Project Plan for CAES: Extending and Improving the Energy Management System

DESIGN PROJECT REPORT

April 2023

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Chapter 1

Introduction

Twente is an organization committed to becoming sustainable in all aspects of its operations and components. From sustainable choices on campus to studies, one of its main missions is to encourage and develop sustainable opportunities. This commitment extends to developing sustainable products and further research that contributes to becoming carbon neutral by 2023.

As part of this sustainability commitment, Twente has installed 31 electrical vehicle charging stations all over campus; enabling students, faculty, and visitors to conveniently charge their electric vehicles with a more sustainable energy choice. While most of the charging stations use energy from the grid, a new solar powered charging park has been added to the campus of Twente to further work on the sustainability of the energy sources.

Research on the efficiency of such charging stations, and methods of incentivizing the solar energy has been continuing through various faculties. As of June 2022, the Computer Architecture for Embedded Systems (CAES) group has been using 4 of the 9 solar compatible charging stations to conduct research on smart scheduling using the grid and solar power gathered from the panels. The purpose of the smart scheduling is utilizing the Energy Management System (EMS) in such a way that solar energy is prioritized over the grid system when they are synchronized.

The smart scheduling system is presented to the user through a mobile application. Through indicating their departure time and the required energy, the system schedules the charging within the time period while maximizing the solar usage and not putting pressure on the grid. The described interface is updated and improved within this project.

The following sections will discuss the updated system in detail. In Chapter 2, the domain of the project will be analyzed. Chapter 3 will give an overview of the proposal and system. Chapter 4 will discuss general design choices while Chapter 5 will go in detail about the justifications of the code. Our risk assessment throughout the project will be presented in Chapter 6, and all the testing components will be described in Chapter 7. Results, evaluation and the work dynamics will be discussed in Chapters 8, 9 and 10 respectively.

Chapter 2

Domain Analysis

This chapter will touch upon the expectations of the client and the current state of the system. The domain in which the EV interfaces are will be looked into and the pre-existing product will be described in detail. The domain will be identified and described to justify the further development of the system.

Problem Statement

The Energy Management System (EMS) created by CAES takes in preferences of the user through an interface and applies the charging algorithm accordingly. For it to function with full efficiency and fulfill the smart management, the user also has to be conscious of the results of the preferences they provide. From the departure time and the charging type to the energy amount the user sets; the amount of solar energy, hour of the day and weather prediction all contribute into the schedule. The algorithms used in the EMS utilize these preferences as input and generate a charging profile that displays the amount of energy the vehicle receives over discrete time intervals.

The purpose of the CAES research is to further develop the EMS with the help of an improved app. Through an intuitive app that both displays how the algorithm works but also motivates the user to make sustainable choices, the results will contribute to improving the algorithm and its potential use. The expectations of the client is to get a new app that not only displays the decisions of the EMS, but also encourages the user to make sustainable decisions in the departure time, energy amount and charging type they choose. The user must be able to plug in the electrical vehicle, start the charging through indicating their preferences on the web-application on their phone and start the charging.

The task provided by CAES for the design project is to fulfill the main purpose explained above with much more emphasis on the sustainability aspect. Our team is expected to improve the current application, and add elements that further inform and encourage the user on how the EMS operates and the consequences of their choices. More conscious choices must be made and different aspects of such a choice process should be taken into consideration while the user charges the car. The user experience should also be improved both visually and functionally. The trustability of the system should be increased through more feedback and transparency.

Software Environment

The existing software system is based on the REST paradigm. The Energy Management System (EMS) manages the vehicle chargers themselves. The EMS is connected with the User Interface through an API. The EMS itself is a complex system composed of multiple technologies. The User Interface communicates with the EMS through an already existing API. The initial API largely satisfies the basic requirements for the project. Some new endpoints have been requested from the client in order to satisfy the new features of the UI. The above described architecture effectively isolates us from the EMS. Indeed, this is what clients had in mind, as altering the backend is beyond the scope of this project.

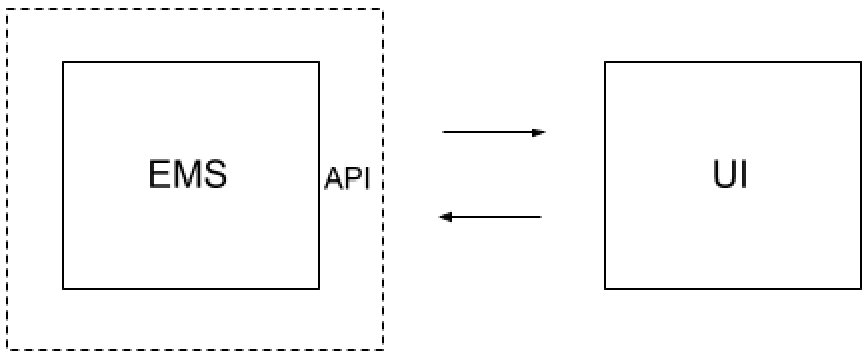


Figure 1: The Components of the Energy Management System

Pre-existing System

The focus of this project, from the software environment described above, is improving the user interface. To identify the necessary changes and requirements of this project, the previous application must be described in detail.

The current usage of the system is as follows: the driver finds an empty charging point, parks their car and plugs in the charging cable. Then, they select their departure time and their requested amount of electricity. The system then chargers the car accordingly, as described in the sections above.

The web application was made with the intention of providing a simple interface that displays the usefulness of the EMS and allows the user to specify the configurations for the algorithm to work. It consists of 2 pages; the schedule and session. The session page allows the user to indicate departure time and charging amount with sliders, and displays the predicted schedule on a graph. The session page provides the user with the session information such as the set departure time, charge amount and the progress of the charging.

The described interface had critical issues such as a lack of feedback to the user and visual discrepancies. The client identified the lack of feedback of the charging state to be an aspect that greatly affected the trustability of the system. Many users were unsure of the success of the charging due to no feedback or notifications from the system. The users were also unable to edit their departure times or change the charging details after the session had begun. Visually, the graphs on the web application were not scaled to the users phone screens which caused unreadable graphs. The client also requested a platform which further encourages sustainability by emphasizing the CO_2 emission rates.

While designing the new interface, existing solutions of different companies were also considered. Many electrical vehicles (EV) have their own apps with personalized information on the car and its emission rate. We analyzed more in depth other platforms such as SMA EV charger app to improve on the user experience and find more inspiration on how to inform and encourage sustainability (SMA EV Charger 7.4 / 22 Met Smart Connected | SMA Solar). Displaying the solar energy amounts in comparison to fast charging options and indicating the impact of such choices in carbon emission was a method such apps used.

Conclusion

In conclusion, the system provided to us contained the API points and the interface that connected to them. We were expected to improve the interface, focusing on the shortcomings of the web applications and more requirements that will be discussed in the next chapter. The team has researched possible alternatives to the current application through looking into 3rd party charging station interfaces and taking inspiration from how they have handled sustainability.

Chapter 3

Proposal Overview

Goals & Motivation

This project aims at improving the existing user interface of the electric vehicle charging station. The changing station is a part of a research project and therefore it is not open to the public; only a small group of drivers use the system. The goal of the charging station is to maximize the green energy usage from solar panels and to reduce the strain on the electric grid and car batteries when charging. The charging station interface is in the form of a web application.

The algorithm governing the chargers themselves is beyond the scope of this project as it is a part of the research carried out using the charging station. Instead, we only focus on the web application itself, which gathers necessary information and then passes it to the charging algorithm.

The client has requested a major upgrade to the web application in order to introduce new features. The priority will be on improving the user experience and user trust towards the system. A number of user experience improvements will be carried out, among others introducing notifications and displaying a charging summary after initiating charging.

Another new feature to be introduced is a gamification element. It is aimed at incentivising drivers to use the charging station in an environmentally friendly manner. The points would be awarded for every kilowatt hour of charge using electricity from the solar panels. The points would be deducted however for fast charging. The exact formula is yet to be determined. The points then would be used to either compete against other drivers on a leaderboard or to exchange them into badges.

The next feature would be charging setting prediction. Currently, when a user initiates a charge, they need to input the departure time and requested charge every single time. The smart settings prediction will suggest the departure time and the charge level automatically, based on previous charges and some other factors. Quite likely a machine learned algorithm will be introduced to determine the suggested settings.

Some additional, low priority features are:

- Delaying the charging finish time during the charging

- Calendar integration for smart settings suggestions
- Availability of charging spots can be checked
- Charging settings can be saved and reused

Requirements

Below are the requirements set by the client for the end product. The goals and motivation above were set in accordance to the expectations of our client and the necessary aspects for the EMS to work efficiently. The user and system requirements presented below were prioritized according to the MoSCoW-method and identified as Must, Should and Could functionalities.

Functional Requirements

Must

1. A user should be able to get a notification upon a successful initiation of charging.
2. A user should be able to get a notification when the car is charged up to the level assigned by the user.
3. A user should be able to inspect the charging plan they assigned.

Should

4. A user should be able to see the CO_2 emissions generated by the charge.
5. The system should be able to predict and suggest the charging settings to the user.
6. The user should be able to collect points based on solar power consumption (as opposed to the grid power) and the uniform charging plan.
7. The user should be able to see the history of how much energy they consumed, how many points they got and what their CO_2 consumption was on a daily basis.

Could

8. A user should be able to delay the charging finish time during the charging.
9. The system should be able to read the user's calendar and adapt the charging setting accordingly.
10. The user should be able to convert the points into rewards.

11. The user should be able to see how many charging spots are available.
12. The user should be able to save a previous session and reuse it.

Quality Requirements

1. The system should be implemented in English.
2. The system should display the weather forecast for Enschede.
3. The system should notify the user when the charging session has successfully started within a second.
4. The system should compute and suggest a charging mode in no more than 5 seconds.
5. The “Eco Charge” button should be green while the “Fast Charge” button should be gray to incentivise users to use the first option.

Stakeholders

This system is developed for the users of the EV charging station and CAES researchers. The main stakeholders can be identified as the users, system administrators and the researchers that collect data. Our clients are, dr. ir. Gerwin Hoogsteen and PhD candidate Bart Nijenhuis, who are both part of the CAES research group. This research is being conducted under the partnership of AmperaPark, which is researching the power grids for parking lots and algorithms related to its efficiency. The requirements provided above mainly focus on the users and their experience since the focus of this project is the user interface and the algorithms are outside of our scope.

