GENG5512 MPE Engineering Research Project Part 2

Final Report

Energy Consumption of Electric Vehicle Charging

Vicky Chow

23638279

School of Engineering, University of Western Australia

Supervisor: Professor Thomas Braunl

School of Engineering, University of Western Australia

Word count: 6528

School of Engineering

University of Western Australia

Submitted: 20 May 2024

Project Summary

The Renewable Energy Vehicle project (REV) is driven by the urgent need to address the environmental and health risks associated with vehicle emissions. REV envisions a future where conventional combustion engine vehicles are replaced by zero-emission, driverless vehicles powered by renewable energy sources. The ultimate goal is to build an extensive charging network fuelled entirely by clean and sustainable energy, thereby reducing the harmful health impacts of vehicle emissions.

In recognition of the importance of data and insights, a system is implemented to provide valuable information on electric vehicles (EVs) usage, station utilization, and emerging usage patterns. Furthermore, the project scope is extended to include the integration of solar photovoltaic (PV) and battery storage systems in rural areas, particularly for larger vehicles like buses.

To facilitate these endeavours, the project introduces the deployment of a Web-Based Monitoring System, devoted to overseeing and analysing the utilization of REV's charging infrastructure. Plotly is used for generating insightful visual reports, including bar and pie charts to display various usage statistics, providing a comprehensive view of charging patterns, user behaviours, and station utilization. Concurrently, a Battery Storage Planning Tool is developed to calculate and proffer optimal configurations for solar PV panels and battery storage systems, considering factors like daily vehicle mileage and the availability of grid power. Highcharts is used to visualize the energy demand and supply pattern by illustrating the trend over time. It dynamically responds to user inputs to explore different scenarios and see impact on energy plans.

Acknowledgements

I would like to express my sincere gratitude to everyone who contributed to the completion of this thesis. First and foremost, I am deeply thankful to my supervisor, Thomas Braunl, for his invaluable guidance, support, and insightful feedback throughout the duration of this project. His expertise and encouragement have been instrumental in shaping this research.

I would also like to acknowledge the Business School at UWA for facilitating and supporting the survey conducted as part of this research. Their collaboration was instrumental in gathering valuable insights and data for this study.

Furthermore, I extend my appreciation to the participants of the survey, whose contributions and responses formed a critical part of the research findings. Without their cooperation and willingness to participate, this study would not have been possible.

Table of Contents

List of Figures

1. Introduction, Background and Project Objectives

1.1 Introduction

In recent years, the global transportation industry faces a critical challenge: the environmental and health risks associated with vehicle emissions. The adverse effects of carbon emissions, air pollution, and the overarching issue of global warming have highlighted the urgent need to shift towards more sustainable, environmentally friendly, and cleaner transportation alternatives. Conventional combustion engine vehicles are substantial contributors to air pollution and greenhouse gas emissions. As a response to this pressing issue, REV has launched an initiative to 'Electrify Everything'. The goal is to envision a future where zero-emission, autonomous vehicles, powered by renewable energy sources, replace the current fleet of conventional vehicles (The REV Project, 2023).

The increasing adoption of electric vehicles (EVs) globally further underscores the necessity of such transformative efforts, with EVs poised to play a pivotal role in mitigating the detrimental impacts of vehicle emissions (IEA, 2023). This report presents a comprehensive account of our achievements and ongoing efforts in developing a Web-Based Monitoring System designed to provide valuable data-driven insights. Additionally, the report introduces an expanded project scope that incorporates the utilization of a Battery Storage Planning Tool. This tool explores the integration of solar photovoltaic (PV) and battery storage systems in rural areas with limited grid power, particularly to support larger vehicles such as buses. The aim is to propose optimized configurations of solar PV panels and battery storage systems that contribute to the development of environmentally sustainable technologies for future transportation needs.

1.2 Background

The growth of EVs as a clean and sustainable mode of transportation has captured widespread attention and gained considerable momentum in recent years. This surge in interest is not confined to a particular region but is a global phenomenon. In regions such as Europe, the United States, China, and Australia, EVs have emerged as a promising solution to address environmental concerns and reduce the carbon footprint associated with traditional internal combustion engine vehicles. One of the primary reasons for the rapid adoption of EVs in these regions is their remarkable environmental benefits. EVs are often touted for their "zero exhaust emissions" feature, which means they produce no tailpipe emissions while driving. This attribute is a game-changer in the context of climate change and air quality concerns. The reduction of greenhouse gases and harmful pollutants in urban environments is of paramount importance, as it directly impacts public health and the overall well-being of communities (Abas et al., 2019).

The urgency to address environmental and health risks associated with vehicle emissions is underscored by the critical challenge posed by CO_2 emissions and greenhouse gases. Conventional combustion engine vehicles are primary contributors to the accumulation of carbon emissions, which in turn, exacerbate the greenhouse effect (Ma et al., 2012). The adverse impacts of CO_2 emissions on global warming and climate change are widely acknowledged. The combustion of fossil fuels in traditional vehicles releases not only CO_2 but also other greenhouse gases such as methane and nitrous oxide, further intensifying the environmental toll. The need to reduce these emissions has become a global imperative, prompting initiatives like REV's commitment to 'Electrify Everything' in a bid to replace conventional vehicles with zero-emission, autonomous counterparts powered by renewable energy sources.

It is essential to recognize the pressing issue of traffic pollution. While significant public funds are rightly spent on raising awareness of road accidents and their associated toll, it's worth noting that traffic pollution poses an even greater threat to public health. According to the research from Doctors for the Environment Australia, it points out that the traffic pollution causes ten times more premature deaths than road accidents, leading to a staggering toll on public health. For instance, in 2021, road accidents claimed the lives of 1,123 people, while the adverse effects of traffic pollution on public health far exceeded this number (2023). This alarming statistic emphasizes the need for continued efforts to reduce traffic-related pollution and promote sustainable transportation alternatives like EVs to mitigate the considerable impact it has on public well-being.

REV currently operates a network of 10 AC chargers and 2 DC chargers in Perth metro area (The REV Project, 2023). While this network serves as a crucial step toward reducing emissions and promoting electric vehicle adoption, it's imperative to recognize the broader challenges at hand. Vehicular emissions remain a pervasive issue affecting not only metropolitan areas but also underserved rural regions. Newman et al. suggest that people in rural area drive considerably more than people in urban area (2014), which exacerbates emissions concerns. In many remote and underserved rural regions, access to clean and convenient charging infrastructure is limited or non-existent, which hinders the adoption of electric vehicles and perpetuates reliance on traditional, polluting vehicles.

To achieve the ultimate goal of widespread sustainable transportation electrification, REV envisions extending the project scope to rural areas, where the need for clean, accessible charging infrastructure is equally pressing. This expansion into rural territories is guided by the imperative to make sustainable transportation not only a reality in city but also in remote and less accessible locations. By doing so, REV takes a significant stride toward its mission of electrifying transportation while reducing the environmental and health impacts of vehicular emissions across diverse geographical landscapes.

1.3 Objectives

The primary objectives of this project are closely aligned with REV's overarching mission and strategic initiatives. Specifically, this project aims to advance REV's goals through the development and implementation of two key components: the Charging Data Monitoring System and the Battery Storage Planning Tool. These critical tools are designed to propel REV towards its vision of sustainable transportation by enhancing data-driven insights and optimizing the integration of renewable energy sources for electric vehicle infrastructure.

1.3.1 Charging Data Monitoring System

The objective within the Charging Data Monitoring System initiative is to develop a comprehensive software system for monitoring and analysing REV's charging station utilization. This system aims to generate insightful visual reports, such as bar and pie charts, to provide a holistic view of charging patterns, user behaviours, and station utilization. Through in-depth analysis of user behaviour patterns and preferences based on charging data, valuable insights into charging frequency, duration, and reasons for charging will be obtained, contributing to a deeper understanding of electric vehicle usage.

In addition to quantitative data analysis, qualitative methods including user feedback mechanisms and surveys will be integrated to capture insights into user satisfaction, preferences, and challenges related to charging infrastructure and services. These efforts will facilitate the identification of adoption barriers and exploration of strategies for promoting sustainable transportation behaviour. This comprehensive approach aims to advance knowledge within academic and scientific circles regarding electric vehicle charging and monitoring, supporting REV's mission to drive the transition towards sustainable transportation solutions.

1.3.2 Battery Storage Planning Tool

The second objective focuses on the development of a user-friendly Battery Storage Planning Tool, designed to facilitate sustainable and cost-effective energy solutions for rural transportation vehicles. It features an intuitive user interface, prioritizing ease of use. It will empower users to input data seamlessly, providing a straightforward and accessible experience. Users can observe the impact on energy plans by dynamically responding to their inputs, allowing them to explore various scenarios. This tool advances the state of the art in energy planning by offering a comprehensive solution that calculates the optimal configuration of solar PV panels and battery storage systems. It considers critical parameters, including daily driving distance, available grid power, vehicles efficiency. This in-depth analysis ensures that the generated solutions are tailored to the specific energy requirements of rural transportation vehicles.

2. Methodology

2.1 Data Collection and Preprocessing

This project leverages data sourced from REV charging stations, integrating both historical data from previous billing providers and new data sources. The data collection process is designed to prioritize precision, timeliness, and completeness, ensuring the integrity and richness of the datasets used for analysis and insights.

2.1.1 Previous Data Collection Process

In the previous process, the Smartcharge API serves as the primary conduit for collecting transaction data. This API provide raw data like start and end time of the transaction, the meter value, price cost, charging station ID, etc., which is utilized to acquire essential information related to charging activities, user interactions, and station utilization. This data is pivotal for generating usage statistics, monitoring trends, and deriving valuable insights into the operation of the charging network. To maintain data currency, the data collection process is executed twice a day. This frequency of updates ensures that the datasets remain aligned with real-time conditions, facilitating the generation of insights and reports based on the most current data available. The automation of data collection is realized through the deployment of the Cron job feature provided by BlueHost. This feature manages the scheduled execution of a data collection script. The script is responsible for transmitting API requests to the Smartcharge platform, retrieving the latest transaction data, and subsequently updating a JSON file that functions as the repository for all transaction records. This automation not only guarantees the regularity of updates but also minimizes manual intervention, promoting operational efficiency and data accuracy.

2.1.2 New Data Collection Process

With the transition to a new billing provider, data collection involves accessing the WeVolt API instead of the previous provider. The newly integrated data collection script incorporates endpoints from the WeVolt API seamlessly, ensuring data integrity and compatibility with the existing system schema. An integration layer is implemented, to manage data formatting and mapping to unify datasets from both Smartcharge and WeVolt, creating a comprehensive foundation for data analysis and visualization.

