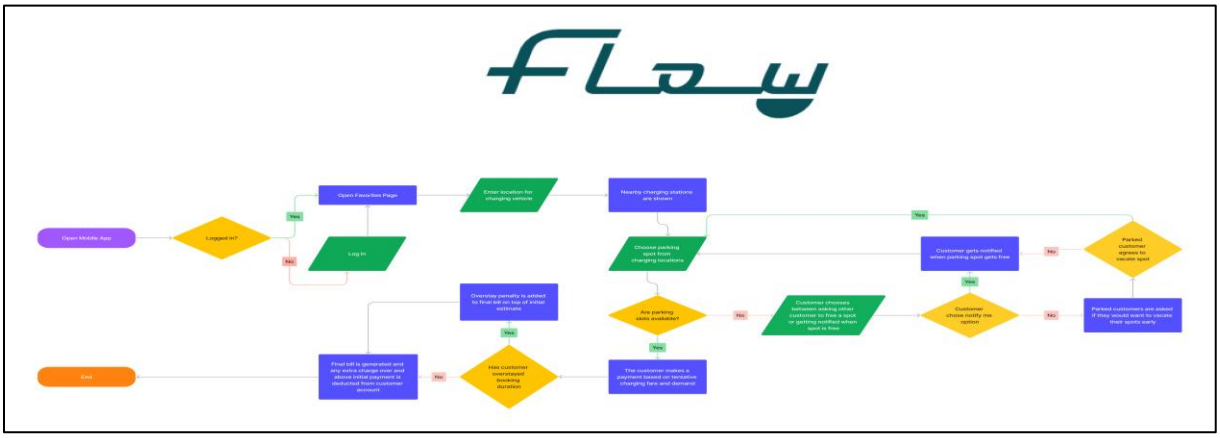

Figure 18: Architecture Diagram

4.2. System Specification

The requirement analysed above motivated us to focus on a web-based booking system with access control through institutional e-mail id and a QR-based charger start functionality for the users to avoid misuse of the chargers. Users can login to the Flow web portal either from computer or mobile phone and make the booking for the slots. Internet connectivity should be ensured for the users at the charging location to scan the QR code when the respective booking slot is active to enable the charging.

4.3. Scheduling Workflow of App

The charging slot allocation window was the primary component to be decided for the scheduling workflow of the FLOW app. In consultation with the EV owners and from the feedback from intermediate user testing, a flexible duration window as a multiple of 30 minutes was designed to ensure a fair amount of SOC for their respective EV's. Also, to avoid a single user taking over all the

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charging slots, we have restricted only one live slot per user. The user can book a different slot when the current charging slot is complete. Also, for the testbed, the users can book to a maximum of two additional working dates from the time of login to avoid overbooking of upcoming days. This can be customized later based on the post survey and user feedback after the pilot. The Flow App for the testbed is designed keeping in mind the simplicity of its usage to attract more EV owners and overcome the challenges in EV adoption.

At a later stage, more advanced features will be added to the scheduler such as adding a buffer time between bookings for charging turnover and avoid clashes between charging. Prioritization algorithms can be incorporated with the scheduler application for different categories such as low battery users, staff with longer commutes, priority charging slots for differently abled staff etc. Escalations rules will be added to the missed bookings and overstay at the charging slots to avoid disputes in slot utilization. For moving to a greener charging environment peak vs off-peak slots will be mapped in the design workflow for cleaner and cheaper charging.

4.4. UI and UX Design

The wireframes for the web interface were already created by the students as an exercise to understand the working of the app and were tested in the section 3. This was further fine-tuned to meet the requirements of the specific testbed at Maynooth University. User flow was defined right from registration to e-mail confirmation to slot selection and confirmation, and finally using the charger. Payment is not included in the user flow as we have opened up the charger as free for user during the piloting phase. E-mail notifications and Telegram integration were also included for communication.

Technology Selection: The frontend was developed using React.js, a modern JavaScript framework chosen for its component-based architecture, responsive design capabilities, and cross-platform compatibility. React enables a single codebase to function seamlessly across desktop browsers and mobile devices, eliminating the need for separate native mobile applications during the pilot phase. This approach significantly reduced development time. The interface leverages Bootstrap 5 for consistent, professional UI components that maintain visual coherence across different screen sizes and devices.

Interactive Booking Interface: The booking interface includes an interactive map powered by Leaflet, integrated with the OpenChargeMap API, to help users locate charging stations geographically within the campus. Once users identify their preferred station location, they proceed to the booking dialogue featuring calendar-based time selection with clear visual indicators for available and occupied time slots. The booking workflow provides immediate validation feedback to prevent scheduling conflicts.

Contactless Access via QR Codes: Physical access to charging stations is facilitated through an integrated QR code scanner, eliminating the need for access cards, PIN codes, or physical keys. Users initiate their charging sessions by scanning station-specific QR codes through the mobile interface, which automatically validates their booking credentials and starts the charging process. This contactless approach reduces friction in the user experience and provides a simple, secure access method.

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Real-Time Feedback and Status Visualisation: The design prioritises clarity and simplicity, with clear visual indicators for station status (available, occupied, booked) and real-time charging state displayed on the slot grid. When viewing available stations, users can see live charging rate information for occupied slots, providing transparency into current charging activity. During their own active sessions, users receive immediate feedback through a persistent dashboard banner displaying elapsed time that updates continuously. The system implements automatic data synchronisation every 30 seconds to ensure users always view current station availability, with additional refresh mechanisms triggered when users return to the application. This real-time synchronisation is critical for efficient shared resource management, preventing booking conflicts and ensuring accurate occupancy information across all user sessions.

4.5. Backend Development

Setting up the central database for storing the user registration and charging information to build analytics and charging pattern information. The backend of the FLOW application is designed as a high-performance, scalable, and reliable system capable of supporting real-time EV charging management, concurrent booking activity, and continuous interaction with physical charging hardware. The architecture focuses on operational correctness, fault tolerance, and extensibility, ensuring the system performs consistently under real-world pilot conditions and can grow into a robust production environment.

4.5.1. Technology Stack

The backend infrastructure is built on **FastAPI (Python)** with a **PostgreSQL** database. These technologies were selected for their speed, strong asynchronous capabilities, mature ecosystem, and reliability in handling concurrent booking requests, real-time charger state updates, and continuously running background tasks.