Prototypes

The Lo-Fi prototype depicts the key requirements (Chapter Requirements), that were discussed and approved with the supervisors, and the design choices that visually integrate the requirements in the system. In order to evaluate the integration of the requirements into the system and evaluate the design decisions, Lo-Fi (low-fidelity) prototypes were provided in two testing phases. After each phase of the Lo-Fi prototype was improved based on the feedback received from the supervisors until we received full approval of the prototype. The prototypes were developed using the application *Justinmind.*

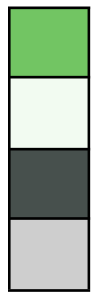
Evolution of the Prototype

1st Prototype

The first prototype was developed during week 1 and week 2 of the project. During this phase we decided upon the following design choices: the color palette, the font (Open Sans), the navigation bar, the widgets on the *Scheduling page.* The prototype was tested in week 3 with our supervisors. You can find the prototype in Appendix A.

The color palette
The application aims to incentivise the users to make sustainable decisions when it comes to charging their electric vehicles. In order to promote the idea of sustainability, a green color palette was chosen. According to multiple sources, the color green also acts as a “call to action” and instigates more sustainable choices (Onextrapixel).

- The Highlight Color: #72C563
- The Neutral Color: #F2FBF1
- The Text Color: #47504D
- The Neutral Text Color: #CECECE



The Navigation Bar (Appendix A, Figure A.5)
The navigation bar contains three items which subsequently denotes three main pages. The central button (car icon) will navigate to the *Scheduling Page*, as it executes the main functionality of the application of scheduling a charging session. The left button (trophy icon) will navigate to the *Leaderboard Page* and the right button (time icon) will navigate to the *History Page*.

2nd Prototype
The second prototype was developed during week 3 of the project, and it represents the improved version of the previous prototype based on the received feedback. During this design phase we decided upon the following design choices: the type of graphs and widgets on each page. The prototype was tested in week 3 with our supervisors. You can find the prototype in Appendix B.

Chapter 4

Global Design

In this chapter, the global and architectural design decisions are explored in detail. An overview of the entire system and its functionalities is provided.

Preliminary Design Choices

After discussing the system with the client, and getting an idea about the current user activity, the following diagrams were designed. As the user and app flow was identified, the rest of the preliminary design aspects such as the programming language and libraries were also decided on.

The diagram below shows the connections between the driver, app and the backend when the prediction of the setting is being set.

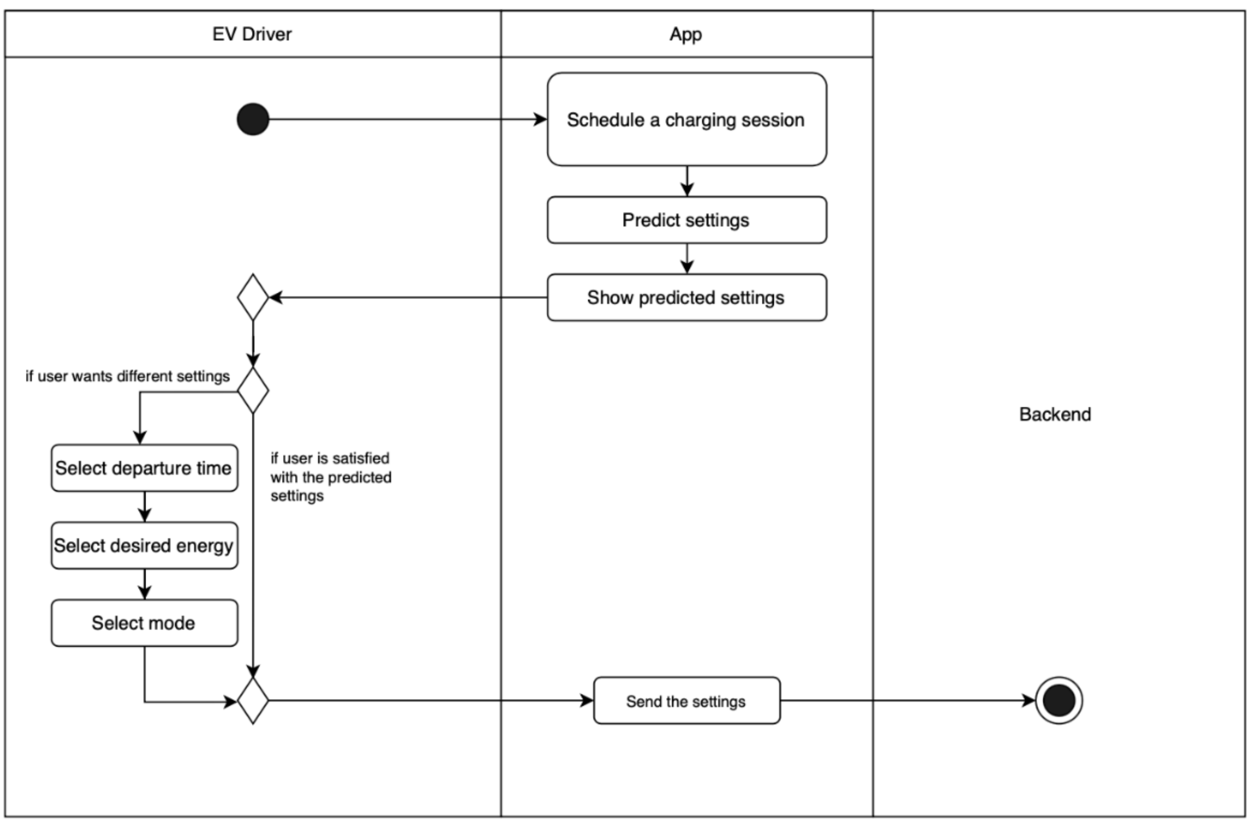
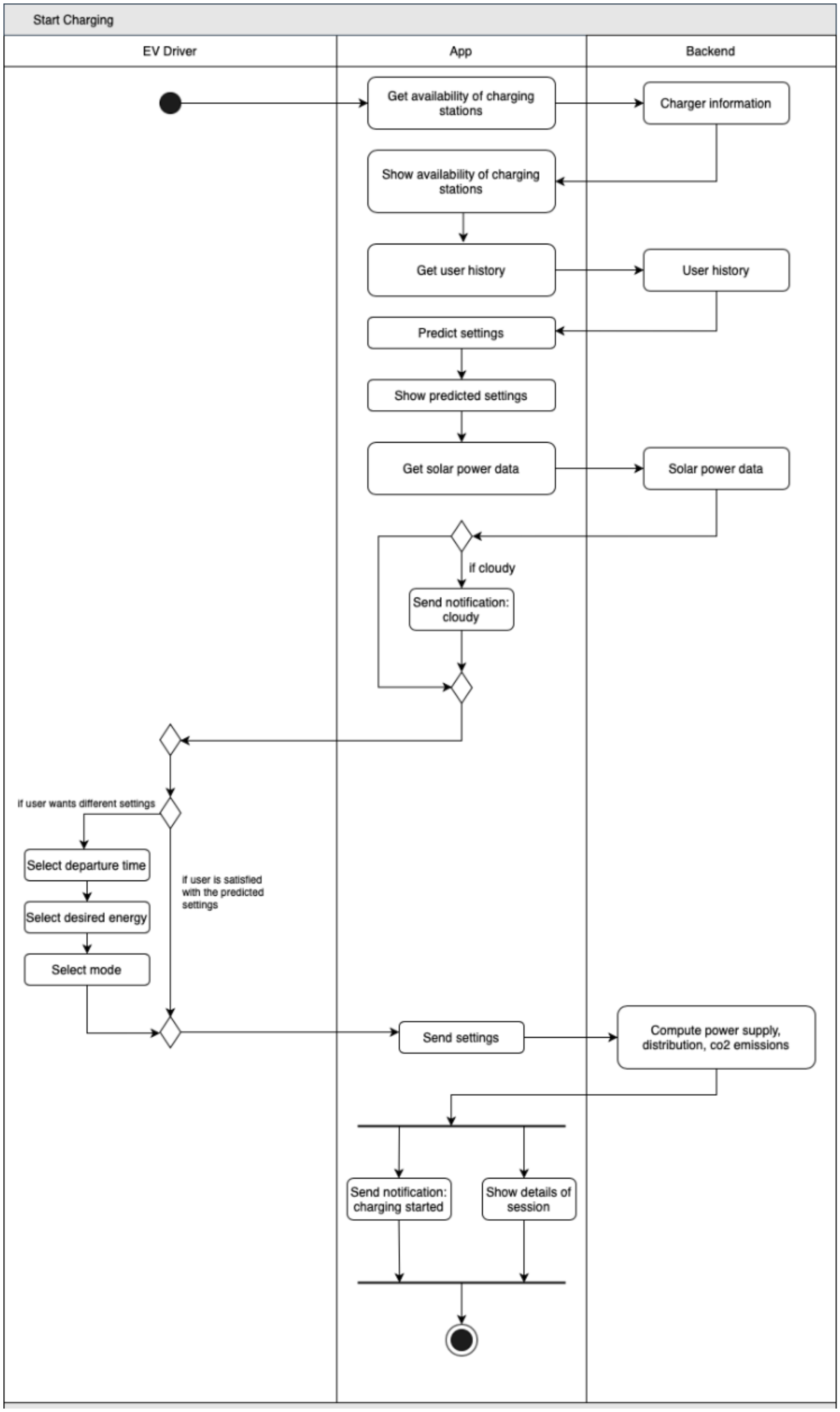


Figure 2: Activity Diagram Predicted Settings


Start Charging
EV Driver
App
Backend
Get availability of charging stations
Charger information
Show availability of charging stations
Get user history
User history
Predict settings
Show predicted settings
Get solar power data
Solar power data
if cloudy
Send notification: cloudy
if user wants different settings
Select departure time
Select desired energy
Select mode
if user is satisfied with the predicted settings
Send settings
Compute power supply, distribution, co2 emissions
Send notification: charging started
Show details of session