To automate this process, a cronjob is scheduled to execute twice daily at 12 AM and 12 PM, retrieving the latest data from the WeVolt API, same as the previous process. Upon retrieval, the raw data undergoes formatting and preprocessing steps, which include standardizing data formats, handling missing values, and filtering out noise and outliers to ensure data quality. Following preprocessing, the cleaned data undergoes validation checks to eliminate inconsistencies or errors. Once the data is processed and validated, it is stored in JSON format, then update the existing centralized data repository. This repository contains all relevant charging data, enabling efficient access and retrieval for subsequent analysis and reporting tasks within the REV charging infrastructure system. The workflow of the new data collection process is illustrated in Figure 2.1.

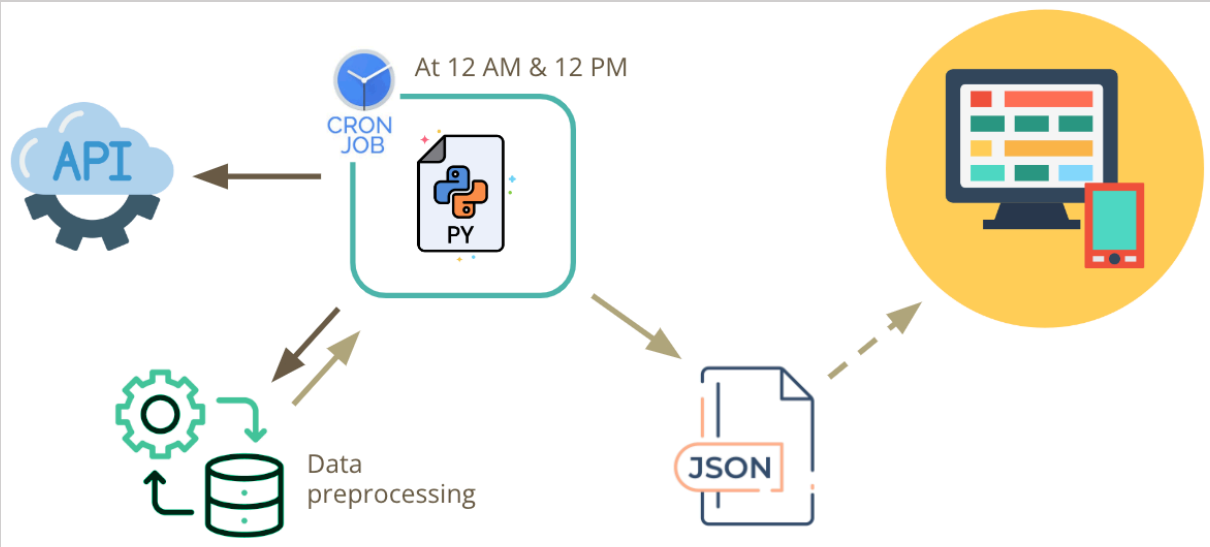


Figure 2.1: Workflow of New Data Collection Process.

2.1.3 Data Integration and Preprocessing

The WeVolt and Smartcharge APIs provide raw transaction data, but they utilized distinct formats and measurement units, as outlined in Figure 2.2. Notably, differences exist in the representation of key attributes such as timestamp formats, energy consumption metrics, and identifier conventions for charging stations. To harmonize this disparate data, the project conducted extensive reformatting and standardization of the legacy data from the Smartcharge API to align it with the structure of the WeVolt API. This process included mapping station identifiers (station IDs) from the old system to correspond with the new system's schema (refer to Appendix A), ensuring seamless integration and compatibility within a unified dataset. The reformatting efforts focused on standardizing critical fields such as start and end time of the transaction (startedAtUnix and endedAtUnix), energy consumption (totalEnergyKwh), charging durations (chargingTimeSeconds), and transaction identifiers (transaction IDs), essential for subsequent analysis and visualization tasks.

```
{
    "tokenId": "WEV***",
    "sessionType": "APP",
    "timestamp": "2024-02-28T03:59:19.987195Z",
    "transactionId": "4818",
    "locationName": "Cockburn Youth Centre",
    "stationId": "qEcmj53s",
    "connectorId": 1,
    "connectorCurrent": "AC",
    "connectorType": "C_TYPE_2",
    "totalEnergyKwh": 15.971,
    "startedAtUnix": 1709092760,
    "endedAtUnix": 1709100563,
    "chargingTimeSeconds": 7803,
    "chargingCostCents": 0,
    "disconnectedAtUnix": 1709100607,
    "parkingTimeSeconds": 44,
    "parkingCostCents": 0,
    "totalTimeSeconds": 7847,
    "totalCostCents": 0
},
```

```
{
    "transactionPk": 167737,
    "startTransactionTs": "2022-10-25T05:36:41.000Z",
    "endTransactionTs": "2022-10-25T05:39:00.000Z",
    "meterValueStart": 200,
    "meterValueStop": 200,
    "idTag": "EMP-610_M_8695",
    "state": "FINISHED",
    "chargeBoxId": "UWA_EG_AC_01",
    "connectorId": 2,
    "roamingType": "unknown",
    "calculatedPrice": 0,
    "connectorName": "AUSMCE00956",
    "priceComponents": {
      "pricePerKwh": 0,
      "pricePerMinute": 0,
      "priceFlatFee": 0,
      "pricePercentFee": 0,
      "vatIncluded": false,
      "currency": "AUD"
    }
  }
```


Figure 2.2: Example data from WeVolt (left) and Smartcharge (right)

The system relies on specific columns from the transaction data to generate insightful graphs and visualizations. These columns include stationId, connectorId, startedAtUnix, endedAtUnix, and totalEnergyKwh, which are essential for capturing key charging session details such as station identification, connector information, start and end times of charging sessions, and total energy consumption in kilowatt-hours (kWh). By focusing on these primary fields, the system streamlines data processing and reduces webpage rendering load during data analysis and visualization processes.

In the frontend implementation, the system utilizes a JSON file that retains only these five essential fields, ensuring optimal performance and efficient handling of charging data. This approach not only enhances the responsiveness of the user interface but also facilitates faster data visualization and analysis. By limiting the dataset to these key attributes, the system maintains a balance between data richness and computational efficiency, enabling users to interact with charging data seamlessly and derive actionable insights effectively.

During preprocessing, missing values, outliers, and noise were addressed, specific data quality criteria were applied to filter out incomplete or erroneous entries. Only data entries with complete information (i.e. no missing values), charging durations exceeding one minute (i.e. endedAtUnix - startedAtUnix > 60), and total energy usage exceeding 1 kWh (i.e. totalEnergyKwh > 1) were retained for further analysis and visualization.

2.2 Data Analysis and Visualisation

Different libraries are used to translate the collected data into meaningful insights and dynamic visualizations. With the collected data in hand, these libraries play a pivotal role in rendering complex datasets comprehensible and interactive, thereby facilitating comprehensive insights and informed decision-making. Plotly is used for the Charging Data Monitoring System for generating various charts. For Battery Storage Planning Tool, Highcharts is used to visualize the energy demand and supply pattern.

2.2.1 Using Plotly for Charging Data Monitoring System

Plotly serves as the primary charting library for the Charging Data Monitoring System, offering a versatile toolkit for generating a diverse range of dynamic charts. This capability enables the system to showcase up-to-date charging station data effectively. In addition to standard chart types, Plotly offers advanced scientific and statistical visualizations, including specialized plots such as box plots and violin plots, which are valuable tools for conducting detailed data analysis and supporting research applications.

One of Plotly's standout features is its interactivity, which significantly enhances user engagement and data exploration. Plotly's interactive capabilities empower users to interact with charging data dynamically. Hover effects enable users to access additional details by simply hovering over data points, facilitating quick insights into specific metrics. This feature allows for seamless data exploration and facilitates deeper analysis without the need for complex interactions. Additionally, Plotly's range sliders provide a versatile means to dynamically adjust data ranges, enabling users to focus on specific time intervals or segments of interest within the charging data. By interacting with range sliders, users can zoom into particular time periods or adjust data views to highlight specific patterns or trends. Moreover, Plotly enables users to interact with legends, allowing for the isolation or deselection of specific data series. This feature provides users with the flexibility to focus on individual charging stations, connector types, or other categorical variables within the dataset, facilitating tailored data exploration and analysis. The combination of hover effects, range sliders, and legend interactions within Plotly fosters an intuitive and efficient user experience, allowing users to extract meaningful insights from the charging data with ease.

By harnessing Plotly's powerful functionalities, the Charging Data Monitoring System enables users to explore, analyze, and derive actionable insights efficiently and interactively. Figure 2.3 illustrates Plotly's dynamic presentation of key charging data metrics, showcasing its pivotal role in enhancing data-driven decision-making and operational monitoring. The interactive visualizations crafted through Plotly not only inform users about charging station performance but also foster user engagement and facilitate effective information extraction. This interactive approach ensures that users can seamlessly interpret and act upon insights gained from the visual representations, leading to more informed operational strategies and optimizations.

Figure 2.3: Example of Charging Data Monitoring System graphs.

2.2.2 Using Highcharts for Battery Storage Planning Tool

In the Battery Storage Planning Tool, Highcharts plays a pivotal role in visualizing energy demand and supply patterns, providing essential insights into energy usage trends over time. The tool utilizes line charts to illustrate temporal variations in energy consumption, highlighting segments corresponding to charging and driving hours of the bus. This visualization approach offers users a comprehensive view of historical trends and supports forecasting future energy demands.

The interactive functionalities of Highcharts are instrumental in facilitating scenario analysis within the energy planning tool. Users can seamlessly explore different scenarios by adjusting parameters and observing real-time changes in energy plans through dynamic chart updates. This interactive capability empowers users to make informed decisions based on varying conditions and operational scenarios, as illustrated in Figure 2.4.

In addition to its interactive features, Highcharts offers a comprehensive suite of interactive features alongside extensive customization and styling options, enriching the adaptability of visualizations to meet specific project requirements and user preferences. With Highcharts, users have the flexibility to fine-tune chart colours, labels, axes, and annotations, allowing for enhanced clarity and usability in the visual representations of complex energy data within the Battery Storage Planning Tool.

This level of customization empowers the Battery Storage Planning Tool to deliver visually appealing and user-friendly representations of energy-related insights. By leveraging these advanced features, users can interact with data more intuitively, facilitating effective energy planning and decision-making processes. The ability to customize visual elements according to project needs enhances the tool's usability and effectiveness, ultimately supporting informed and optimized energy management strategies.