Technology Stack

Component	Technology	Purpose
Web Framework	FastAPI (Python)	High-performance async REST API
Database	PostgreSQL	Relational data storage
ORM	SQLAlchemy	Object-relational mapping
Migrations	Alembic	Database schema versioning
Authentication	JWT (HS256)	Secure token-based authentication
Task Scheduler	APScheduler	Background job processing
Email Service	Brevo SMTP	Notification delivery

Figure 19: Technology Stack

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4.5.2. System Architecture Overview

The backend follows a **layered and modular architecture**, separating concerns across distinct logical components. This approach ensures that business logic, data access, API routing, and background automation remain isolated and independently maintainable.

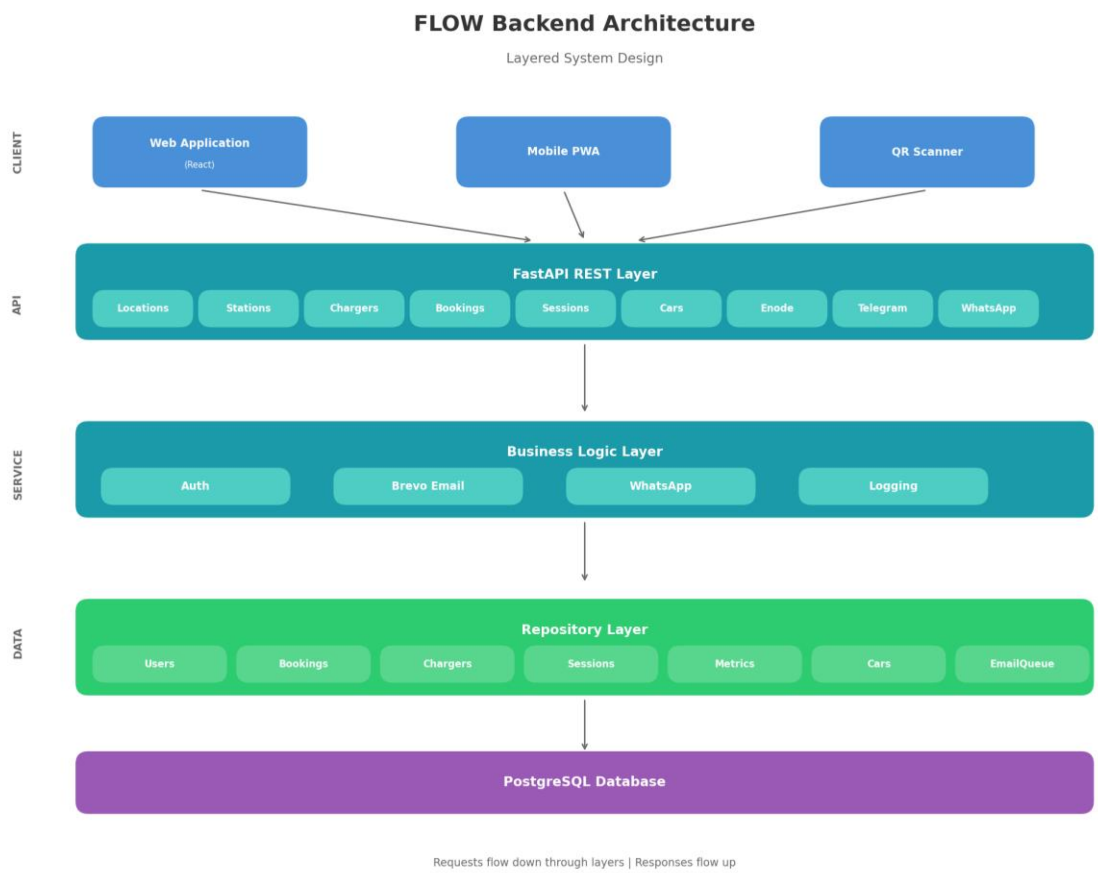

Figure 20: FLOW Backend Architecture

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4.5.3. Database Schema Design

The database schema is optimised for efficient booking lookups, charger integration, session tracking, and time-series storage. It maintains strong referential integrity between users, vehicles, stations, bookings, sessions, and metrics.

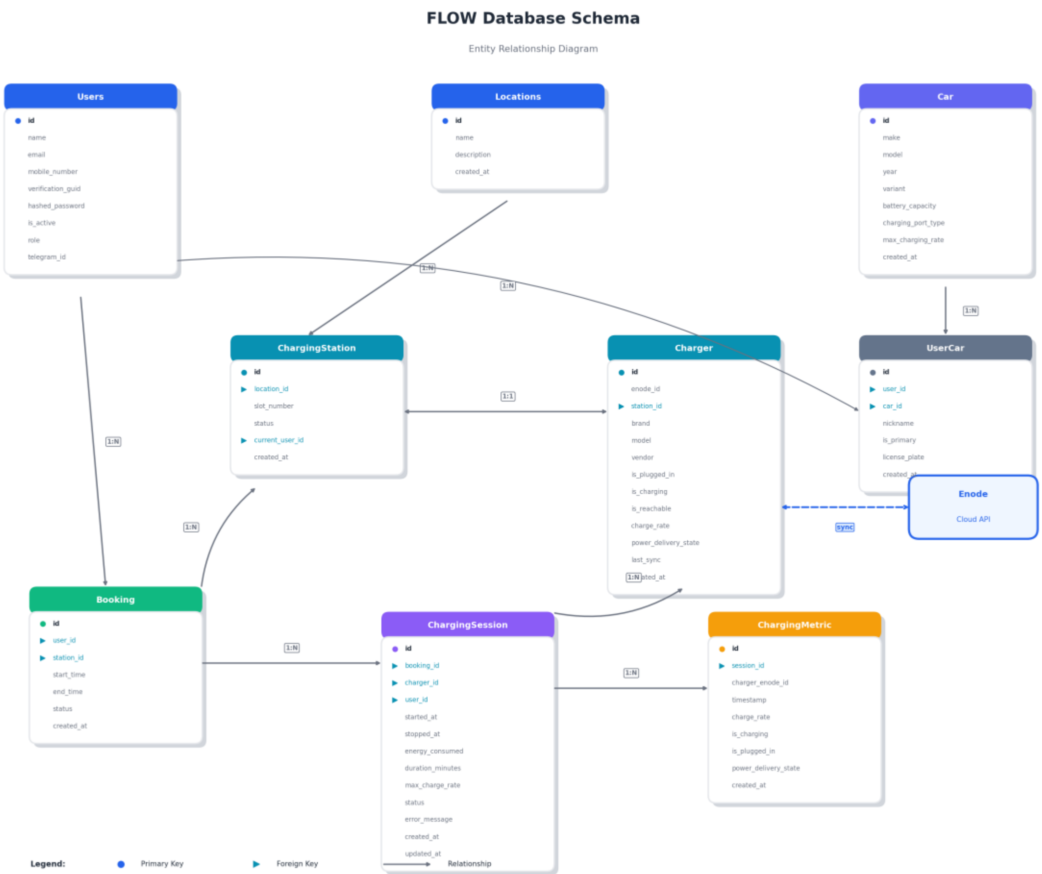

Figure 21: FLOW Database Schema

The schema ensures:

- Fast filtering of slot availability
- Consistent booking state transitions
- Accurate linking between chargers and Enode devices
- Efficient aggregation of charging metrics

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This design enables robust analytical capabilities and operational transparency.

4.5.4. Booking Management Engine

A core function of the backend is the **Booking Management Engine**, ensuring fair and conflict-free resource allocation. The booking module implements:

- Enforcement of **one active booking per user**
- Automatic **conflict prevention**
- Strict **time-based access control**
- Real-time restrictions based on station occupancy
- Automatic expiration and slot release for unused bookings
- Correct transitions to active sessions once charging begins

This engine acts as a guardrail, ensuring predictable behaviour under concurrent usage.

4.5.5. Core Backend Modules

The backend is organised into the following functional modules:

Authentication Module: Implements secure user registration with email verification, JWT-based session management, and password reset functionality. Users authenticate using institutional email addresses, and tokens are validated on each API request.

Booking Management Module: Handles the complete booking lifecycle, including slot availability checking, conflict detection, reservation creation, and automatic expiration of unused bookings. The system enforces fair usage policies by limiting each user to one active booking at a time.

Charging Session Module: Manages active charging sessions, tracks real-time charger state from the Enode API, records energy consumption metrics at 30-second intervals, and handles session termination when bookings expire.

Notification Module: Implements an asynchronous email queue system using Brevo SMTP for the delivery of booking confirmations, session notifications, and system alerts. Integration with Telegram enables real-time push notifications and interactive vacate requests.

4.5.6. Background Task Scheduler

The system employs APScheduler to run a set of automated operational tasks that ensure seamless system operation, including booking expiration monitoring, automatic session termination at booking end times, charger state synchronisation, metrics data collection, and email notification processing, significantly reducing the need for manual administrative intervention.

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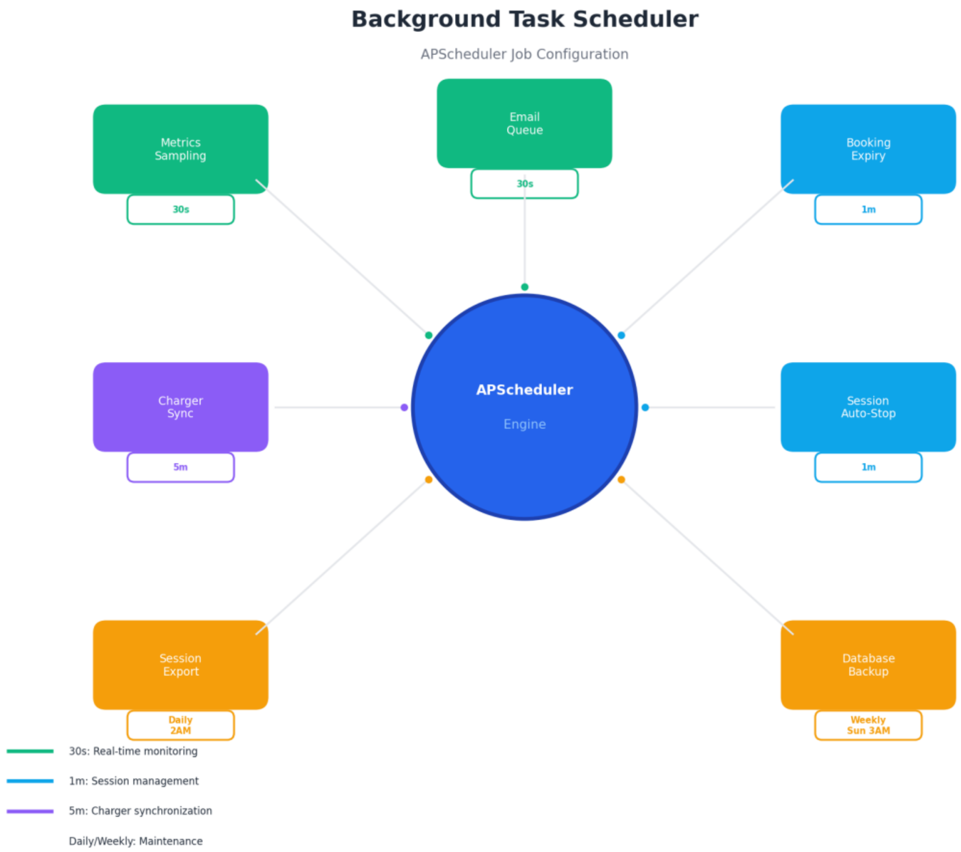

Figure 22: FLOW Background Task Scheduler

4.5.6. Charger Integration & Real-Time Synchronization

FLOW integrates directly with the **Enode API**, which serves as a cloud-based bridge to physical EV chargers. The backend synchronises charger state, controls charging operations, and collects telemetry.

Capabilities include:

- Plug-in detection
- Charging start/stop tracking
- Power delivery state reporting
- Rate and consumption monitoring
- Polling and syncing charger attributes

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4.6. System Integration

The FLOW application integrates multiple external systems to deliver a seamless EV charging experience. This section describes the integration architecture, communication protocols, and data flow between system components.