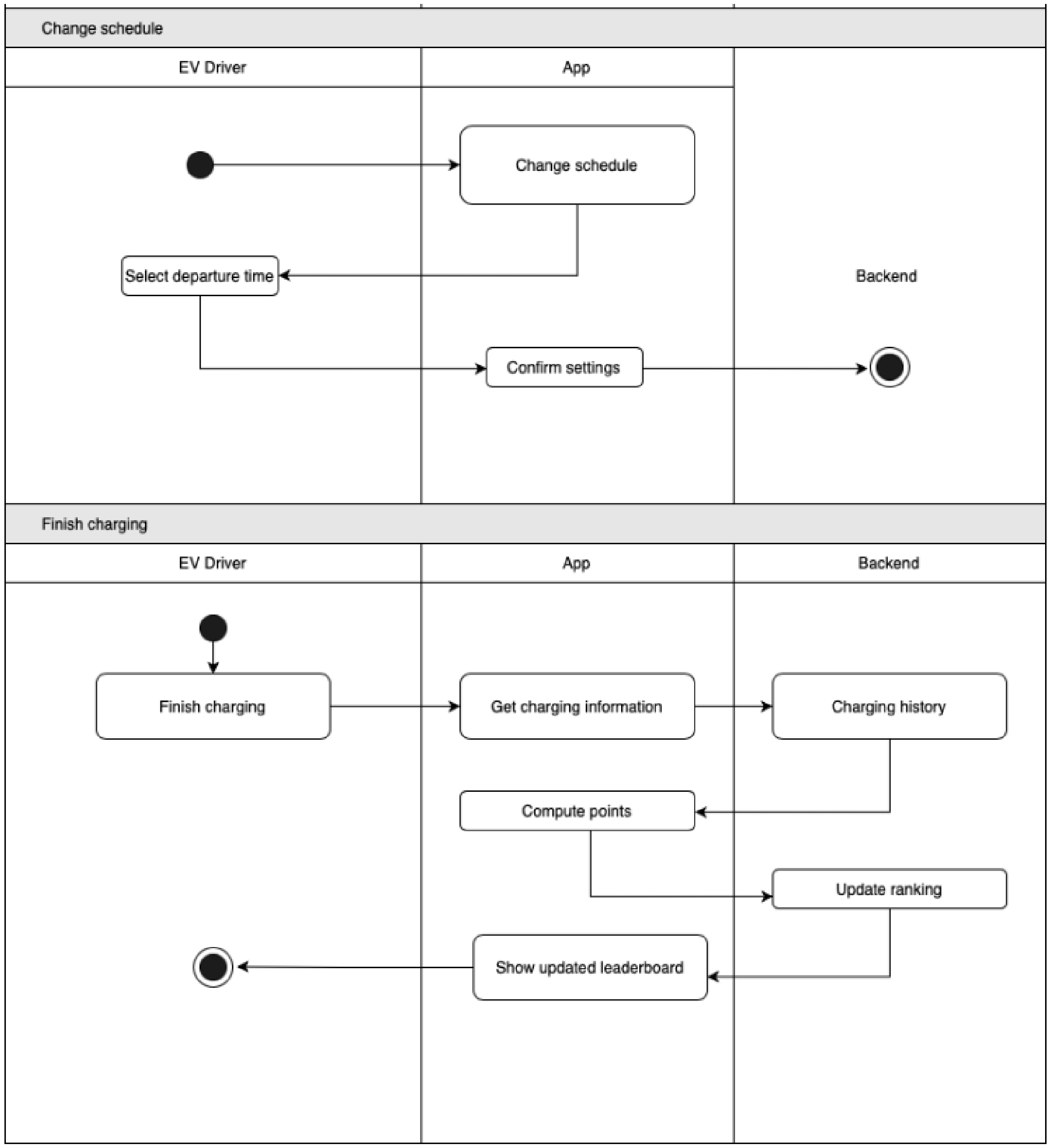


Figure 3: Activity Diagram System

Above you can find the activity diagram of the system, identifying the stages of charging and changing the schedule. The diagram showcases the connections between the charging station, the user interface and the backend of the EMS.

The diagram below is the activity diagram of the notifications and how they interact within the system.

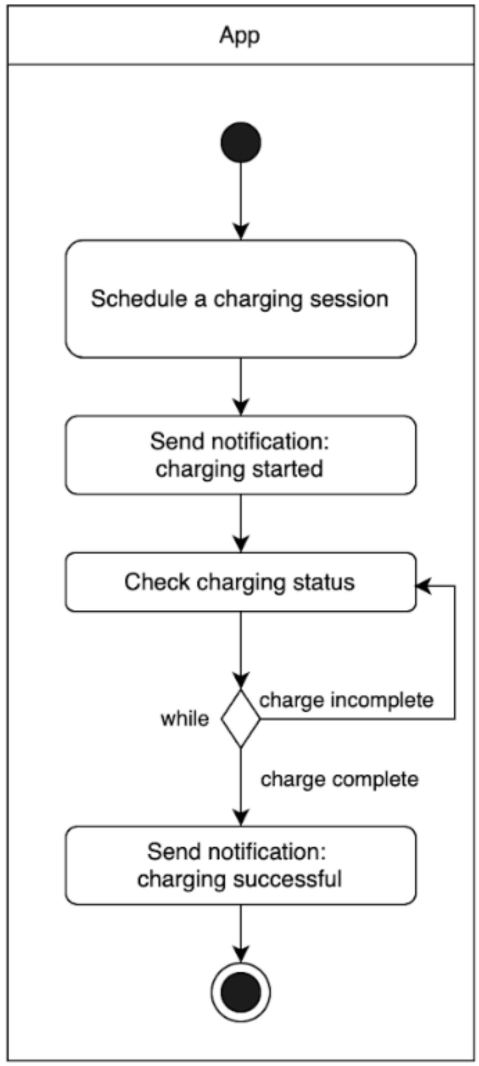


Figure 4:Activity Diagram of Notifications

Libraries and Frameworks

The system uses the following frameworks to build the web application:

- Justinmind: Design of the Lo-Fi to be presented to the client
- React JS: A JS framework that enables building interactive web applications efficiently
- Cypress: User for unit testing

Within the frameworks, Cypress was used for testing as it provides a user-friendly interface for interacting with the application and allows you to easily test user flows and interactions (Gruenbaum). As an extension of the frameworks, a variety of libraries were used. Some of the important libraries are:

- Reactstrap: Component library for React similar to Bootstrap
- ChartJS: Library used to create the graphs
- Material UI: React Component Library

Programming Language

The following programming languages were used in the system.

- TypeScript
- Javascript for React Hooks
- Python
- SCSS

Typescript enhances Javascript by adding type annotations to constants, function parameters, and return values. Although the UI can be developed solely using Javascript, using Typescript can prevent errors that might arise. In this project, Javascript is mainly used for React Hooks. Instead of having to use class components, hooks are used to add functionality to components, which makes it easier to manage complex UI interactions and dynamic data.

SCSS (Sass Cascading Style Sheets) is an extension of CSS that provides additional features and functionalities to simplify the usage of CSS. SCSS provides features that make it easier to write and maintain large and complex style sheets.

Architectural Design Choices

The URL links of the web application are as follows. While this structure might bring up some security issues as the user id is displayed in the URL, it enables the user and researcher to immediately access the pages necessary. Considering that the system is currently for research purposes, this is much more convenient for the researchers which is given priority until the product is publicly available.

Page	URL
Start Page	chargeview.com/login/${user_id}/
Schedule Page	chargeview.com/schedule
Session Page	chargeview.com/session
History Page	chargeview.com/history
Leaderboard Page	chargeview.com/leaderboard

Overview

The system consists of 5 separate pages and varying notification pop-ups. The system works as follows: the set page displays the username and switches to the schedule planning page. The schedule planning page navigates to the session page after all preferences have been made. From the session page it is possible to go to the leaderboard and history pages with the navigation bar.

Set Page

This page is the entrance page for the system. As the user logs in through the QR, this page is opened. The page contains a hello message with the user's name and a start button to enter the app. When the button is pressed, the app navigates to the schedule page.

Schedule Page

This page is used for the drivers to schedule their departure time and charging type, and provide all the information for the charging to begin. The page setup is as follows: the departure time input, charging amount input, fast or eco charging options, a graph that represents the charging schedule and a start button.

The departure time is set by clicking on the time button and it showcases a pop-up of a clock that indicates the time of departure. A slider is used for the desired charge, and a similar conversion of the previous product was kept. The conversion is between kilometer and kilowatt, and is handled by the backend according to the car model. Below the slider, 2 buttons to choose between eco and fast charging are placed. The page startup is automatically loaded with the eco option chosen to further motivate the user to make the choice. Even before the departure and energy choices are made by the user, the graph below the charging options display the solar energy prediction of the charging station. The graph displays the KW per hour of the day, and as the information (departure and energy) are indicated by the user, the schedule of the charging throughout the day is visible. The start button is positioned at the bottom of the page and it navigates to the session page.

Session Page

After the schedule is set with the scheduling page, the screen is navigated to the session page which contains the information about the current charge. This page has the purpose of displaying the status of the car and schedule as well as stop the session if needed. The indicated information about the current session is provided at the top of the page with options to end or edit the session. Below are 2 boxes, one, displaying the percentage of the indicated energy that is transferred and other, displaying the carbon emission of the current session. The graph gives an overview of the charging process and updates the user on the amounts per hour. The navigation bar at the bottom contains 3 icons, and it is possible to navigate to the leaderboard and the history pages.

Leaderboard Page

This page was created to motivate the users to choose more sustainable options while scheduling their sessions. Current carbon emission and solar score are presented under the rank of the user. A small explanation on how the scores are calculated is given below to keep the users aware of their habits. Underneath the ranks of the users, as well as their name and scores are displayed.

History Page

The history page provides the list of previous sessions and the total consumption and emission of the user. All the information can be displayed in different intervals, week, month and year. The page consists of the total data points, a graph that helps track the distribution and a list of all the individual sessions. Top of the page presents the total carbon emission, total energy and total charge time within the indicated time frame. Below is a graph of charged energy per day, with 3 buttons underneath to indicate the timeline of the axis. All the previous sessions are also listed underneath with the duration, energy, emissions indicated.