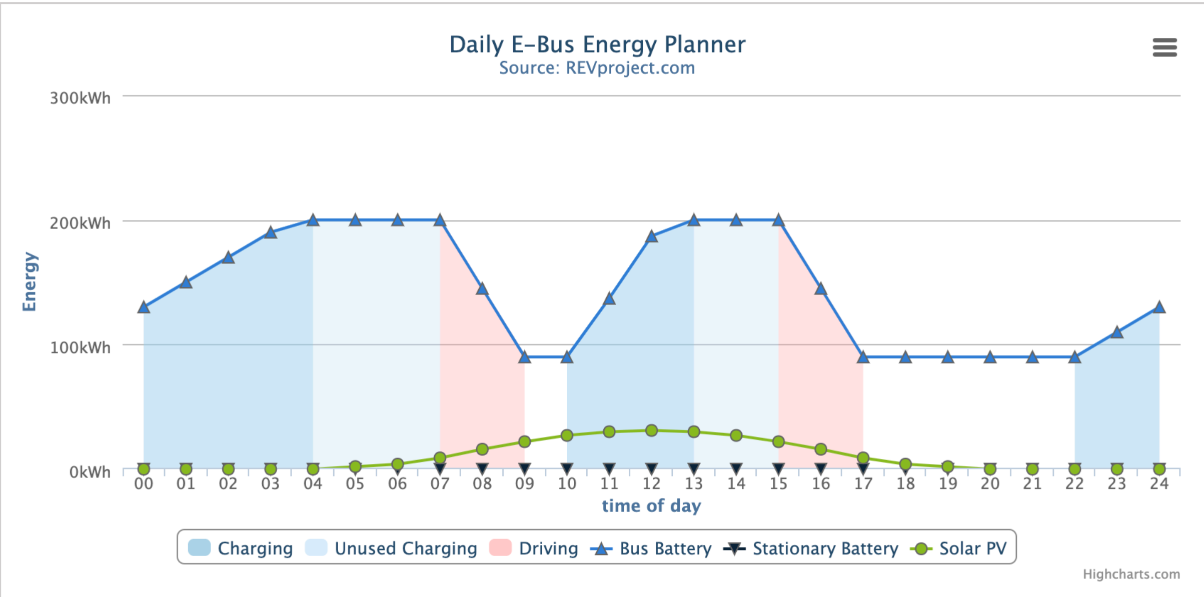


Figure 2.4: Energy consumption chart of Battery Storage Planning Tool.

2.2.3 Energy Series and Optimization

There are three primary data series underpin the battery planning graph: the bus battery, stationary battery, and solar PV (see Figure 2.4).

i. When stationary battery is unavailable

In scenarios where the stationary battery is unavailable, the bus battery energy is accumulated through the sum of grid power and solar PV. The Solar PV data series simulates solar energy by configuring the peak power of the PV system and create a sine curve. Equation (2.1) defines the battery of the bus at time t+1, where $B_b(t)$ is the bus battery, $G(t)$ is the grid power, and $S(t)$ is the solar power. The solar PV output $S(t)$ is calculated using Equation (2.2), which defines the sine curve based on the peak power P_{peak} of the PV system.

$$B_b(t+1) = B_b(t) + G(t) + S(t) \tag{2.1}$$

$$S(t) = P_{peak} \times \sin(\pi t/12 - \pi/2), \text{ where } 5 \leq t \leq 19 \tag{2.2}$$

ii. When stationary battery is available

In scenarios where a stationary battery is available, the grid charges the stationary battery instead of directly charging the bus battery. It is accumulated through the sum of grid power $G(t)$ and solar PV output $S(t)$. It subsequently discharges battery to buses before departure. Buses rely entirely on the energy stored in the stationary battery. Equation (2.2) remains consistent for calculating solar PV output. Equation (2.3) defines the stationary battery $B_s(t)$, which represents the accumulated energy of the stationary battery over time t. Equation (2.4) defines the bus battery $B_b(t)$ when a stationary battery is available, highlighting the dependency of the bus battery on the energy stored in the stationary battery.

$$B_S(t+1) = B_S(t) + G(t) + S(t) \tag{2.3}$$

$$B_b(t+1) = B_b(t) + B_S(t) \tag{2.4}$$

iii. Generating optimal solution

The optimization process aims to maximize solar power generation while minimizing the size of the bus battery, thereby enhancing energy efficiency and sustainability in transportation systems. The strategy involves a iterative approach where solar power utilization is prioritized initially. If the energy required for driving exceeds the available solar power, the bus battery size is incrementally increased to meet the demand. Subsequently, the optimization process recalculates the solar power utilization to leverage renewable energy sources more effectively. This iterative cycle continues until the energy required for driving matches the energy available for charging, achieving a balanced and optimized energy usage scenario.

By prioritizing solar power utilization and minimizing bus battery size, this strategy promotes the sustainable integration of renewable energy sources into transportation infrastructure.

2.3 User Interface Design

2.3.1 Charging Data Monitoring System

The Charging Data Monitoring System is a critical component of the software interface, designed to provide real-time insights into charging station usage, user behaviours, and station performance. The user interface for the system incorporates several key design considerations to ensure usability, functionality, and intuitive interaction.

The interface adopts a user-centric approach, emphasizing simplicity, interactivity, and flexibility. Users have the ability to select specific chargers and time spans (by date, month, or year) for graph visualization, as demonstrated in Figure 2.5. Date selection is facilitated through an intuitive calendar interface, enhancing user control and enabling customized exploration of data relevant to individual interests and requirements. To improve user experience, chargers are displayed with understandable names rather than solely relying on IDs. Navigation through data intervals is facilitated with "Previous" and "Next" buttons, allowing users to seamlessly explore historical charging data.

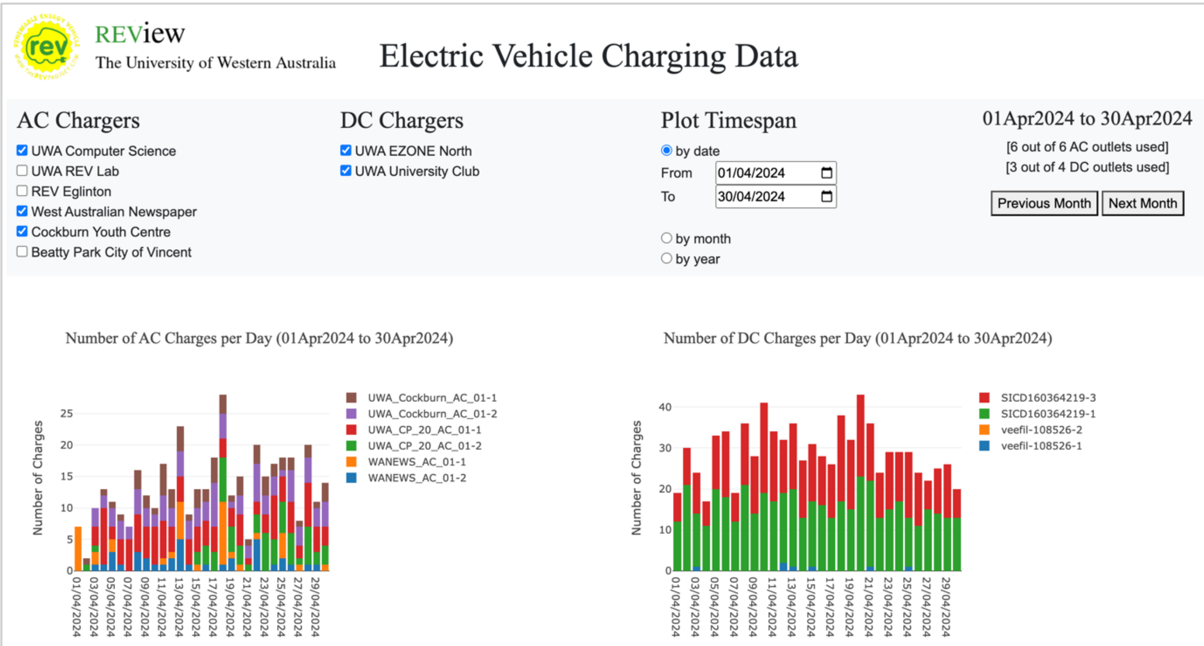


Figure 2.5: User interface of Charging Data Monitoring System

Users can leverage advanced features from Plotly, such as panning, hovering, legend selection, and legend isolation, to gain deeper insights into the data. These interactive capabilities empower users to interact with the visualizations and extract meaningful information.

The system features 12 dynamic graphs, each presenting unique insights into charging behaviours and station utilization. It integrates with the data collection pipeline, ensuring that real-time updates from REV charging stations are reflected instantaneously in the interface. This integration enables users to monitor live charging activities, track historical trends, and identify emerging patterns with ease.

2.3.2 Battery Storage Planning Tool

The Battery Storage Planning Tool is characterized by an intuitive user interface designed to streamline the input of data. Users can conveniently adjust various parameters through sliders on the left, as illustrated in Figure 2.6, enabling the exploration of diverse scenarios. Additionally, a button positioned in the top left corner of the interface (see Figure 2.6) to toggle the graph between daily and weekly view. Which allows users to have a broader insight on energy planning.

Users have the option to select different bus sizes using radio buttons, offering choices ranging from 'S' (small) to 'XL' (extra-large). Furthermore, a checkbox allows users to lock the Y-axis of the graph, ensuring consistency in visual data representation for enhanced analysis and decision-making.

Figure 2.6: User interface of Battery Storage Planning Tool.

Users have the flexibility to modify parameters such as daily driving distance, bus efficiency, grid power availability, peak solar PV capacity, sizes of bus and stationary battery, and the midday and night charging hours, making it easy to simulate and assess different scenarios. The red highlighted area represents the bus is driving, and the blue area indicates that the bus battery is being charged. Inside the blue area, a distinction is made between light blue and dark blue segments. Light blue represents the potential for charging, indicating times when the battery is available for replenishment but is not actively charging. The dark blue segments signify moments when the bus battery is actively being charged. This distinction aids users in understanding the dynamics of energy utilization and the efficiency of charging during specific time frames.

There are three key boxes situated under the graph provide users with vital insights into their energy planning scenarios: Daily Energy Used for Charging, Daily Energy Used for Driving, and Maximum Available Charging Energy (See Figure 2.6). For daily energy used for charging box, it displays the total energy utilized for charging the bus battery on a daily basis, helping users gauge the energy consumption and efficiency of charging. The daily energy used for driving showcases the energy expended during daily driving, enabling users to assess the energy requirements and efficiency of bus operations. The maximum available charging energy presents the maximum energy available for charging in terms of the charging hours initialized by users, which is a critical factor in optimizing the configuration of solar PV panels and battery storage systems. It can help users to do configuration on bus and stationary battery size, grid power and solar power.