4.6.1. Integration Architecture Overview

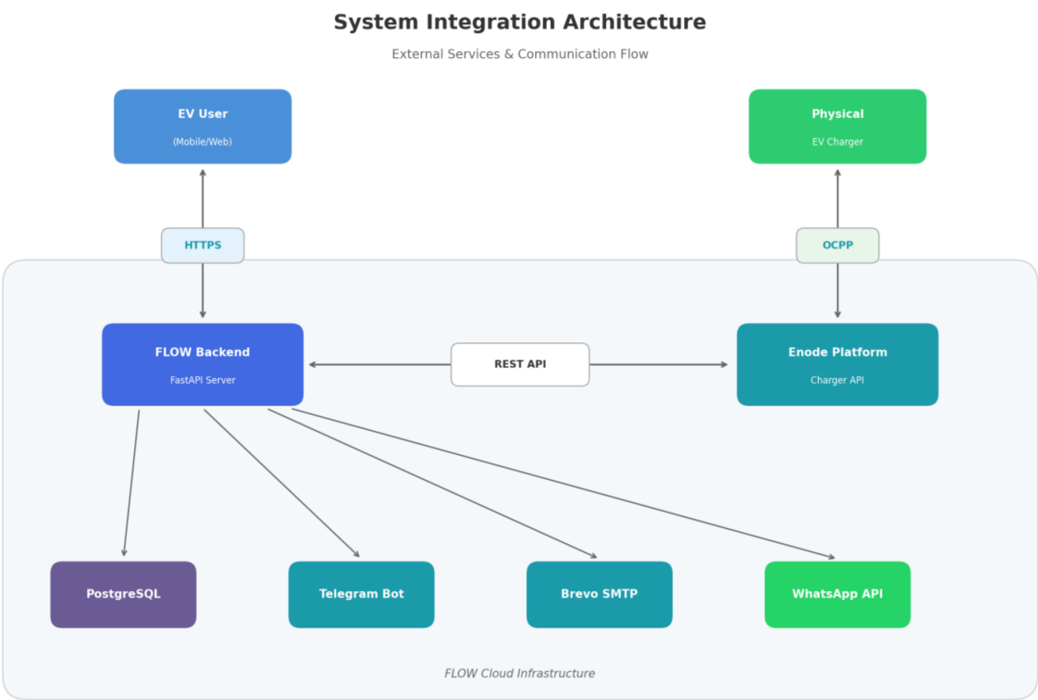

Figure 23: FLOW System Integration Architecture

4.6.2. Enode Integration for Charger Control

The primary external integration is with the Enode platform, which provides a unified API for controlling EV charging equipment regardless of manufacturer. In the current implementation, FLOW communicates with Easee chargers through Enode's REST API, which translates API calls into OCPP (Open Charge Point Protocol) commands for the physical hardware.

This integration enables the FLOW application to:

• Monitor Charger State: Real-time status including plugged-in state,

charging state, current power delivery, and charger availability

• Control Charging Sessions: Start and stop charging commands sent directly to the physical charger.

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• Configure Charging Rate: Dynamic adjustment of maximum current to support load balancing.

• Synchronise Data: Periodic polling ensures database consistency with the actual charger state.

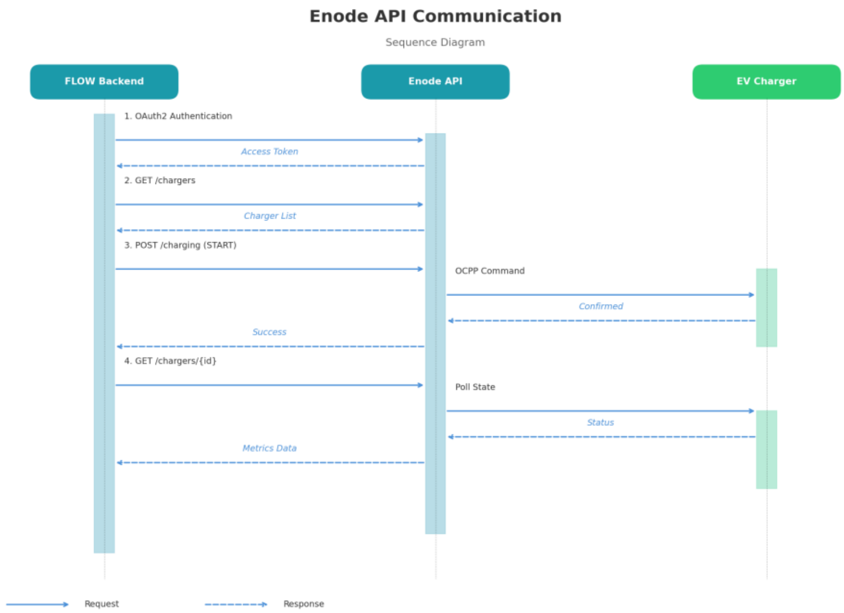

Figure 24: Enode API Communication

The sequence diagram illustrates the communication flow between the FLOW Backend, Enode API, and Easee charger. All interactions follow a request-response pattern where the backend initiates requests (solid arrows) and receives responses (dashed arrows) from Enode or the charger.

1. OAuth2 Authentication – The backend obtains an access token using client credentials. Tokens are cached locally and refreshed automatically prior to expiration.
2. GET /chargers – Retrieves the list of linked chargers with current state information including model, serial number, and availability status.
3. POST /charging (START/STOP) – Sends charging control commands to Enode, which forwards them to the Easee charger via OCPP protocol. The charger confirms execution before returning success.
4. GET /chargers/{id} – Polls individual charger state to retrieve real-time metrics including power delivery rate, connection status, and charging progress.

4.6.3. Communication Platform Integration

The system integrates with multiple messaging platforms to deliver real-time notifications and enable interactive user communication.

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Telegram Bot Integration: A dedicated Telegram bot enables interactive vacate request functionality. When a user needs a charging slot that is currently occupied, the system sends a vacate request to the current occupant via Telegram. The occupant can respond directly within Telegram using inline buttons to accept or decline the request. Upon acceptance, the slot is automatically reassigned and both parties receive confirmation. Users link their Telegram accounts via a secure email-based verification process.

Email Integration: The Brevo SMTP service handles transactional emails including account verification, password reset, booking confirmations, and daily analytics reports. An asynchronous queue system ensures reliable delivery with automatic retry for failed messages.