Notifications

To increase the user trustability and strengthen the feedback mechanism we have added notifications to the application. The user will now be able to receive notifications indicating the availability of the charging stations, whenever the weather is cloudy and when the charging has started.

Chapter 5

Detailed Design

This section touches upon each element of the system in detail and provides descriptions on the choices and designs made. The structure of different widgets and graphs are provided as well as the through process behind each design choice.

Widgets

This section briefly describes the design choices for the individual elements of the system.

Charging Progress and Emissions Indicator

Charging progress is a vertical, square shaped progress bar component. It informs the user about the charging progress of the current session. We recognise a possible confusion for the user, namely they might think the percentage refers to the entire car battery capacity and not the progress of the session. Benefiting the extra space in the component bounds, a clarifying annotation has been added.

Emissions Indicator follows the same design pattern as Charging Progress but it is used to display the amount of CO_2 Emissions reduced when using the Smart Charging option in the application.

Energy Selector

The Energy Selector is a controlled slider input for indicating the amount of energy desired for the charging session. It is limited by the maximum amount of energy that can be provided by the grid for the corresponding departure time and the vehicle's EV capacity itself.

History Bar Graph

History Bar Graph is the central piece of the History page. It can be toggled to show both energy consumption and emissions over a period of time in a bar graph form. The user can specify the time frame for data display using the period selector. The available time periods are: weekly, monthly and yearly. Additionaly, the period selector returns data to its parent component allowing for other components to read the selected time period. This ability is used by the charge history table present on the same page.

Square Display

The square selector is a versatile display space for various statistics. It aims at making the user more aware of their usage of the system. Currently there are three square displays on the History page. They show the sum of carbon emissions, energy consumption ang charging time. Square displays are also coupled with the period selector element of the History Bar Graph. This solution allows for displaying statistics for week, month and year dynamically.

Mode Selector

Mode Selector is a group of toggle-buttons serving the purpose of displaying the user's choice for selected energy mode for their planning. They've been revamped using MUI components and restyled to incentivize users to choose the Eco-charge (pre-selection and darker coloring)

Navigation Bar

Navigation bar for the History, Charging Session and Leaderboard pages. The navigation bar is fixed to the bottom of the screen; this design choice is to prevent the navigation bar from disappearing off the screen when resizing. Although resizing is hardly ever done, this constraint prevents the user from getting stuck in a page. Navigation bar is only shown when charging is in session; in other words, it is not visible in the Schedule or Login pages.

Figure 5: Navigation Bar

Plan Graph

A reactive graph displaying the available solar energy and the allocation of power in kWs for selected charging settings (departure time, mode, and desired energy). The graph changes instantly based on the selected settings by the user.

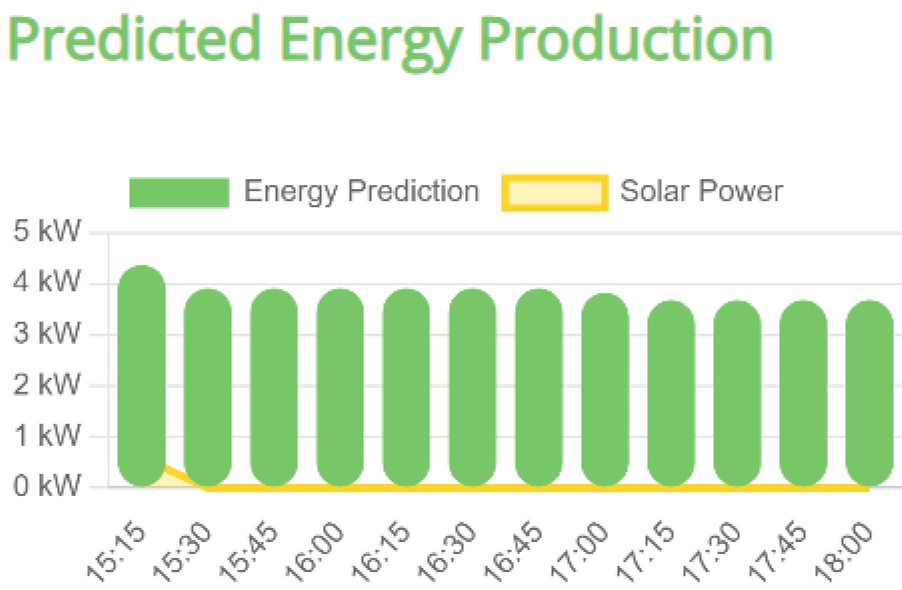


Figure 6: Plan Graph

Progress Graph

The progress graph displays the user’s current charging plan from current time until the departure time. It serves the purpose of giving more insight into the charging system for the EV.

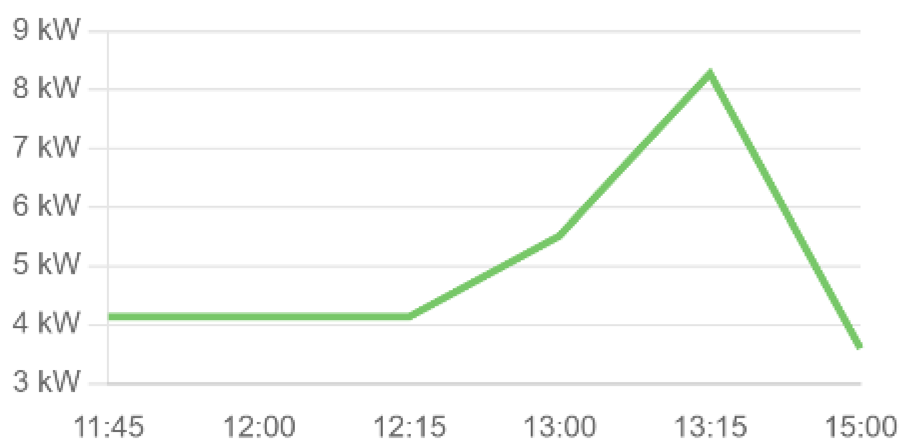


Figure 7: Progress Graph

Summary Card

The Summary Card is a basic card widget which displays the essential information about the charging session (Departure time, Charging Mode, Current Energy). Additionally, it houses buttons to cancel and edit the current session.

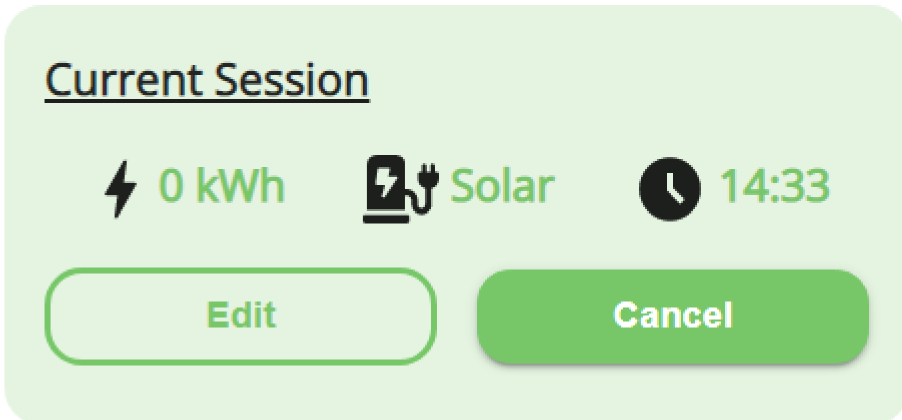


Figure 8: Summary Card

Time Input

The Time Input widget is a revamp of the time input field used by the application in the previous version. It utilizes the MUI-based mobile time picker for ease of access and UI aesthetics when selecting departure time.

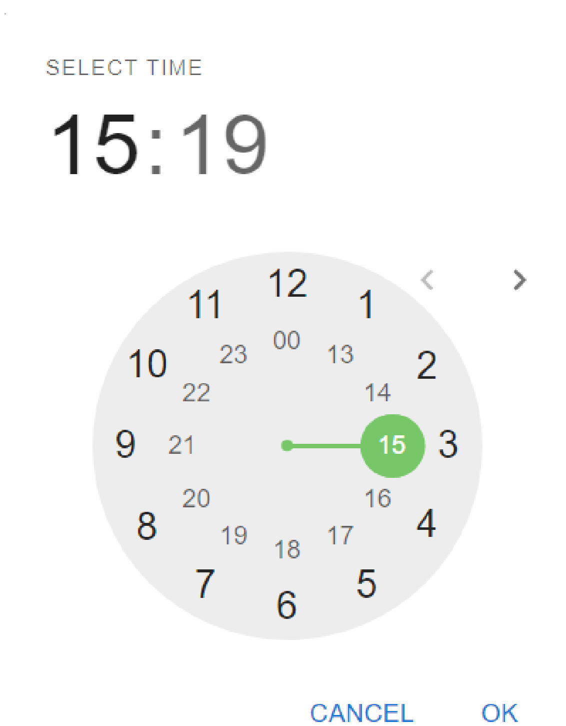


Figure 9: Time Input

Leaderboard Formula

The point system of the ranking of the leaderboard depends on 3 aspects; accuracy, flexibility and carbon emission. The formula that calculates the points was created to produce 30 points at max per charging and depends equally on the mentioned components. For the calculation of the point system, the following formula was proposed to the client:

Carbon Emission:
$(-\ 0.02x\ +\ 11)$, x being the carbon emission in KG. This equation provides a decreasing graph with a max of 500 and a minimum of 50. This provides points ranging from 0 to 10; 10 for only 50 kg of carbon emission which is almost unachievable, however the slope of the graph provides a balanced point system.

Accuracy:
The accuracy of the system is measured by inserting the difference of departure and scheduled departure in minutes, $unplugging\ time\ -\ scheduled\ departure$, into the function:

$$f(x) = \begin{cases} \frac{x}{10} & \text{for } \frac{x}{10} \leq 10 \\ 10 & \text{for } \frac{x}{10} > 10 \end{cases}$$

Which provides points ranging from 1 to 10 for the first 100 minutes, the function then plateaus at 10.