On the bottom left corner, there is a button for users to generate optimal solution (see Figure 2.6). It will suggest optimal bus and stationary battery sizes based on user-defined parameters. An animated notification box will appear when the optimal solution is calculating, to let users know the system is running (see Figure 2.7).

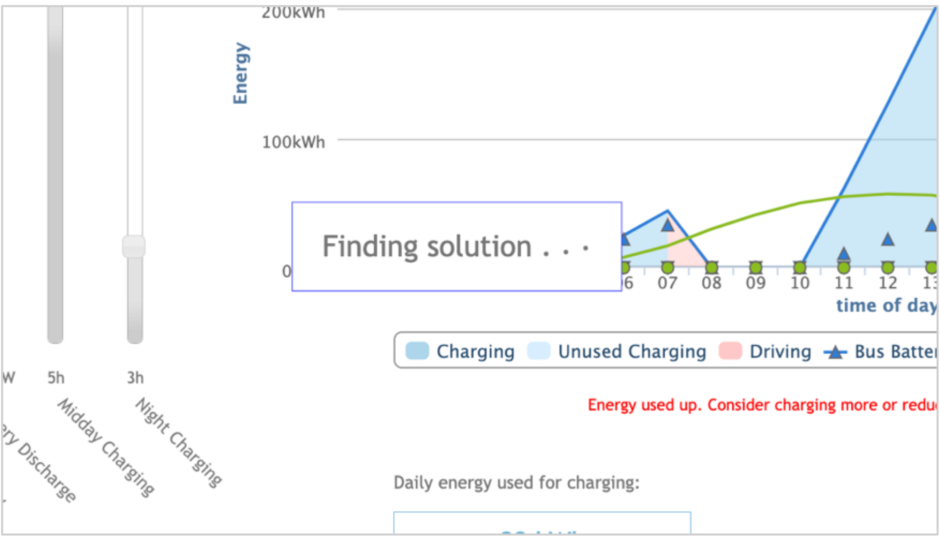


Figure 2.7: Notification box when generating solution

In addition to the daily view, the tool offers a comprehensive weekly view of the chart (see Figure 2.8). This feature enables users to zoom out and analyse energy planning and consumption patterns over a broader time frame. Users can observe trends and make more informed decisions for long-term energy management. The weekly view provides a strategic perspective for optimizing energy solutions.

Figure 2.8: Weekly view of Battery Storage Planning Tool.

2.4 Survey on User Behaviour

To gain deeper insights into user behaviour and preferences, a collaborative survey was conducted in partnership with the Business School of UWA. The survey focused on several key aspects, including the number of electric vehicles owned, charging frequency, charging duration, home charging capabilities, and priorities when choosing a public charging station. This comprehensive approach aimed to gather valuable data on user behaviour and preferences related to electric vehicle charging, contributing to a more nuanced understanding of user needs and considerations in the context of charging infrastructure.

3. Results and Discussion

3.1 Charging Data Monitoring System

In the analysis of charging station data, particular attention was given to DC stations, considering the associated tariff adjustments that took effect from February 2024. According to The REV Project, the updated tariff structure introduced specific changes to private use rates during designated time periods and implemented penalties for overstaying charging durations:

- Time-of-Use Rates:
  - 9:00 - 15:00 hours: 15 cents per kWh.
  - 15:00 - 9:00 hours: 28 cents per kWh.
- Overstaying Penalty:
  - A penalty of 25 cents per minute was enforced for exceeding the maximum charging time of 30 minutes.

Other detailed tariff information can be referred to Appendix B. This investigation focused on understanding how these tariff changes influenced charging behaviour and station utilization patterns.

3.1.1 Number of charges per month

By observing the number of charges per month in the past 8 months, there is a significant increase since February 2024. There was an average of 700 charges per month before tariff adjustment, while there is over 800 charges per month after applying price change, as shown in Figure 3.1. This suggests that the revised pricing scheme may have incentivized greater usage of DC charging stations.

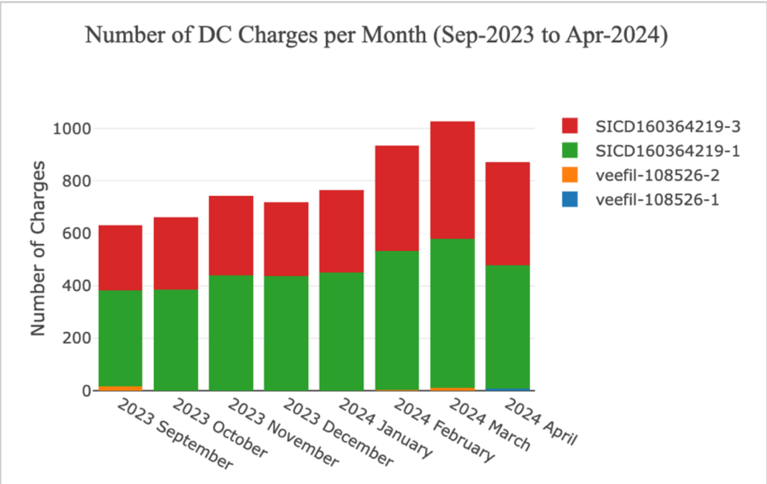


Figure 3.1: Number of DC Charges per Month from Sep 2023 to Apr 2024

3.1.2 Peak charging times comparison

Comparing the peak charging times before (September 2023 - January 2024) and after (February - March 2024) the tariff changes, a distinct shift in usage patterns is evident. As illustrated in Figure 3.2(a), prior price change, the peak charging times were typically observed during the late afternoon hours (16:00-18:00). However, post-tariff changes, peak charging times shifted to earlier periods, particularly between 09:00-10:00 and 12:00-14: 00 (Figure 3.2(b)). This suggests that more users shifted to charge during non peak hours due to lower cost during that period.

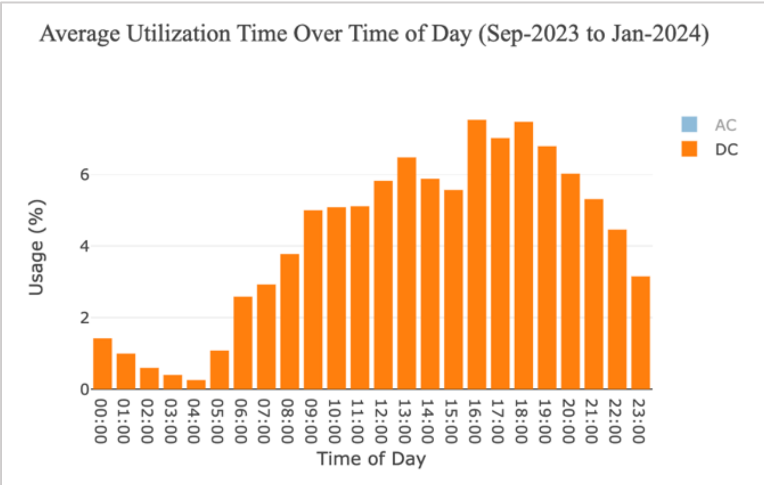


Figure 3.2(a): Average Utilizaion Time Over Time of Day (Sep 2023 to Jan 2024)

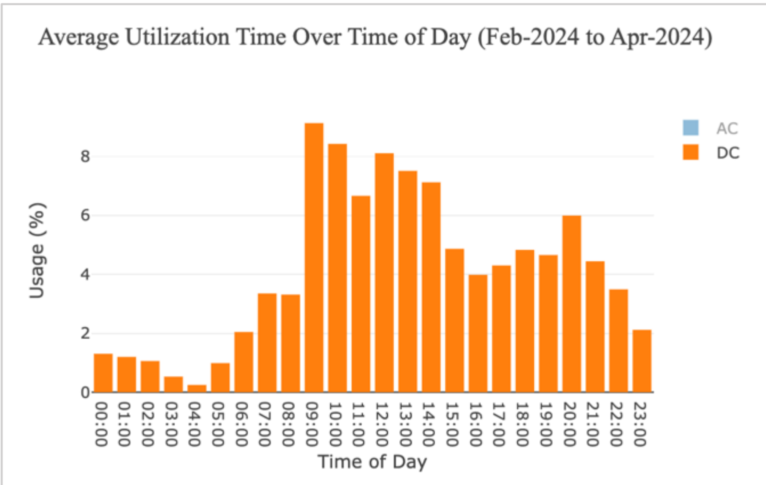


Figure 3.2(b): Average Utilizaion Time Over Time of Day (Feb 2024 to Apr 2024)

3.1.3 Charging duration

The analysis of charging duration reveals a notable decrease in average session length subsequent to the enforcement of penalties for overstaying the maximum charging time of 30 minutes. This observation is depicted graphically in Figure 3.3. The findings suggest that users have become more conscious of their charging durations, likely in response to the imposed penalty of 25 cents per minute for exceeding the allotted time. This behavioural shift indicates that penalties have effectively incentivized users to optimize their charging sessions within the designated time limits.

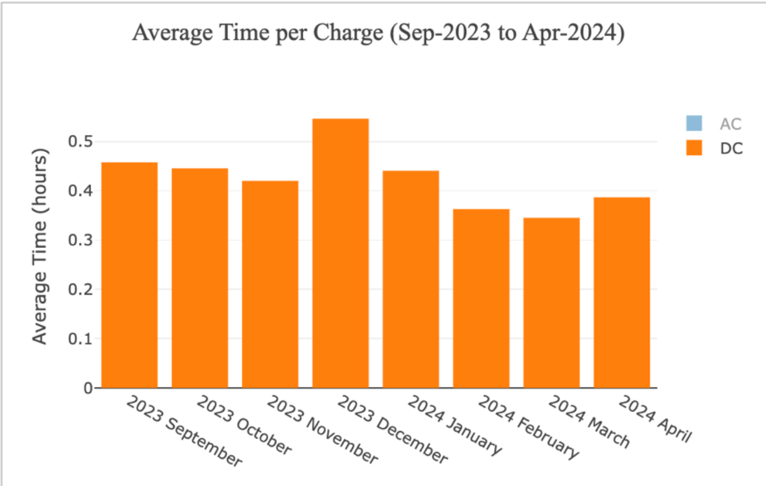


Figure 3.3: Average Time per Charge from Sep 2023 to Apr 2024

Further examination of charging durations over specific time periods reveals compelling trends. From September to November 2023, as depicted in Figure 3.4(a), the median charging time was approximately 0.59 hours, with the third quartile at 0.585 hours. Conversely, in February to April 2024 (Figure 3.4(b)), the median charging time decreased to 0.47 hours, and the third quartile reduced to 0.50 hours. These observations highlight a tangible reduction in charging duration following the implementation of penalties, underscoring the efficacy of this approach in promoting more efficient and time-conscious charging behaviour among users.