4.6.4. QR Code Access Control Integration

The system implements QR code-based access control to ensure only authorized users can activate their booked charging sessions:

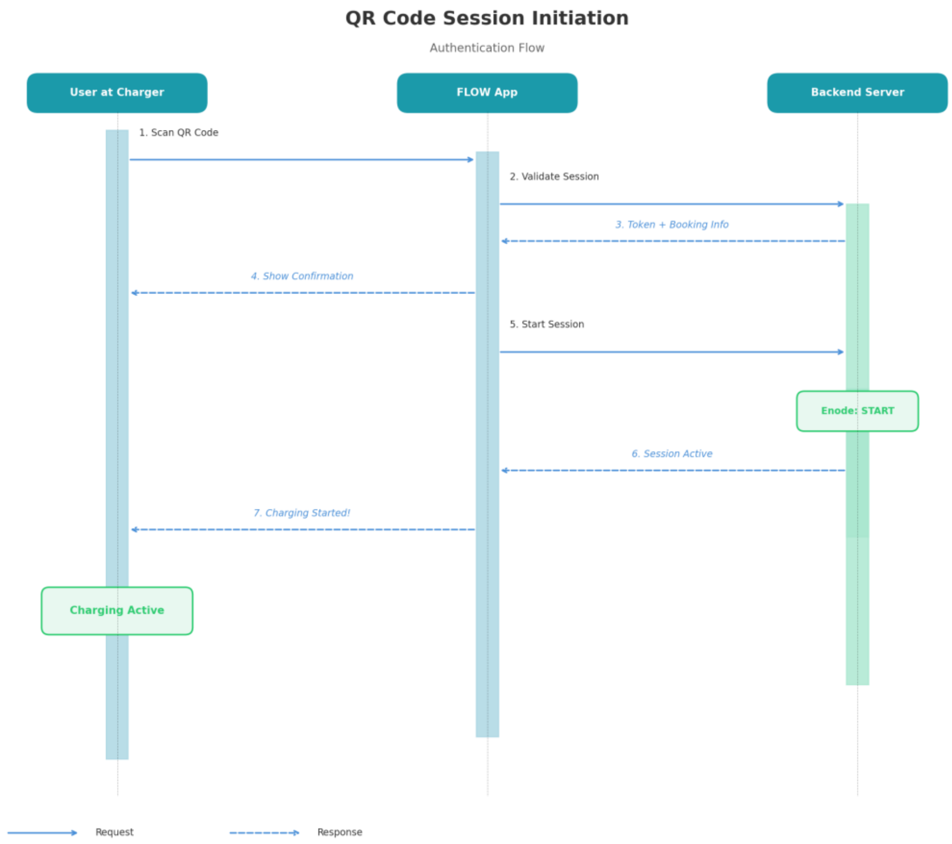

Figure 25: QR Code Session Initiation

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4.7. Data Analytics Framework

From the data acquired from the booking slots and the energy consumption patterns, we are analysing the key data points including the booking frequency, energy consumption, peak hours, cancellations etc. This will be used to build analytics dashboard for the testbed and real-time monitoring in future. The data will also help to set up analytics for identifying patterns in the slot demand and weekly/monthly consumption demands.

4.8. User Engagement Workshop

The Project Manager have designed a user engagement workshop to ensure the ease with which EV owners can use the charger. We have also discussed with EV owners who were willing to participate in the pilot to study the preferred slot duration and interface features. This was helpful in gathering user expectations around the reliability, client support, transparency, and fairness of booking.

4.9. Pilot Testing

From the participants of the survey and analysis through the user engagement workshop, we were able to find 15-20 participants for the pilot testing. The main priority was to have users who can regularly use the charger and also use the EV for long-distance travels so that we can build better insights from analytics and also work on analysing the impact of scheduling to nudge user behaviour. For the pilot testing, we wanted to analyse the different scenarios such as regular booking, repeated bookings, peak booking slots, emergency usage, cancellations, communication through telegram app etc. In the pilot we also conducted the technical tests to check the server load, database capabilities, enode communication, email notifications etc. The Project manager collected user responses and addreseds issues before full rollout of the testbed.

4.10. Refinements and Optimizations on App

Refinements on design of the Flow application were done based on the feedback from the pilot and also on the basis of intermediate user testing done in section 3. We have revised the rules of booking, user flow, slot selection, charger start/stop QR functionalities etc. This was validated with an internal round of testing.

4.11. Full Deployment

Production servers were configured with the final version of the application and ensured the availability of service at https://flowparking.io/. We also ensured customer support over telephone/mail availability during rollout week and a project representative was available on-site to monitor any issues with plugging/unplugging the charger gun and also ensuring fair movement of the vehicles before and after charging. Campus security was also informed to ensure no traffic congestions in accessing the charging slots.

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4.12. Analysis of Post Survey

In the post survey, we intend to collect data with pilot participants on their experience with the setup of the new charger and their feedback on different features of the application to define future changes in the application.

5. Design

5.1. Identifying the Charger location

Based on the location finalised in Section 1.3.3 ., the project team conducted a detailed site survey to map terrain, traffic flow, lighting, parking geometry, convenience for the disabled parking and utility access. The accessibility of the charging location, and Safety of the EV owners were the key factors kept for fixing the charger location

5.2. Testbed Site Layout Plan

Designed parking bay markings, poster, electrical and cable management systems, charger-specific QR codes and signage placement to ensure the site is safe and does not cause any inconvenience to EV owners and to the university. We ensure compliance with accessibility standards of the university for spacing between cars while parking, ramps and lighting. Alternative layout plans were also developed to address any inconvenience if reported by users or the university during the current pilot at the testbed.