Flexibility:
Flexibility of the system is deducted by the pressure the charging puts on the grid. Therefore the equation is created as the overall capacity - scheduled charging rate of the system over the capacity of the grid in kilowatts. The grid capacity relates to the maximum rate of charging the grid can offer at full capacity. This ranges from (0,1) and by multiplying it with 10, we get the range to (0,10) :

$$\frac{grid\ capacity - charging\ rate}{grid\ capacity} *\ 10$$

The sum of all these values will provide the point of the user, with a maximum of 30.

Chapter 6

Risk Assessment

This section will introduce potential risks associated with the process of creating the system and the regular operations of the system. The risks listed below also come with a mitigation strategy that we have followed.

Risk	**Risk description**	**Likelihood of the risk occurring**	**Impact of the risk occurs**
User adaptation	Users may be discouraged when adapting to the new layout	3 - medium	2 - Low
Multiple alerts	Increase in the no. of notifications might become annoying to the users if the updates are given too frequently	2 - low	3 - medium
Privacy Risk	Display of names on leaderboards	2 - low	4 - high
Scheduling errors	Lack of clear timelines in the app (departure times)	2 - low	4 - high

User Adaptation

The new product may potentially be confusing and discouraging. Since we will introduce a lot of new features the layout of the website will change. The users will therefore have to adapt to the new design. For many that might be confusing and thus discouraging.

The users expect a simple and smooth experience; we have therefore preserved the old layout of the website that the users are used to, as much as possible. We have also followed the well known mobile app design solutions so that the new website feels intuitive. Additionally, we conducted user tests with the prototypes and improved on the feedback gathered from the user.

Multiple Alerts

The new product is a more interactive system with additional notifications and options. The increase in the number of notifications might become annoying to the users if the updates on the charging status are given too frequently throughout the day.

To regulate the number of notifications, we have limited the updates to when the charging stops and restarts. This was further discussed with the users and more feedback was taken from the wireframe as well as the prior interviews we conducted.

Privacy Risk

The new product will come with a leaderboard to further motivate the users to choose more eco friendly options. This board displays the users with the most points in accordance with their energy consumption. This obviously is a privacy risk due to personal information such as the user's name being shown to others.

In order to prevent this risk, explicit permission from the user will be asked and their consent will be taken on the app before they are put on the leaderboard. We have given them the option of participating in the leaderboard only if they have consented to do so.

Scheduling Errors

The charging station operates under the assumption that the user knows their departure time and has enough trust in the system to deliver the energy within the time period. For new users, this often is not the case. Setting an earlier departure time to give an error margin or waiting until the car starts charging when it is scheduled to start in an hour, are possible risks of such a system.

To overcome the distrust, we have implemented a “current charge” section that displays how much the car has charged to keep the user updated and increase their trust in the system. As well as this, we have added the gamification element to this problem. One of the ways to gain points will be to predict the correct departure time and gain points accordingly, this will motivate people to be more realistic with their timelines.

Chapter 7

Testing

The tests conducted on the system were divided into unit, system and user tests. The extent of the tests are discussed in this section.

Unit Tests

Since the provided code-base was a hand-down from one of the previous iterations of Design Project, the required unit-tests were already in place with the use of Cypress. However, since we moved some pages around, we modified the tests accordingly. All tests basically tested the navigation and existence of components when there's a change in a state.

System Tests

Pages

During the development phase we have identified a lot of problems regarding pages. Namely, the sizing of the components and their placements. Oftentimes the elements were overlapping one another, weren't centered, floated off the screen or were improperly sized. All of those issues derived from the variable size of the screen.

Therefore for each page a manual test is carried out after an addition or deletion of the element. The test is simply to render the page in multiple screen resolutions. It is worth noting that certain pages when being resized dynamically, i.e. when the screen resolution is changed after the page has been rendered, do fail the test. This however is not a problem, because in practice the screen resolution on a device never changes. Pages that fail the tests need to simply be refreshed in the browser to render properly.

Fixing the dynamic resizing issue is not a priority, as mentioned earlier, it does not pose a problem in practical use of the application. It is mentioned for completeness.

User Tests

User tests were conducted before and after the final version of the application, and questions found in Appendix C were asked to the attendees. Improved functionalities and visual aspects of the application were discussed and possible improvements were noted. No implementation errors were found during the testing period and the most impactful improvement to the system was the changed formula for the leaderboard. The results of the user test will be discussed in detail in the User Acceptance Test section under Chapter 8.

Chapter 8

Results

This section will go through the results of the tests mentioned above and categorize the requirements as completed and uncompleted. The results of the tests will be discussed in detail, including their cause and effect.

Unit and System Tests

The unit and system tests conducted on the application were run without errors or bugs. The system proved to be adjustable to any screen type including mobile and desktop. The unit tests conducted on each of the components of the application also did not have any issues or bugs. Overall the system is robust and without problems.

User Acceptance Tests

The user acceptance tests were conducted with 5 users from the CAES research group to provide their final feedback and experience with the finished product. The conducted tests were done on a single test group, actual users of the system, since their profiles provided enough variety to cover all the scenarios identified by the team. The users profiles ranged from daily users to weekly users with varying degrees of information on sustainability and usage types. The users were asked to also consider a different scenario as well as their own in their answers, and the scenarios given were chosen from the list at Appendix C. Each user first used the system as they would on a personal basis, then answered questions with a profile opposite their own. This acted as a method to remind the user of different ways of using the system as well as to get an overall view of the quality of the product.

This section will analyze the user's experience and feedback, identify similarities and consistencies on their response, and point out differences of each profile.

The first questions of the acceptance tests identified the user’s profile type through establishing their charging pattern, degree of consideration on sustainability and trust on the current system. As expected, following profiles were interviewed:

- Daily user, with trust in the system, with high consideration to sustainability (making decisions inline with all eco-friendly practices)

- Daily user, without significant trust on the system, conscious of the sustainability choices but hesitant in following them due to mistrust
- Semi-regular user, trust in the system, high consideration of sustainability (making decisions inline with all eco-friendly practices, charging fully due to the usage style)
- Semi-regular user, without significant trust on the system, conscious of the sustainability choices but hesitant in following them due to mistrust

The users were then asked to go through the product and schedule a session as they would do on a regular basis. This process took approximately 1 minute per person and the users expressed their ease due to the familiar structure of the web application.

Overall, the new indicators and widgets were found to be more user friendly. Some users found the time indicator to be better than the slider for the ease of use when moving. The interface also visually looked more appealing and modern to the users.

The users were satisfied with the amount of notifications that the system now provided. Indicating the availability of the charging spots were found to be very useful as well as the additional feedback about the beginning of the charging phase. Especially the users that were using the stations weekly with long distances were very pleased with the live charging bar and the additional trustability of the system.

Especially the users without much regard to sustainability expressed their appreciation of the newly implemented CO_2 emission graphs and explanations. They requested a bit more information to be given on the consequences of CO_2, as it was not clear what it exactly meant. All users in that regard appreciated the increased efforts to promote sustainability and seemed to be fond of the leaderboard.

One of the aspects the users asked for improvement on is adding the option of seeing the car charge in terms of percentage or the app displaying the current charge level of the car at the session page. Also giving an estimation for the charging losses that happen due to the hardware (cables etc.) and the temperature. One of the users requested an error margin to be provided on the app to have a more accurate charging experience. These were not possible to implement due to the time limitations but the improvement of expressing the charging amount in percentages as well as KW was already implemented.

One of the users suggested that for the future, the saved settings or suggestions can be adjusted according to the previous usages. Instead of waiting for the users to manually

set the suggestions, it might be automatically calculated with a relative weight to both the history average and the previous days usage for example:
85% old time average + 15% previous day = new KW
The current system only displays the setting prediction once the user manually sets it, this was found to be more user friendly according to the team. Due to different user types, such as weekly users that do not use the system for a set time, the suggestions were kept to be user adjusted.

In the current system, users having more than one car was not taken into account. Thus the app automatically starts the previously used car, instead of querying for the switch. This was an implementation we were unaware of, and will be mentioned in Future Works.

One of the users had many suggestions on how to improve the ranking formula for the leaderboard, to make the system even more sustainable. They were concerned about certain imbalances of the point system, such as the lack of solar energy in the later times of the day and how that decreased the points of the user due to the use of grid power. These suggestions will be further discussed in the Future Works.

The comments made by the users were followed with ratings (1-5) on the trustability, visual appeal, ease of use, system feedback and satisfaction. The range went from unsatisfactory to satisfactory. These questions were asked both about the previous product as well as the new system to all users. The average results were as follows:

	Trustability	Visual appeal	Ease of Use	System Feedback	Satisfaction
Previous System	4.4	4.6	5	4.2	4
New System	4.7	5	5	5	4.5

The system, from the given scores, were improved in the eyes of the users. The critical requirements that were given to the system, such as increasing trustability, were certainly achieved both visible from the trustability and feedback scores. The risk, multiple alerts were found to be solved as the users were pleased with the amount and information provided. The sustainability aspect was also improved as the leaderboard provided a way of staying conscious and responsible of the choices made by the users.

Overall, the system received great feedback from the users and was a successful implementation.

Requirements

All the “Must Have” and “Should Have” requirements of the system were completed and successfully implemented. The only requirement the team was unable to meet was the calendar implementation which was identified as a “Could Have”. Due to time constraints, this requirement was disregarded since the main goals of the upgrade of the user interface were trustability and sustainability.

Conclusion

The redesign has the potential to significantly improve the usability of the charging station and enhance the user experience for EV owners. By implementing the recommendations outlined in this report, we have ensured that our charging station remains a user-friendly and convenient solution for EV owners, contributing to a more sustainable future. The project involved close collaboration with clients to understand user preferences and requirements, resulting in a UI that is intuitive and easy to use while offering the necessary features. User acceptance testing indicated that the UI was well-received, with room for improvement which will be discussed in the Future Works. While most requirements were achieved and received well by the users, some implementations to enhance the user experience, such as the calendar implementation, were left to be completed by future researchers.

Evaluation

This section will evaluate the project in accordance with additional material that could be looked upon and the team dynamics during the quartile. The future works will contain the expectations of the users for further implementations as well as ideas and concerns that could be expanded upon.