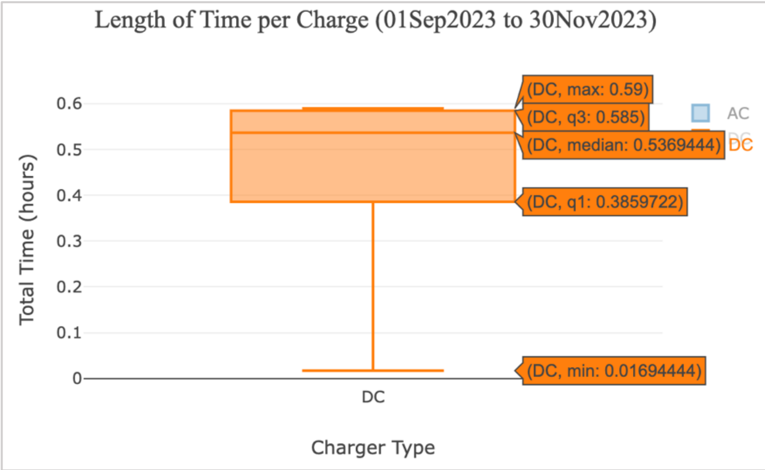


Figure 3.4(a): Length of Time per Charge (Sep 2023 to Nov 2023)

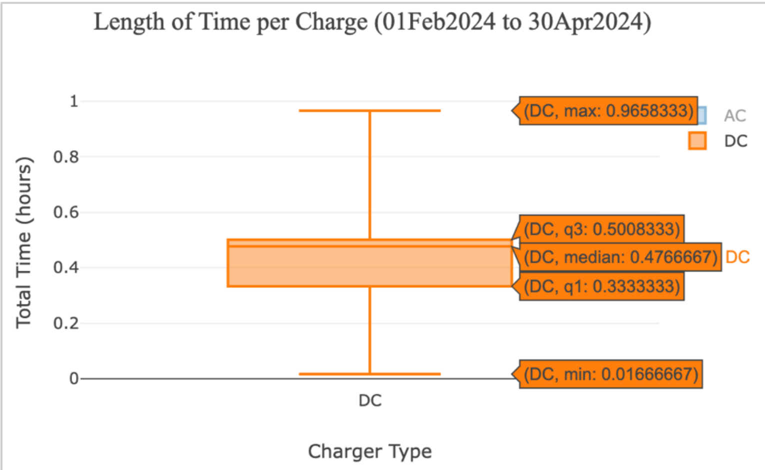


Figure 3.4(b): Length of Time per Charge (Feb 2024 to Apr 2024)

3.2 Battery Storage Planning Tool

The Battery Planning Tool implemented in the system yielded notable outcomes, enabling users to observe changes instantly across various scenarios, enhancing user experience, and facilitating informed decision-making.

3.2.1 Immediate scenario observation

This tool allowed users to promptly visualize and assess various scenarios by adjusting parameters such as solar PV capacity, battery size, and grid power availability using intuitive sliders. Users could monitor key energy metrics, including daily Energy used for charging, daily energy used for driving, and maximum available charging energy, in real-time (refer to Figure 2.6 and 2.7). This interactive capability allowed users to instantly observe the impact on energy demand and supply patterns, providing valuable insights for energy planning and optimization within daily or weekly perspectives.

3.2.2 Energy depletion reminder

A user-friendly reminder was integrated into the Battery Planning Tool to notify users when energy resources were depleted. The red text will show under the graph if energy used up during the day, which remind users to increase the charging time or reducing daily distance, as shown in Figure 3.5. This proactive feature aimed to prevent interruptions in energy supply and optimize energy utilization, ensuring efficient operation of electric vehicle charging systems.

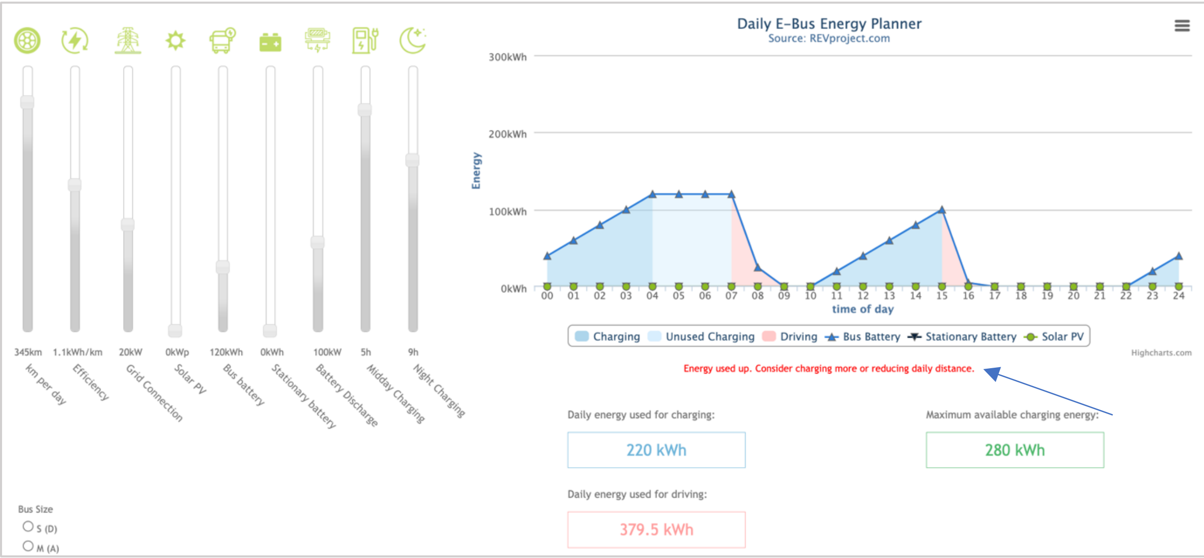


Figure 3.5: Energy depletion reminder

3.2.3 Generation of optimal solution

The Battery Planning Tool demonstrated the capability to generate optimal solutions based on predefined constraints. By leveraging algorithmic calculations, the tool recommended configurations for solar PV system and battery storage, aimed at maximizing energy efficiency and minimizing costs. This functionality empowered users to make informed decisions regarding system design and implementation.

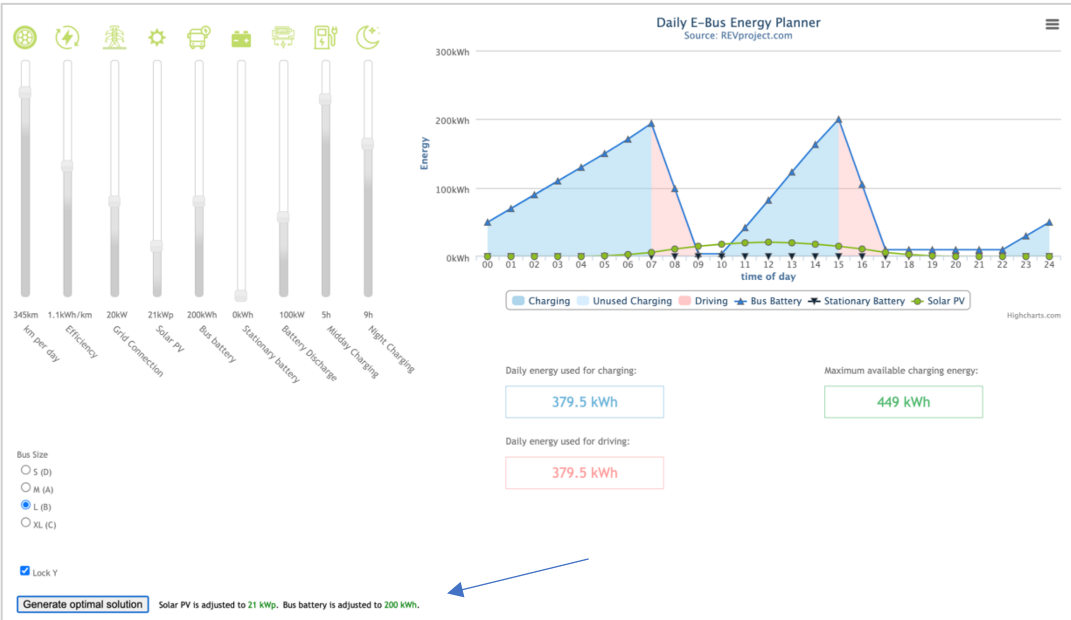


Figure 3.6: Generation of optimal solution

For example, users could utilize the tool by clicking the "Generate optimal solution" button to access suggested configurations for solar PV power and bus battery settings. Upon clicking the button, the tool automatically applies the recommended changes, allowing users to observe the updates in real-time. Additionally, the updated configuration is displayed numerically next to the button, as illustrated in Figure 3.6, providing users with detailed information on the changes made. This interactive feature significantly streamlined the process of exploring and implementing optimized energy solutions within the electric vehicle charging infrastructure, enhancing user experience and efficiency.

3.3 Survey Results on User Behaviour

A survey titled *Electric Vehicle Charging Behaviour* has been conducted between the UWA Engineering and Business School in May 2024, it provided valuable insights into user behaviour and preferences related to electric vehicle charging in terms of the use of home charging and public charging stations (2024). A total of 97 responses were collected, providing a comprehensive dataset for analysing user needs and considerations within the charging infrastructure context. This survey focused on key aspects such as the number of electric vehicles owned, charging frequency, duration, home charging capabilities, and priorities when selecting a public charging station. The findings from this survey contribute significantly to the understanding of user behaviour and preferences.

3.3.1 Number of Electric Vehicles owned

The survey data revealed that most respondents owned a single electric vehicle, with 22 individuals reporting ownership of two or more EVs, see Figure 3.7. This trend highlights the increasing adoption of electric vehicles within households, emphasizing the need for scalable and accessible charging infrastructure to support multiple EVs per household.