5.3. Final Design of the FLOW App

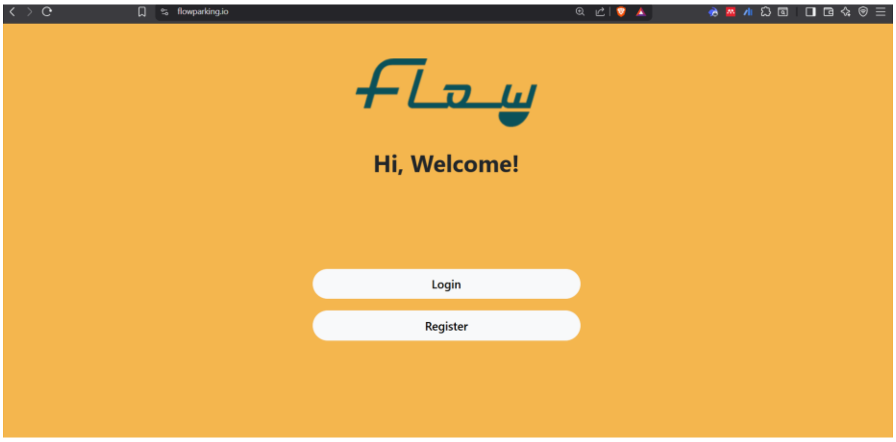

Figure 26 : Home Page of Flow App

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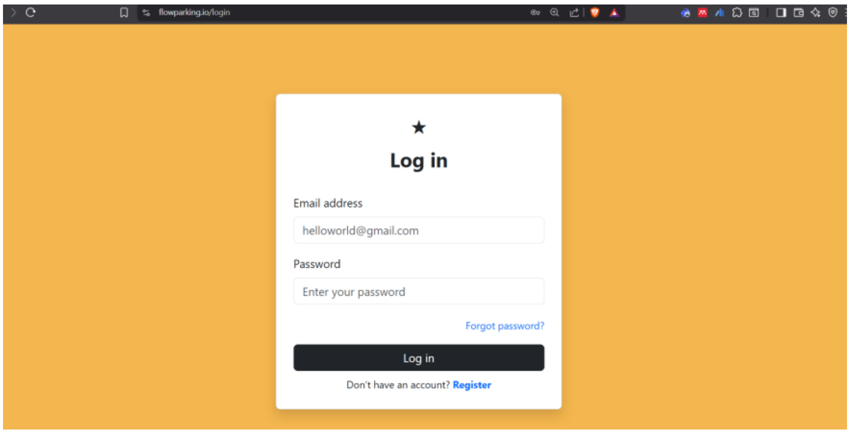

Figure 27: Login Page

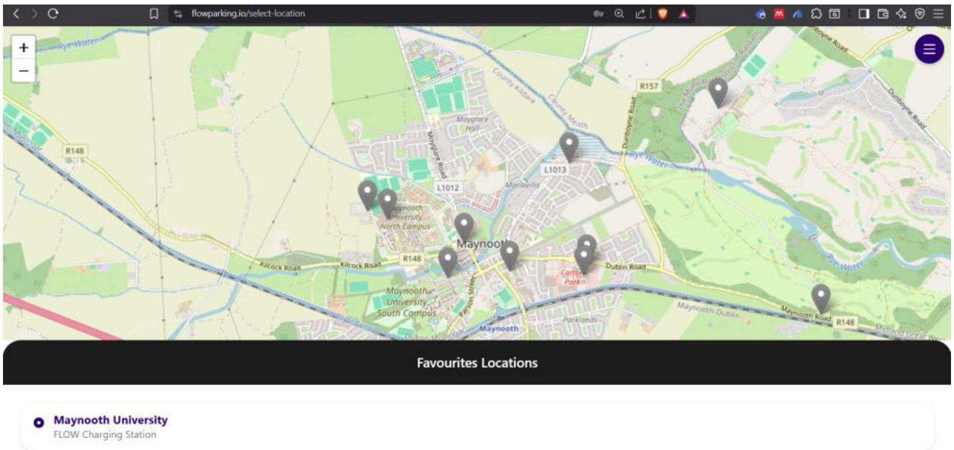

Figure 28: Charger Location

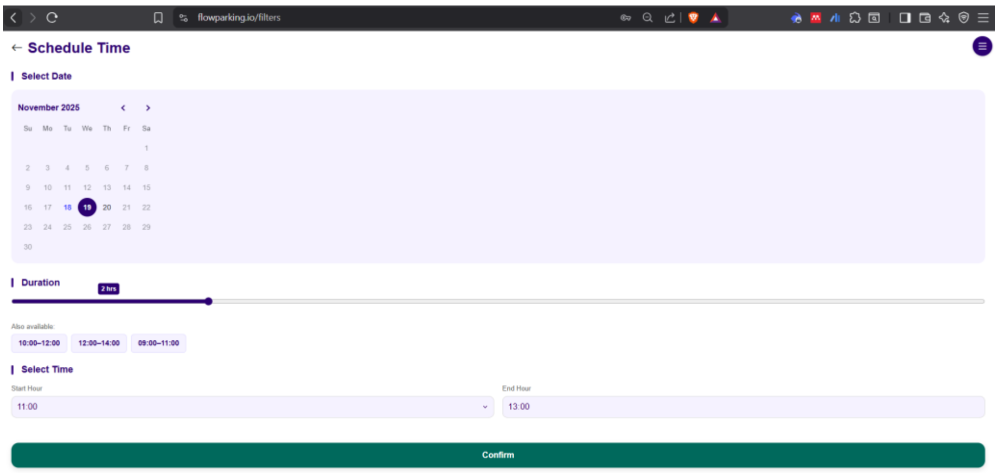

Figure 29: Booking Screen

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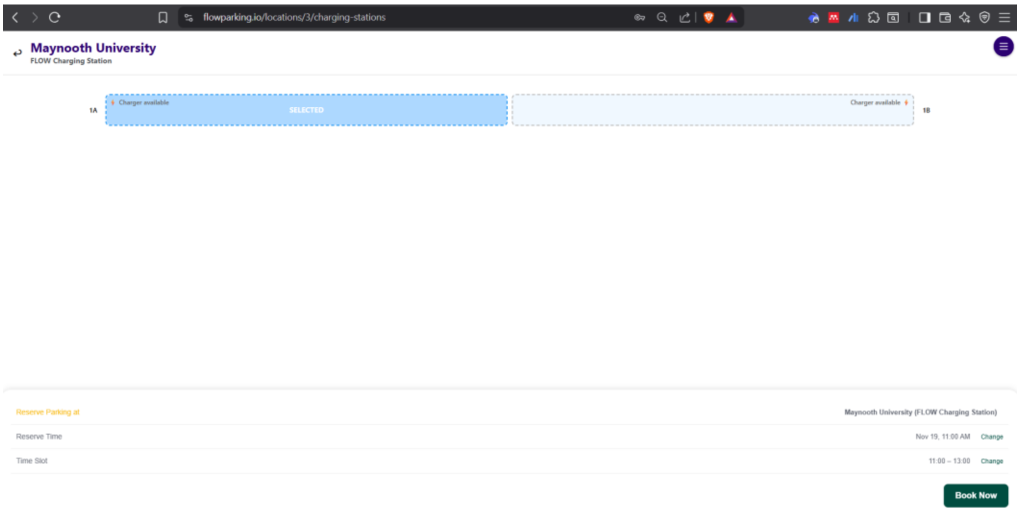

Figure 30: Slot selection

5.4. Understanding the User Behaviour

6. Installation

This stage involves assessing the type, capacity, and scale of the charging infrastructure based on expected usage and site conditions. This was done based on the survey and user interaction testing.