Future Works

For the future implementations of the system, our team suggests that the researchers give access to the backend to the next developers. While just focusing on the interface simplified the tasks, the process would actually be much smoother with access to the backend of the system.

Login to the System

Current users log into the system through the use of a QR code unique to themselves. When the project is expanded to all EV drivers to use across campus, the system will need to have a connection through a common QR code that allows the user to login. This login will likely be through a UT account, or a guest user type will be set. For future implementations of the system, the web application should have a guest account as well as the already existing user. This will enable the charging station to be used by a variety of people. Connecting the application with the UT account will also enable more functions to be implemented. While our team was unable to implement the calendar integration, this process will be made easier if the UT account is already within the system.

Sustainability

Sustainability is the main purpose of the charging station and the EMS. While the web application is made to support and encourage the users to be more environmentally conscious, there are ways to further look at sustainability and inform the drivers of their choices. One of the users suggested that sustainability is not individualistic but has to be considered to a wider degree than just the grid on campus. For overall sustainability, the pressure on the grid of the city must be considered, and perhaps the formula for the ranking system could take into account the overall CO_2 emission for the city, which is a more global comparison point for sustainability. This way the users will also be more aware of the timing of their charging, and how the method affects more than just a singular charging station. For the future, the relative CO_2 emissions should be considered while giving points to the users and this must be communicated to the user.

The app can also include graphs regarding this, as visual representations will increase the impact of the consequences.

Price

For the further implementation of the application, the price of the energy should also be considered. The current system does not regard the pricing of the energy, as the researchers do not pay for the energy, however graphs and history pages should also include the prices.

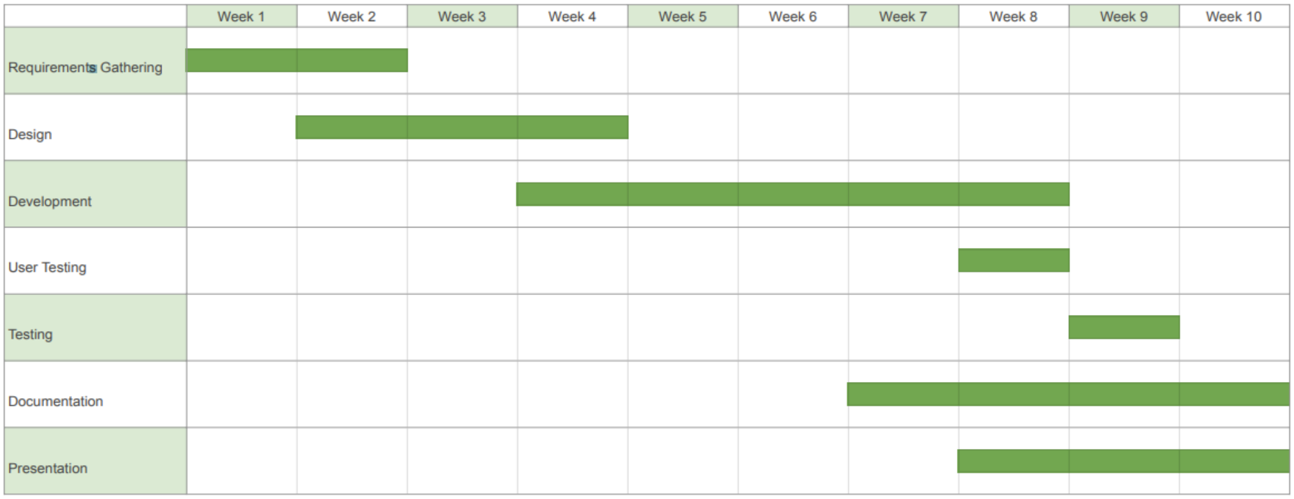
For future considerations, the implications of adding the pricing should be discussed. In conventional charging stations, the price of the energy also depends on the length of the stay of the user at the station. There will inevitably be a compromise between staying longer and charging with solar energy which takes longer: for widespread usage, what will be the advantage of choosing eco charging if the price is also depending on the overall stay. More graphs and encouragement should be added to the interface when the incentive to choose solar energy decreases due to the price.

Team Evaluation

This section will discuss the internal planning and responsibilities distributions of the team. The work progress and difficult points of the assignment will be identified.

Planning

The planning was not strict during the process of developing the web application. We used the Waterfall development methodology, as it aligned with the scope of the project which was mainly front-end development. The development process was split into 5 stages (Figure): requirements gathering and documentation **(Week 1 - Week 2)**, system design **(Week 2 - Week 4)**, implementation **(Week 4 - Week 8)**, testing **(Week 8 - Week 9)**, delivery/presentation **(Week 8 - 10)**. Each phase was monitored by our supervisors, who would determine the successful completion of one phase based on which we would transition to the next development phase.



We had meetings with our client every 2 weeks and the group meetings were done when deemed necessary. Most meetings happened in the first 2 weeks and identification of the requirements were done within the first week after the initial meeting with the supervisors. Some members of the team got together to work on the progress mainly when there were problems with the setup or certain aspects of the pages.

We based our planning and progress on the deadlines set on our initial meeting. From feedback sessions to supervisor meetings, all of our milestones were documented on the proposal report. This gave us an overview of the whole quartile and necessary discussion on work distribution was done through communicating on Whatsapp. The issues were assigned on Gitlab and members claimed them as their schedule allowed.

One evaluation point is the scheduled time for the final user tests. The final user tests were conducted on the 8th week of the quartile as scheduled. However this proved to be too late into the module to change or add significant elements to the project. These elements were mentioned above in the future works section.

Work Distribution

The work among the group members was distributed accordingly to personal scheduling and preferences. Since the web application was regarding the user interface, only frontend, specializations were not taken into consideration. None of the members were familiar with React thus the distribution was made according to the issues claimed by the participants on GitLab. The assignment distribution is listed below:

Michael:

- Developing the History and Leaderboard pages
- Creating HistoryBarGraph, NavigationBar and SquareDisplay widgets

- Creating useChargingHistory, useRanking and useSuggestion React hooks

Sadat:

- In-charge of UI revamp
- Creating TimeInput, SummaryCard, ChargingProgress and other widgets
- Defining and optimizing internal data flow
- Creating reactive graphs for planning and progress
- Modifying Cypress Tests
- Code management on GitHub

Doortje:

- Developing the notifications:
    - Availability of charging stations
    - Information about cloudy weather
    - Information that charging has started
- Creating useChargerStatus
- Diagrams for the system
- Ethics/reflection report

Valeria:

- Develop the prototype
- Create the final presentation and poster
- Assist Duru with the user interviews
- Report (Prototype Section)

Duru:

- Conducting the user interviews
- Creating the formula for the leaderboard
- Report

Team Evaluation

While the workflow of the project was as planned and quite smooth, the work distribution among the group members could have been improved. All of the deadlines and implementations were delivered on time but the allocation of tasks were very distinct, due to personal scheduling conflicts, which allocated specific tasks to members. More collaboration within the group would lessen the workload on everyone, however the tasks were completed since all members were competent and able to complete the required tasks.

Conclusion

If the entirety of the project is considered, the implementation and planning were all successes. The system that was developed for the client, achieved all requirements that were deemed necessary and more. The group worked in harmony, as tasks were predefined, even though the imbalances could have been solved by allocating tasks outside of predefined sections. Overall, the system and the team was successful and the project was completed.

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(2) Onextrapixel. “Anatomy of Colors in Web Design: Green and Environmental Concept.” *Onextrapixel*, Sept. 2011, onextrapixel.com/anatomy-of-colors-in-web-design-green-and-environmental-concept.

(3) *SMA EV Charger 7.4 / 22 Met Smart Connected | SMA Solar*. www.sma-benelux.com/producten/sma-ev-charger-74-22.