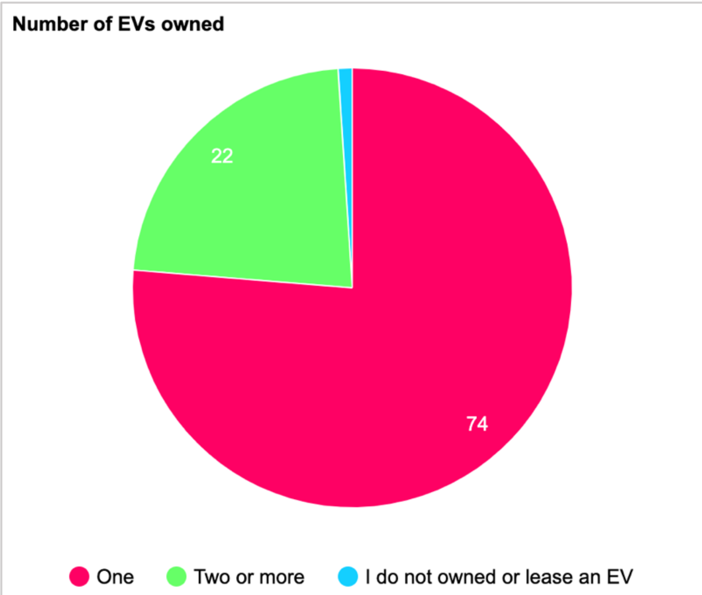


Figure 3.7: Number of EVs owned

3.3.2 Home charging capabilities

Among the respondents, 72 indicated having solar panels at home, see Figure 3.8. This suggests that while public charging infrastructure is crucial, home charging solutions play a vital role in the overall charging ecosystem. Users with home charging capabilities tended to use public charging stations less frequently, primarily relying on them for longer trips or when home charging was not feasible.

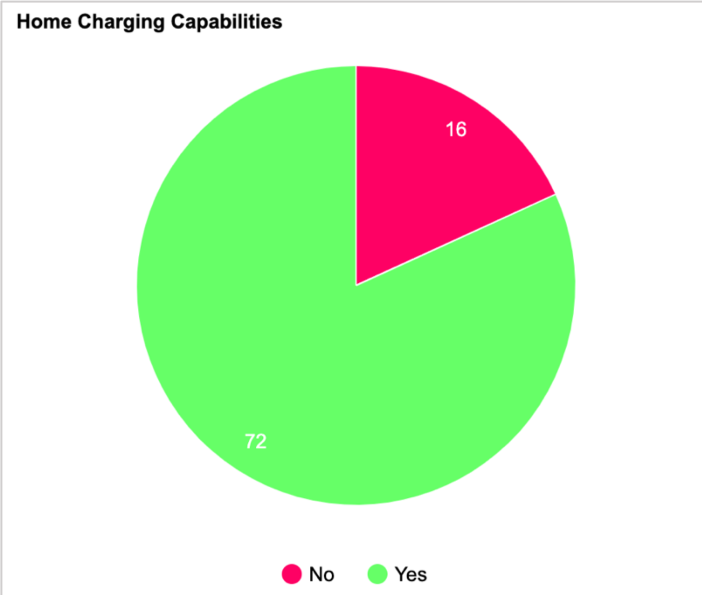


Figure 3.8: Home Charging Capabilities

3.3.3 Charging frequency

The survey showed that the majority of users prefer charging their vehicles at home, with 37 individuals charging daily, 26 charging more than three times a week, and 19 charging once or twice a week, see Figure 3.9. In contrast, most users seldom used public charging stations, with 53 respondents charging less than once a fortnight, see Figure 3.10. The primary reasons for avoiding public stations were a preference for home or workplace charging, with public stations reserved for long trips.

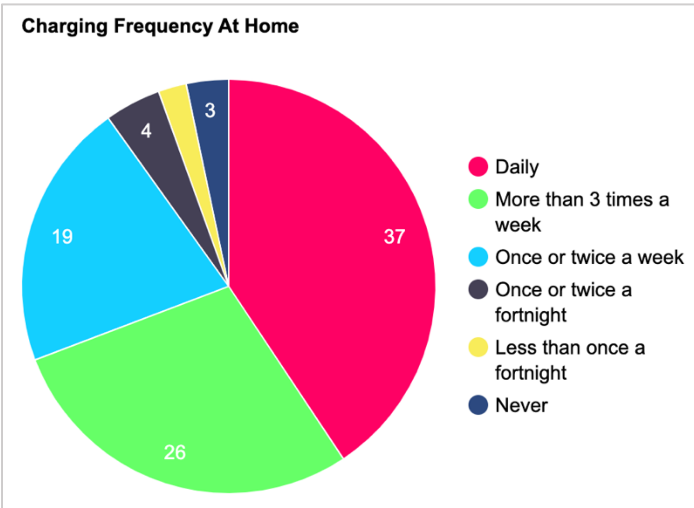


Figure 3.9: Frequency of Charging at Home

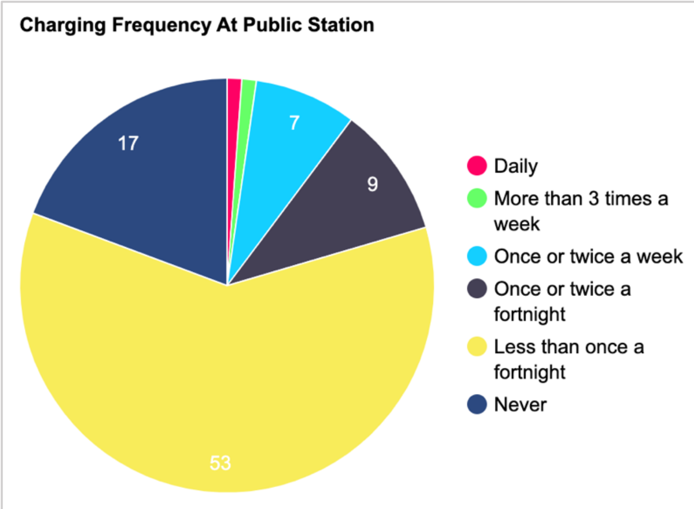


Figure 3.10: Frequency of using Public Charging Stations

3.3.4 Charging time at public station

Figure 3.11 shows that the peak charging hours for public stations were between 10 a.m. and 2 p.m., this pattern closely aligns with the results observed from the Charging Data Monitoring System, suggesting that the lower tariffs applied during non-peak hours significantly influence users' choice of charging times. The alignment of these peak hours indicates that users are strategically opting to charge their vehicles during periods when the cost is reduced, thereby optimizing their charging expenses. This behavior underscores the impact of tariff structures on user charging habits and highlights the importance of pricing strategies in managing public charging station utilization.

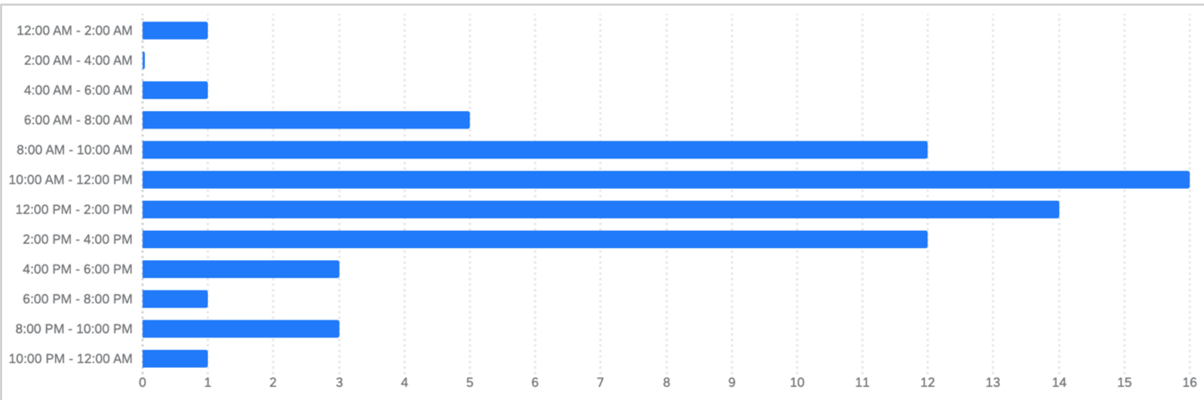


Figure 3.11: Charging time at Public Stations

3.3.5 Charging duration

At home, most users left their vehicles charging for 2 to 4 hours (see Figure 3.12), taking advantage of longer charging sessions without the pressure of time constraints. This extended charging duration at home allows users to fully recharge their vehicles, ensuring they have enough energy for their daily commutes or longer trips.

In contrast, when using public charging stations, users typically limited their charging sessions to less than 30 minutes (see Figure 3.13). This behaviour is likely driven by concerns over overstaying penalties. The shorter charging duration at public stations reflects a strategic approach by users to avoid these penalties, indicating a high level of awareness and adaptation to the tariff structures and penalties in place. This behaviour highlights the importance of public charging infrastructure that supports quick and efficient charging to accommodate the needs of users who require a rapid energy top-up during their busy schedules. The preference for shorter charging sessions at public stations underscores the need for continued development and implementation of fast-charging technologies to better serve the EV community.

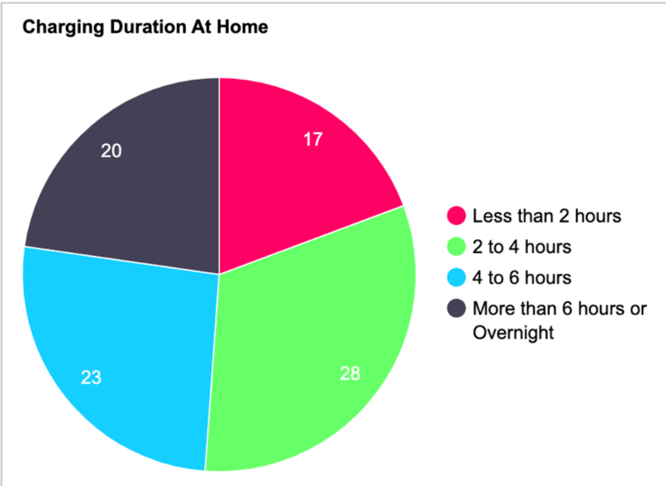


Figure 3.12: Charging Duration at Home

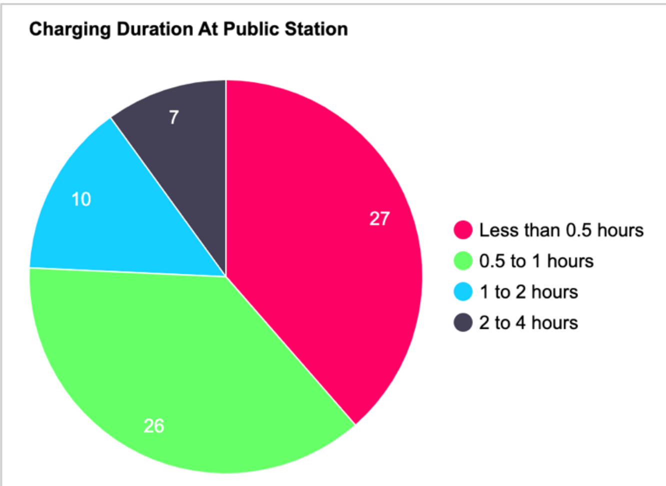


Figure 3.13: Charging Duration at Public Stations

3.3.5 Consideration Priorities for Public Charging

As illustrated in Figure 3.14, price emerged as the most critical factor, with a majority of respondents placing it as their top priority. This finding underscores the significant impact of pricing on user decision-making when selecting public charging stations. Followed by distance traveled, time of day, and flexibility. Understanding these priorities is helps optimizing public charging infrastructure to better align with user needs and preferences.