6.1. Identifying the charger infrastructure

6.1.1. Electrical Load Assessment

Evaluate the existing electrical capacity of the site to determine if the grid can support additional charging demand.

6.1.2. Charger Type Selection

Choosing the right type of charger for the testbed. With the budget constraints and compatibility to all available EV models, we decided to install a 22KW AC Fast charger for the testbed so that all EV owners can use their own charger gun to use the charging station.

6.1.3. Site Survey

Detailed site inspection to identify optimal locations for charger placement — ensuring accessibility, safety, and minimal obstruction to regular traffic flow

6.1.4. Network and Connectivity

Determine connectivity requirements (Wi-Fi, 4G/5G, or Ethernet) for smart chargers to support monitoring, billing, and load management.

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6.2. Bidding for provider

6.2.1. Preparation of Tender Documents

Define technical specifications, installation standards, safety codes, and performance expectations clearly in the request for proposal (RFP)

6.2.2. Vendor Eligibility and Approval Criteria

Evaluate bidders based on experience, certifications, after-sales service, and past project references.

6.2.3. Quotation Evaluation

Compare quotations not only on upfront equipment cost but also on installation, warranty, software licenses, and maintenance package

6.2.4. Contract Finalisation

Select the most technically compliant and financially competitive bidder, with clear SLAs (Service Level Agreements) and warranty clauses.

6.3. Civil and Electrical works

6.3.1. Site approval for civil works

Levelling the ground, paving, and marking designated EV parking and charging zones

6.3.2. Foundation and Mounting for Charger

Constructing concrete foundations or pedestals to support chargers, ensuring protection from vibration and environmental factors.

6.3.3. Cable Trenching and Conduits

Installing underground or overhead conduits for power and data cables, following safety and accessibility standards.

6.3.4. Earthing and Surge Protection

Ensuring proper grounding and protection systems to safeguard users and equipment from electrical faults or lightning.

6.3.5. Sign Boards and Safety Markings

Erecting clear directional and instructional signage for users and emergency responders.

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6.4. Environmental Precautions

6.4.1. Waste Disposal

Proper disposal or recycling of construction debris, packaging materials, and any hazardous waste (e.g., cables, oils).

6.4.2. Soil and Water Conservation

Prevent soil erosion and water contamination during excavation or construction by using sediment barriers and drainage management.

6.4.3. Preserving Flora and Fauna

Avoid disturbing local vegetation or animal habitats, especially in suburban or greenfield installations.

7. Commissioning

This phase ensures that all installations made for the Flow Project meet technical, ethical, and regulatory requirements, and that the charging infrastructure is safe, reliable, and ready for public or organisational use. This is the final and critical stage of EV charger installation, involving a systematic verification of safety, functionality, and compliance before the system is made operational.

7.1. Clearances from Grounds Department

Before activating the charging system, approval from the Grounds Department was secured to confirm that all civil and landscape works had been completed satisfactorily. The team made verification that civil works, such as foundations, pavements, and surface finishes, are restored and compliant with site standards. We also conducted the inspection of the charging site and accessibility to ensure minimal disruption to pedestrian or vehicular movement as this area was previously designated as a 'No Parking' zone. The grounds department also provided confirmation that drainage, cable routing, and landscaping have been completed without affecting existing underground utilities.

7.2. Ethical Approval

Ethical approval was obtained from the university, ensuring EV user safety and accessibility standards are met — including adequate lighting, walkways, signage, and provisions for differently-abled users. We also secured confirmation that no ethical conflicts exist, such as unfair vendor selection, non-compliance with green procurement guidelines, or misuse of funds.

7.3. Sanctioning from the Electrical department

The Electrical department of the university verified and validated that the power supply, distribution panels, and meters are correctly rated and connected. Charger installation vendor also submitted the updated electrical layout drawings and schematics reflecting the final installation. Inspection and testing were carried out for load test, earthing, polarity etc.

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7.4. Clearance from Campus Security

The Campus Security validated vehicle and pedestrian traffic flow, ensuring the charging zone does not obstruct essential access routes or pose safety hazards.

8. Operation and Maintenance Procedures

8.1. QR-Based Access Control

The charger is equipped with a QR-based access control for ensuring only the legitimate EV owner who booked the slot can use the charger at the particular time slot.

8.2. Portal Management

A dedicated development team ensures management of the Flow portal as well as the Telegram communication and any other grievances relating to the portal.

8.3. Data Logging

The FLOW testbed implements comprehensive logging to support operational monitoring and maintenance. All critical system operations are logged with timestamps and detailed status information.

8.3.1 Automated Operations Logging

Seven automated background jobs handle system operations: five run continuously at regular intervals, while two execute on scheduled times for data export and backup. All activities are logged

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for monitoring and troubleshooting purposes.

All Background Jobs
Five scheduled jobs running concurrently

```
● /backend/app/logs/main.log

2025-11-25 14:00:00,123   - app  - INFO  - --------------- Booking expiry job running ---------------
2025-11-25 14:00:00,234   - app  - INFO  - --------------- Auto-stop sessions job running ---------------
2025-11-25 14:00:00,345   - app  - INFO  - No sessions to auto-stop
2025-11-25 14:00:00,456   - app  - INFO  - Expired bookings processed successfully

2025-11-25 14:00:15,567   - app  - INFO  - Sampling metrics for 2 active session(s)
2025-11-25 14:00:16,789   - app  - INFO  - Successfully sampled 2 session(s)

2025-11-25 14:00:30,123   - app  - INFO  - Processing 3 pending email(s) from queue
2025-11-25 14:00:30,456   - app  - INFO  - Attempt 1/3 - Sending email to user@example.com
2025-11-25 14:00:31,234   - app  - INFO  - ▯ Email sent successfully to user@example.com
2025-11-25 14:00:31,567   - app  - INFO  - Email queue processed - Sent: 3, Failed: 0

2025-11-25 14:05:00,234   - app  - INFO  - --------------- Charger sync job running ---------------
2025-11-25 14:05:01,567   - app  - INFO  - Charger sync completed - Success: 3, Errors: 0
```

Figure 31: Operations Log

The system automatically handles the expiry of bookings and termination of charging sessions when time limits are reached. This includes communication with physical chargers via the Enode API to ensure proper session closure.