Appendices

Appendix A: First Version of *Lo-Fi Prototype*

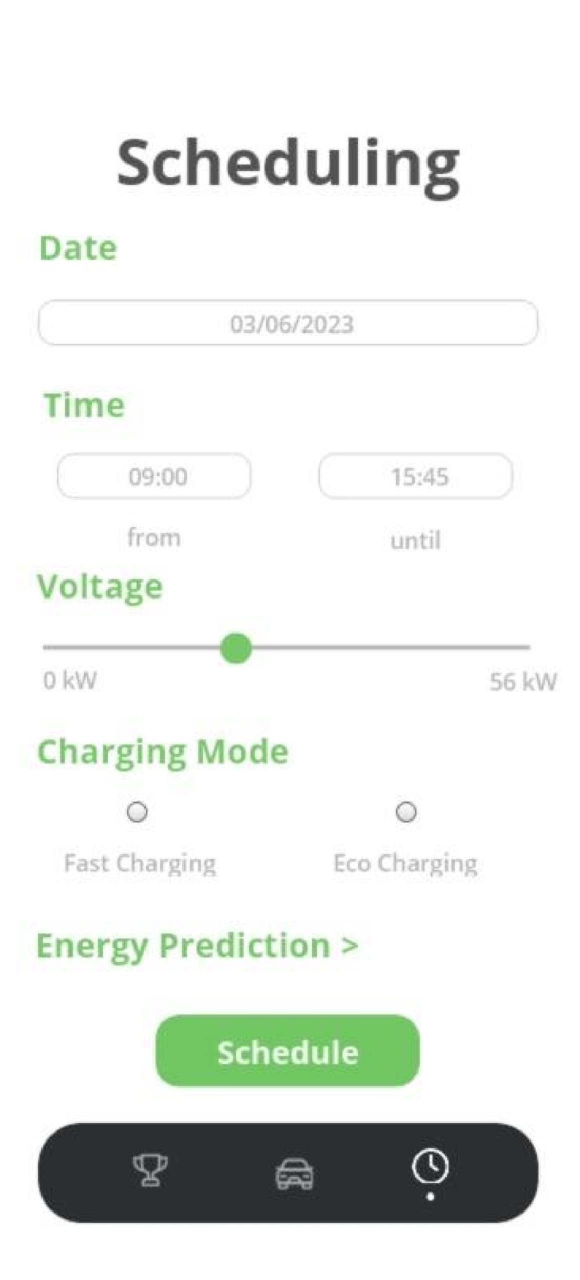

Figure 1: Scheduling Charging Session Page

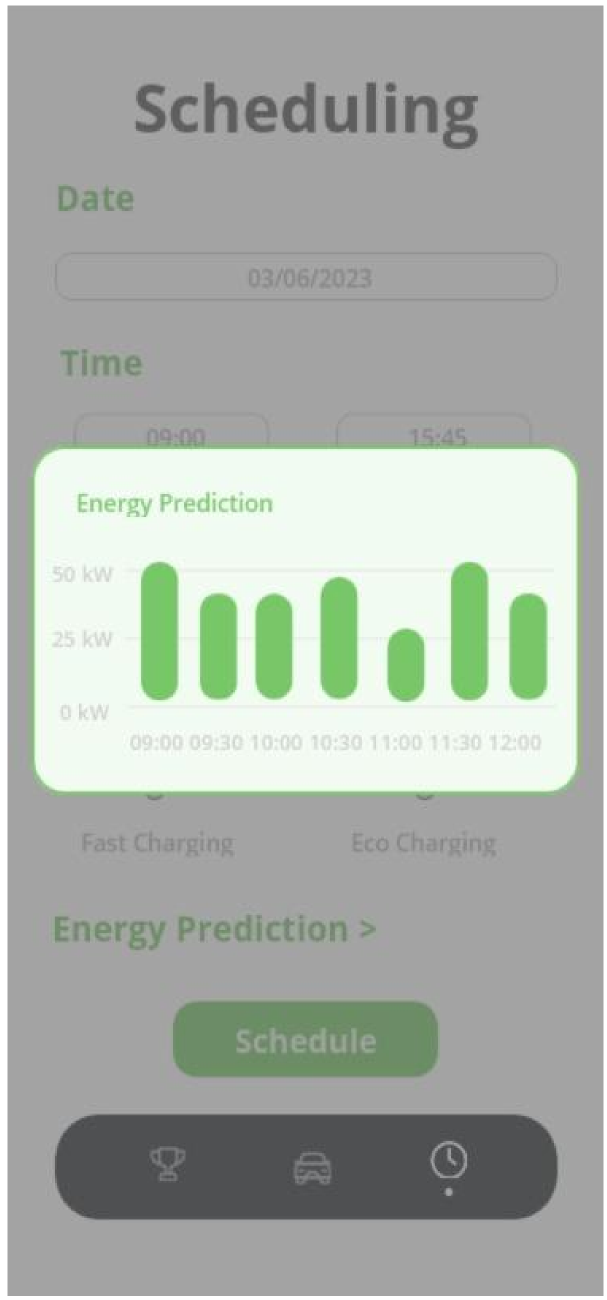

Figure 2: Scheduling Charging Session Page (Energy Prediction)