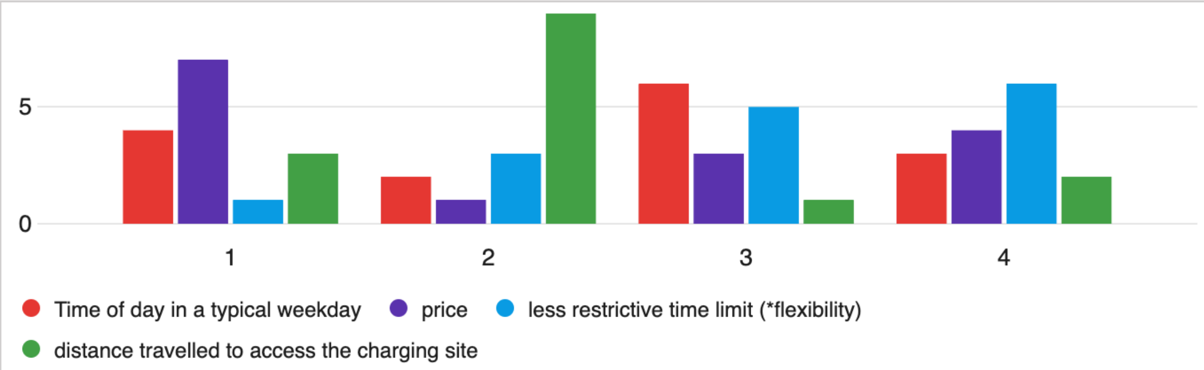


Figure 3.14: Considerations priority for charging at public stations

To gain deeper insights into how users select charging stations, participants were presented with scenarios where they had to choose between two charging stations based on specific criteria, including time of use, price, time limit, and detour distance (refer to Appendix C for detailed scenario descriptions). For peak pricing scenarios, Station 1 represented scenarios with standard pricing, and charge during work hours, while Station 2 represented scenarios with peak rates applied, and charge after 5 p.m. A majority of users indicated a preference for charging during non-peak hours (Station 1) to avoid higher tariffs, as illustrated in Figure 3.15. This reflects a desire to optimize cost-effectiveness by selecting the most economically advantageous charging times.

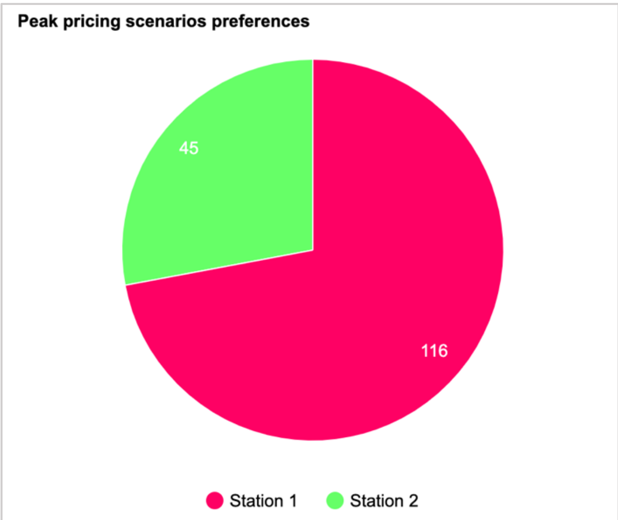


Figure 3.15: Peak pricing scenarios preferences

For off-peak discount preferences, Station 1 represented scenarios with discounted pricing, and charge during work hours, while Station 2 represented scenarios with full tariff, and charge after 5 p.m. Respondents leaned towards utilizing charging stations during these discounted periods, see Figure 3.16. The availability of fast charging facilities, coupled with convenient detour distances, played a significant role in shaping their preferences.

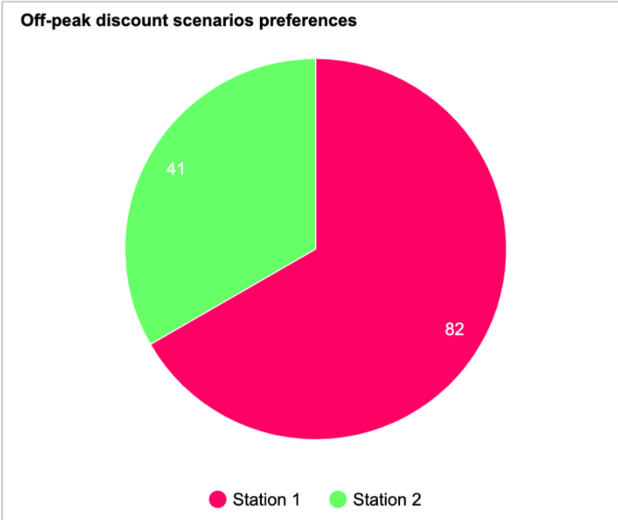


Figure 3.16: Off-peak discount scenarios preferences

4. Conclusions and Future Work

The primary objectives of this project are closely aligned with REV's overarching mission and strategic initiatives. Specifically, this project aimed to advance REV's goals through the development and implementation of two key components: the Charging Data Monitoring System and the Battery Storage Planning Tool. These critical tools were designed to propel REV towards its vision of sustainable transportation by enhancing data-driven insights and optimizing the integration of renewable energy sources for electric vehicle infrastructure.

4.1 Conclusion

The Charging Data Monitoring System has proven instrumental in providing real-time insights into charging station usage, user behaviours, and station performance. Through intuitive visualizations and interactive features, users can analyse charging data effectively, enabling informed decision-making and operational optimization.

The observed changes in charging behavior following the tariff adjustments underscore the effectiveness of pricing strategies in influencing user choices and station utilization patterns. The shift towards earlier peak charging times and reduced charging durations indicates a responsive adaptation to the revised tariff structure. These findings provide valuable insights for optimizing charging station operations and pricing strategies to promote efficient and sustainable usage of DC charging facilities.

The Battery Planning Tool has demonstrated its capability to generate optimal configurations for solar PV systems and battery storage, balancing energy efficiency and cost-effectiveness. By leveraging algorithmic calculations, users can design and implement tailored sustainable energy solutions to meet specific charging infrastructure needs.

The tool features a user-friendly interface that allows users to view trends based on their inputs and preferences, suggesting optimal solutions for maximizing solar power utilization and optimizing bus battery size. This promotes sustainable energy practices within EV charging infrastructure. Through iterative development, the tool has evolved to meet user requirements, showcasing its adaptability and responsiveness to evolving needs in energy management and sustainability within electric vehicle charging infrastructure. This evolution underscores the tool's value in enhancing sustainability and optimizing energy utilization.

4.3 Future planning

The project has successfully addressed initial challenges related to integrating charging data from diverse billing providers, focusing on reformatting, standardization, and preprocessing to align datasets and ensure data quality. Moving forward, the project will continue to refine and enhance these efforts to optimize the usability and reliability of the charging data.

To further improve data quality, the project will explore advanced techniques for data cleaning and preprocessing. This includes ongoing refinement of outlier detection and removal methods to mitigate the impact of erroneous or anomalous readings. Additionally, the project will prioritize noise reduction techniques to enhance data clarity and precision, ensuring that the retained dataset is robust for comprehensive analysis and visualization.

In parallel, the project will deepen its analysis of user behavior patterns and preferences derived from charging data. This analysis will involve a detailed examination of charging frequency, duration, reasons for charging, and evaluation of home charging capabilities. To complement quantitative insights, the project will integrate user feedback mechanisms and surveys to capture qualitative insights into user satisfaction, preferences, and challenges related to charging infrastructure and services.

Moreover, the project will investigate factors influencing user acceptance of electric vehicles, identify adoption barriers, and explore strategies to promote sustainable transportation behavior. By synthesizing quantitative data analysis with qualitative user feedback, the project aims to optimize the usability, effectiveness, and sustainability of electric vehicle charging infrastructure.

Through these ongoing efforts, the project seeks to build upon its achievements and contribute to the advancement of data-driven insights and optimized energy solutions within the realm of electric vehicle charging infrastructure.

References

Abas, A. P., Yong, J. E. D., Mahlia, T. M. I., & Hannan, M. A. (2019). Techno-economic analysis and environmental impact of electric vehicle. *IEEE Access*, *7*, 98565-98578.

Doctors for the Environment Australia. (2023, February 23). *Major new report: Vehicle emissions may cause over 11,000 deaths a year - DEA*. https://dea.org.au/major-new-report-vehicle-emissions-may-cause-over-11000-deaths-a-year/#:~:text=While%20significant%20public%20funds%20are

IEA (2023), *Global EV Outlook 2023*, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2023, Licence: CC BY 4.0

Ma, H., Balthasar, F., Tait, N., Riera-Palou, X., & Harrison, A. (2012). A new comparison between the life cycle greenhouse gas emissions of battery electric vehicles and internal combustion vehicles. *Energy policy*, *44*, 160-173.

Newman, D., Wells, P., Donovan, C., Nieuwenhuis, P., & Davies, H. (2014). Urban, sub-urban or rural: where is the best place for electric vehicles?. *International Journal of Automotive Technology and Management*, *14*(3-4), 306-323.

The REV Project. (2023). Retrieved from https://therevproject.com/

Electric Vehicle Charging Behavior Survey. (2024). Unpublished survey conducted at the University of Western Australia, May 2024.