Auto-Stop Sessions
Automatic session termination when booking expires

```
● /backend/app/logs/main.log

2025-11-25 15:45:00,123   - app  - INFO  - --------------- Auto-stop sessions job running ---------------
2025-11-25 15:45:01,234   - app  - INFO  - Successfully stopped charger ABC123 via Enode API
2025-11-25 15:45:01,567   - app  - INFO  - Auto-stopped session 45 (booking 89 ended at 2025-11-25 15:45:00)
2025-11-25 15:45:02,123   - app  - INFO  - Auto-stopped 1 session(s)
```

Figure 32: Charger Communication Log

Continuous sampling of charging data occurs every 30 seconds during active sessions, providing precise energy consumption tracking for research and billing purposes.

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Figure 33: Energy Consumption Tracking

Email queue processing with automatic retry logic ensures reliable delivery of user notifications. The system handles transient failures gracefully through a fault-tolerant retry mechanism.

Figure 34: E-mail Queue Processing

Automated daily export of session data and weekly database backups ensure data availability and disaster recovery capability.

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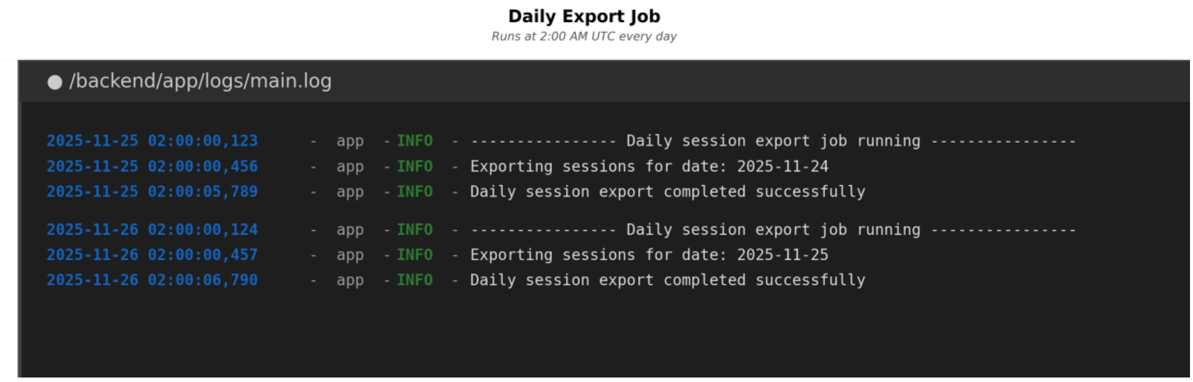

Figure 35: Automated Reporting

8.3.2 Error Tracking

System errors are logged with detailed diagnostic information to facilitate troubleshooting and maintenance. The logging system captures database connection issues, API communication failures, and email delivery problems, enabling administrators to quickly identify and resolve operational issues.

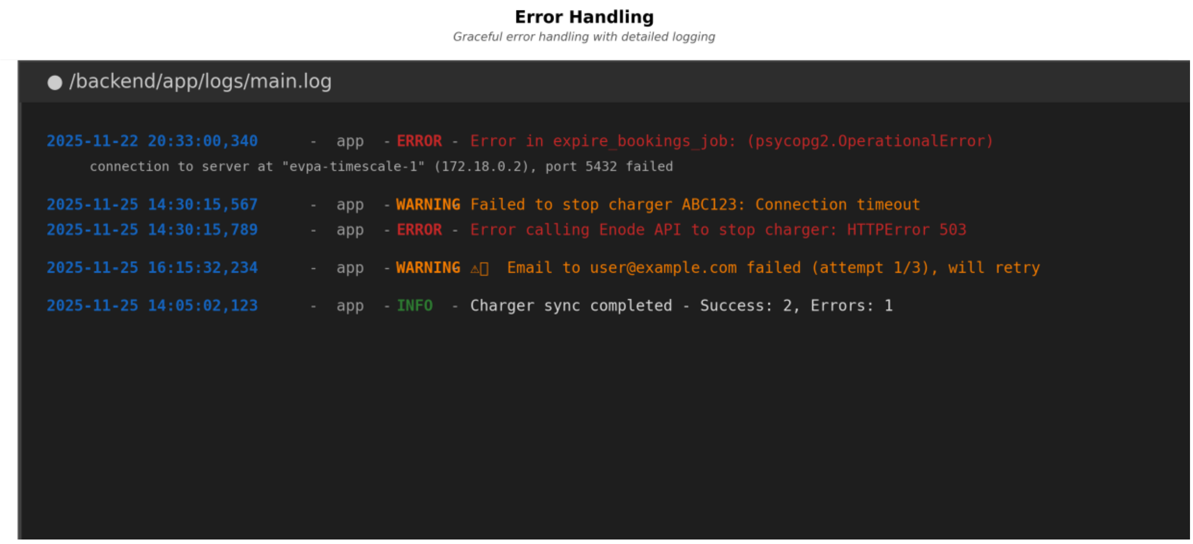

Figure 36: Error Tracker

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8.4. Operational Hours

Set charging availability hours with a 2-day window for booking and ensure compliance with campus or organisational policies. Weekends and bank holidays were excluded from the charging calendar as the users will have limited access to the campus parking.

8.5. Routine Inspection

Weekly inspection of the site and charger was scheduled by the Project Manager, and reporting will be done.

8.6. Periodic Maintenance

As per the AMC with the vendor, periodic maintenance of the charger will be carried out. Updates on server or enode configurations will also be done without affecting the booking system and informing the EV users in advance about such events. Ensure backend software is updated regularly for stability and data integrity. Periodic validation of enode communication protocols with central servers will also be carried out to ensure charging is not disrupted due to a communication failure of the charger.

8.7. Fault Reporting and Grievance Redressal

The Project manager maintains a log of faults, corrective actions, and recurring issues for long-term optimisation. A grievance redressal system through e-mail and telephone was also provided for the EV owners.

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