Figure 3: Statistics Page

Figure 4: Charge Session

Appendix B: Second Version of *Lo-Fi Prototype*

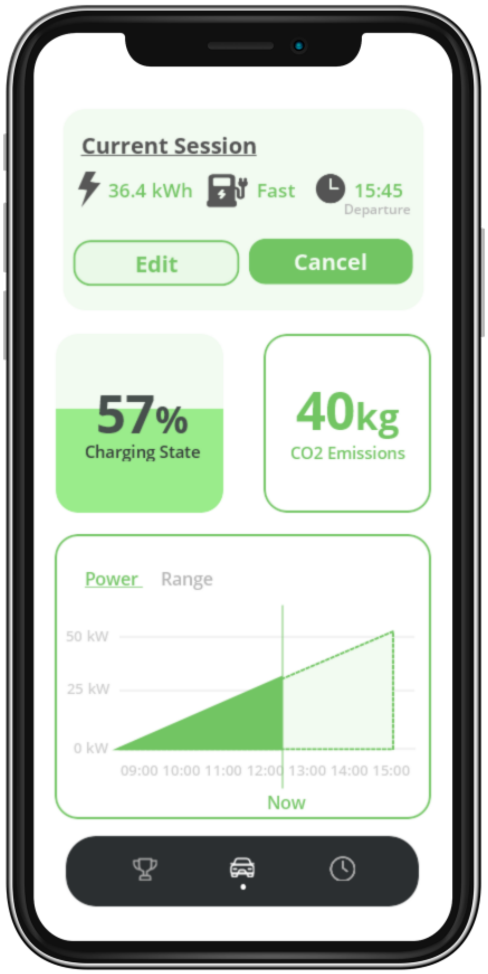

Figure 1: Current Charging Session Page

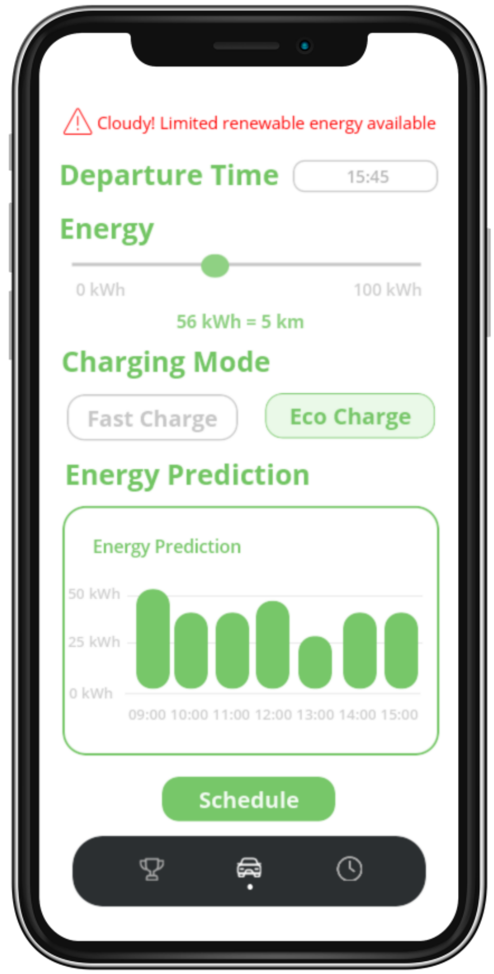

Figure 2: Scheduling Page

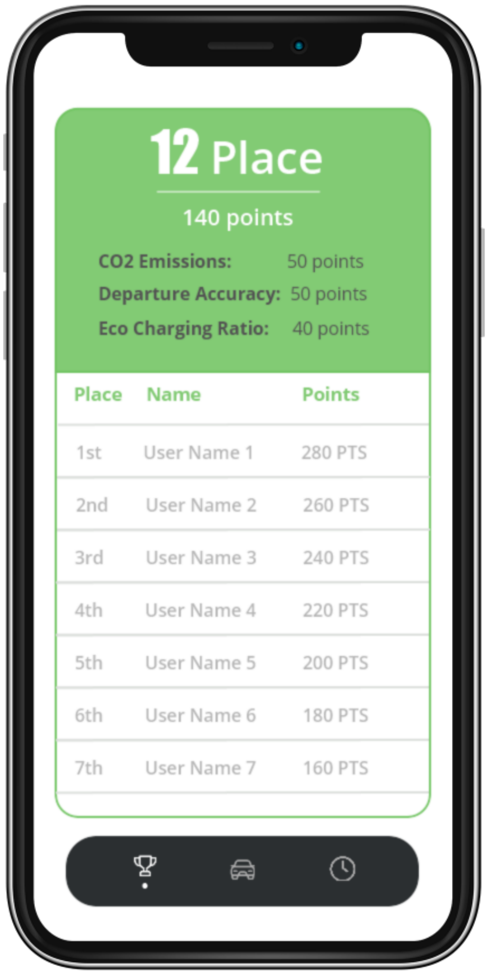

Figure 3: Leaderboard (Gamification) Page

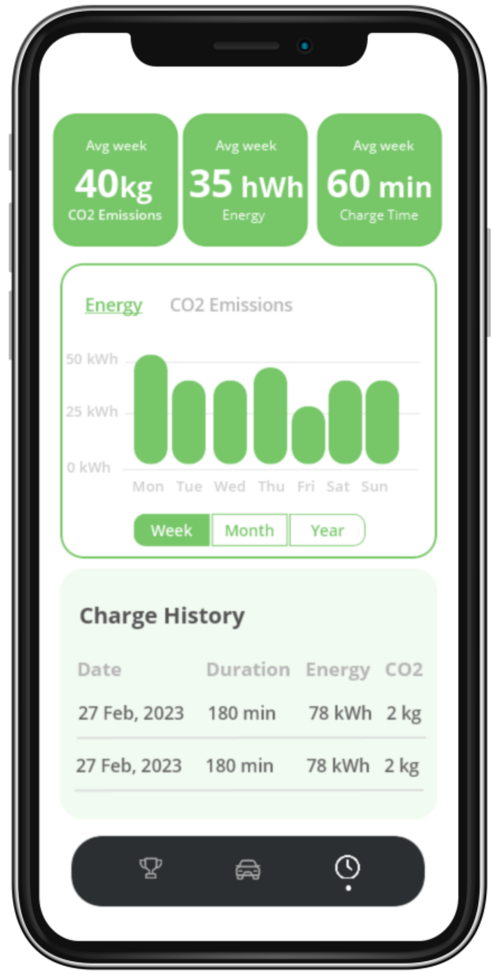

Figure 4: History Page

Figure 5: Navigation Bar

Appendix C: Final version of the Application

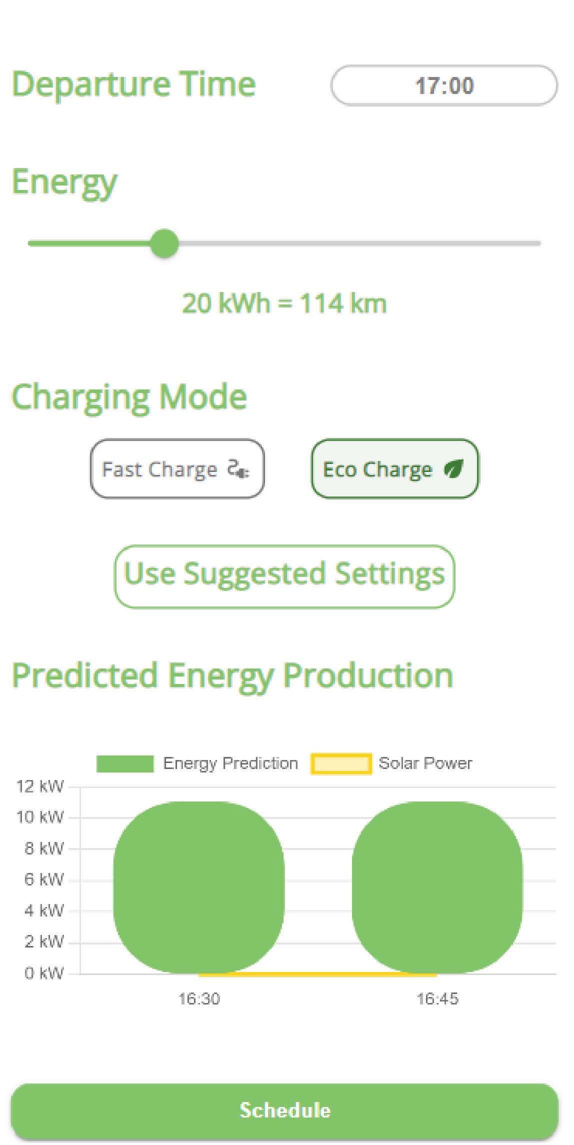

Figure 1: Scheduling Page

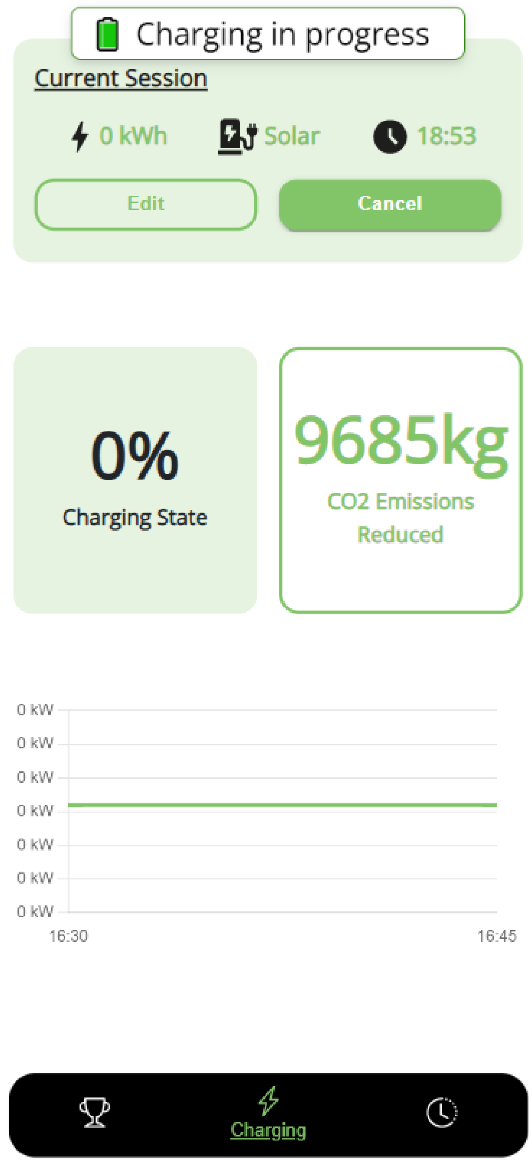

Figure 2.: Charging Page + Notification

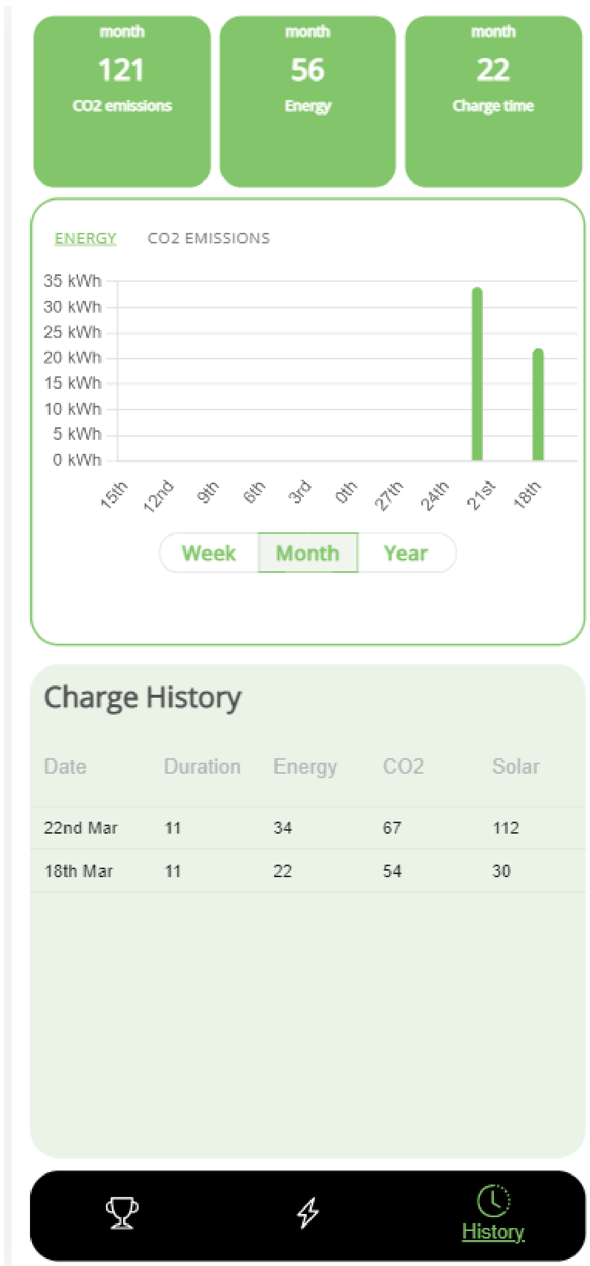

Figure 3.: History Page

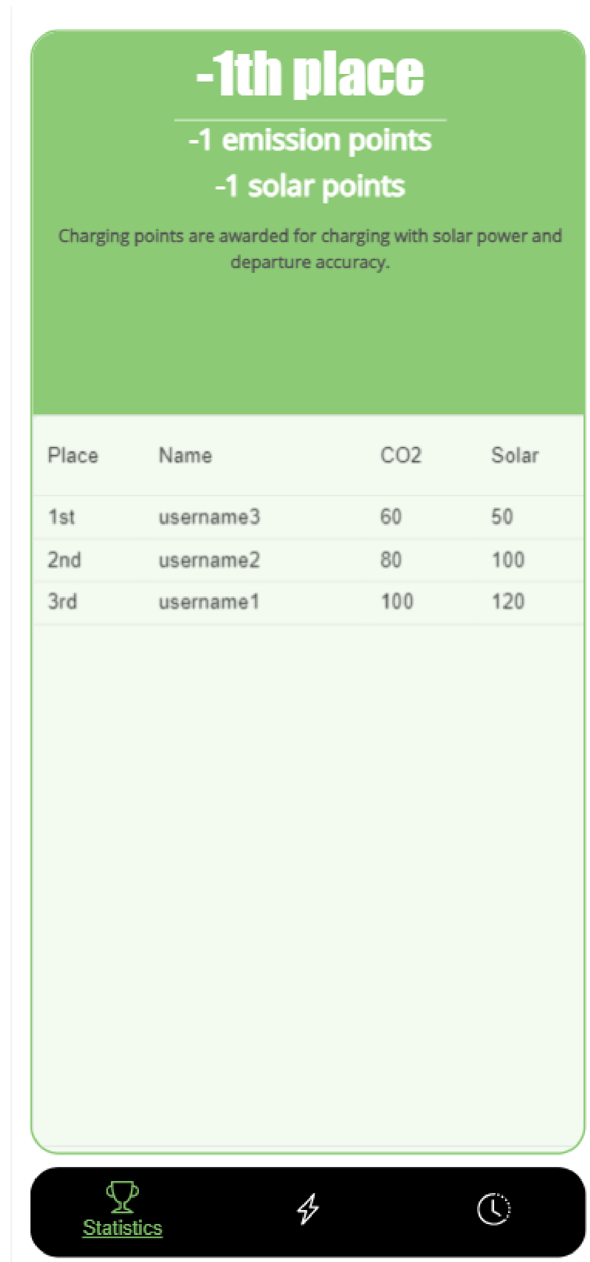

Figure 4.: Leaderboard Page

Appendix D: *User interview*

Below are the questions used to conduct the user interviews. The interviews started with a small introduction of the team, and the purpose of the product. The users were then asked questions about their usage and opinions on the current system. The product test was done through asking the user the prompted test questions, and noting down their struggles with the product. Finally an evaluation was done with the product design and general comment questions. Any additional questions and concerns were also noted down.

1. **Getting user profile**
    a. Age and sex
    b. How long have they been using the system
    c. Average usage throughout the week
    d. Which charging option they regularly use (fast/eco)
    e. What is their reasoning for choosing between the options
    f. Do you charge your car enough for a roundtrip or fully
    g. Do you have issues finding an available charging station (with the system)
    h. Overall accuracy of their scheduling
    i. Current satisfaction level of the product (1-5)
    j. Current trust in the system (1-5)
2. **Product Test**
    a. **Prompted tests**
        i. Can you identify the purpose of the main page
        ii. Please set a schedule for 5pm with the eco charge option
        iii. Are the graphs clear?
        iv. Navigation bar - is the purpose of each page and icon clear
        v. Can you easily see your CO2 emission
        vi. Can you see your charge history
        vii. Can you identify the purpose of the leaderboard
    b. **Product design**
        i. Clarity of the functionalities
        ii. General look of the product (1-5)
        iii. Ease of use (1-5)
        iv. Feedback of the system (1-5)
        v. Leaderboard - functionality/purpose
        vi. Notifications – charging status, weather
    c. **General comments / feedback**
        i. Current satisfaction level of the product (1-5)
        ii. Current trust in the system (1-5)

Appendix E: Code base

The code can be found in the following GitHub repository:

https://github.com/SaDaT895/design-project-group3-2023

The owner of the repository is Sadat Ahmad. Project supervisors have access to the repository through their GitHub accounts. The manual in form of a readme file is located in the root folder of the repository.