Appendix A: Charging Station ID mapping

New System Info	Old System chargeBoxId	
1. Charger ID: dfhaDErN - Location: UWA Uni Club	veefil-108526	UWA University Club
https://www.plugshare.com/location/57171		
2. Charger ID: TFEnGqBz - Location: UWA-CS	UWA_CP_20_AC_01	UWA Computer Science
https://www.plugshare.com/location/428450		
3. Charger ID: jIRzVzV2 - Location: UWA REV LAB	UWA_Rev_Lab_AC_01	UWA REV Lab
https://www.plugshare.com/location/122507		
4. Charger ID: V3m9zKGO - Location: UWA EZONE North	SICD160364219	UWA EZONE North
https://www.plugshare.com/location/545316		
5. Charger ID: DYwZU2q6 - Location: Stockland Amberton Beach Sales Office in our system	UWA_EG_AC_01	REV Eglinton
Eglinton Shuttle bus charger (dual AC)		
https://www.plugshare.com/location/501011		
6. Charger ID: lxefhlNt - Location: Seven West Media in our system	WANEWS_AC_01	West Australian Newspaper
Seven West Media / West Australian Newspaper, Osborne Park (dual AC)		
https://www.plugshare.com/location/466869		
7. Charger ID: qEcmj53s - Location: Cockburn Youth Centre in our system	UWA_Cockburn_AC_01	Cockburn Youth Centre
Cockburn, Youth Centre (dual AC)		
https://www.plugshare.com/location/71686		
8. Charger ID: TasgJdat - Location: Beatty Park Leisure Centre in our system	100281214	Beatty Park City of Vincent
Beatty Park, City of Vincent (dual AC)		
https://www.plugshare.com/location/521335		

Appendix B: REV charging stations tariff information

The REV Project - EV Charger Usage

For using all REV charging stations:

- Create an account with billing provider Wevolt
- For activating a charger with a smart card or token, add your existing card's ID number (e.g. UWA staff/student ID or SmartRider) via the app.
- You can read out your card's ID number with a smartphone using NFC Tools.

Fee Structure UWA DC Stations as of Feb. 2024

- Private use (time-of-use):
  15 cents per kWh from 9:00 – 15:00 hours
  28 cents per kWh from 15:00 – 9:00 hours
- Commercial use or when charging over 300kWh per month (flat fee):
  45 cents per kWh
- no transaction fee charged to the customer
- min. payment amount of $1 to cover our fees
- max charging time 30 min.
- overstaying penalty 25 cents per minute

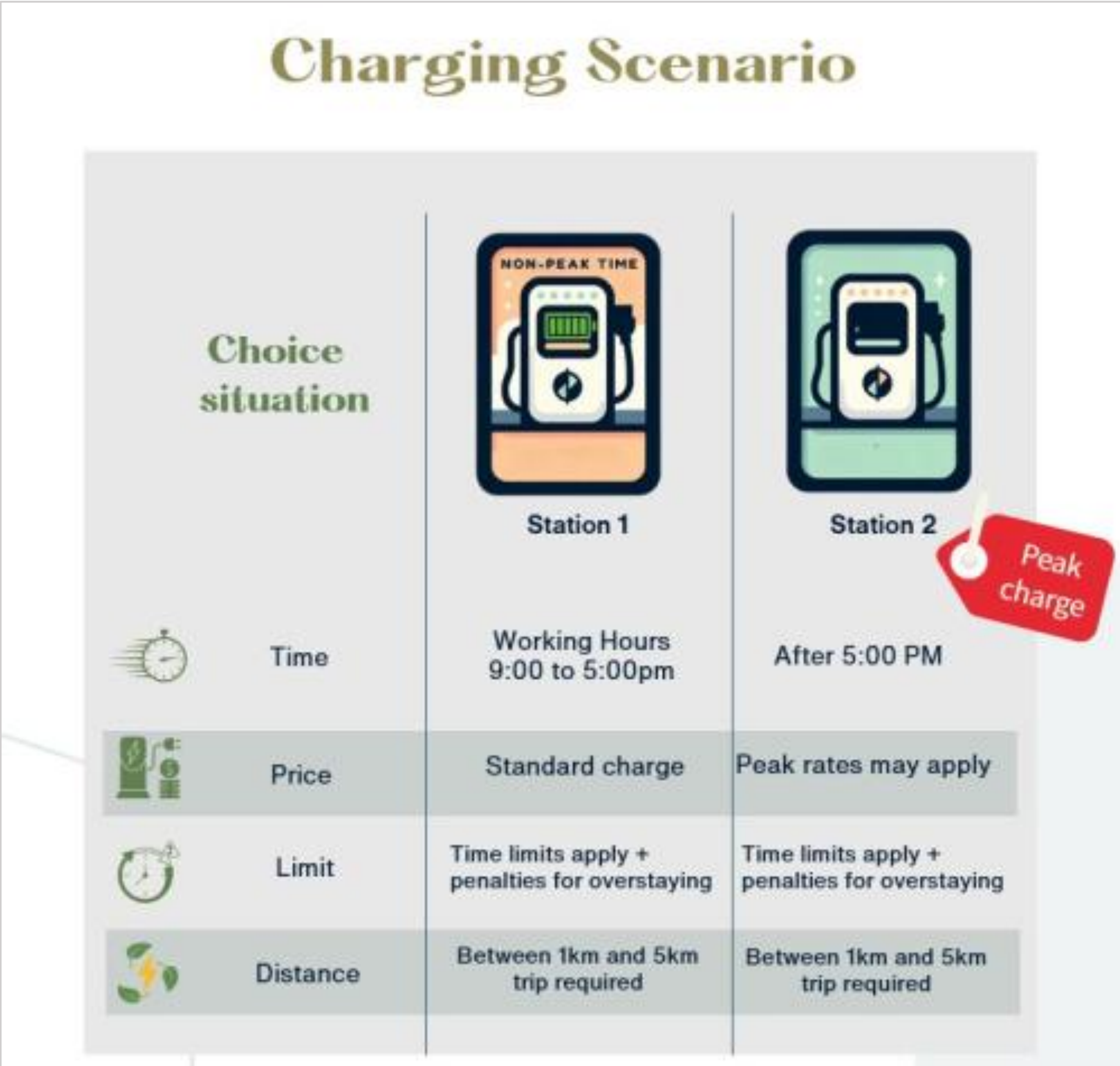
Fee Structure UWA AC Stations

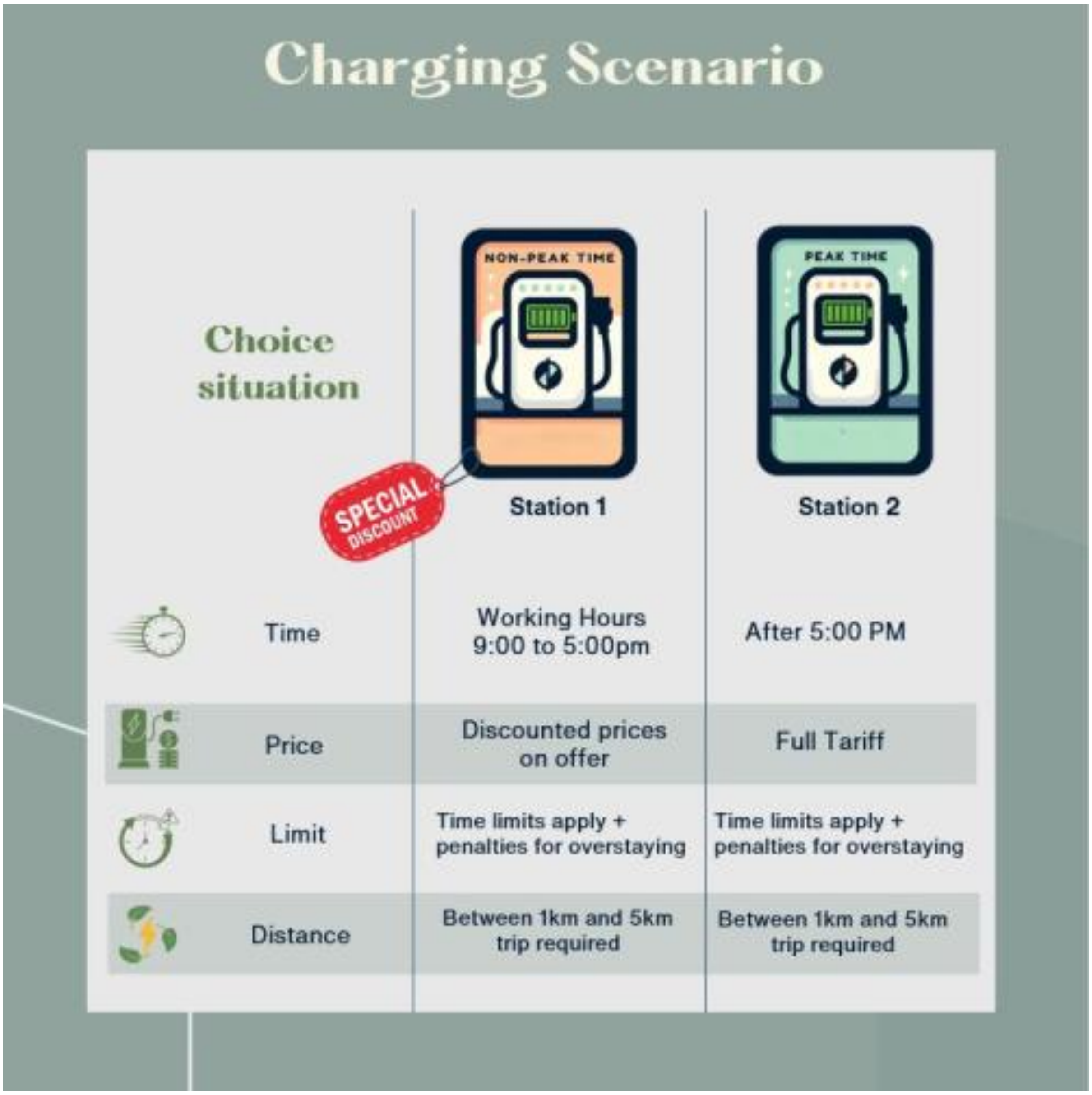
- free use
- max charging time 4 hours
- overstaying penalty 25 cents per minute (min. payment $1)

Contact
UWA REV Project
School of Engineering
35 Stirling Highway
Crawley WA 6009

Email: rev@theREVproject.com

Appendix C: Peak pricing and Off-peak discount scenarios description





Charging Scenario

Choice situation	Station 1	Station 2
Time	Working Hours 9:00 to 5:00pm	After 5:00 PM
Price	Discounted prices on offer	Full Tariff
Limit	Time limits apply + penalties for overstaying	Time limits apply + penalties for overstaying
Distance	Between 1km and 5km trip required	Between 1km and 5km trip required