KURYENTA: SOLAR-POWERED RENTAL STATION WITH DETACHABLE POWER SOURCES

An Undergraduate Thesis

Presented to the
Faculty of Bachelor of Science in Computer Engineering
University of Science and Technology of Southern Philippines
Cagayan de Oro City

In Partial Fulfillment
of the Requirements for the Degree of
BACHELOR OF SCIENCE IN COMPUTER ENGINEERING

CZAREIGN MAE Q. BALUCOS
MARY ANN Y. CALALIN
ALJHON G. MANGMANG
HUGO JAMES P. OKIT
SHEENA MAE L. SIMON
November 2025

TABLE OF CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

List of Equations

No. Equation **Page No.**

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Electricity is essential to everyday living, powering household activities from lights and appliances to connectivity. It is the most used energy source and a notable expense among Filipino households, with a 94.8% usage rate (Philippine Statistics Authority, 2023). Frequent power interruptions disrupt comfort, work, and livelihoods, forcing households to rely on diesel generators as temporary backup. However, these generators are costly and contribute to noise and air pollution, highlighting the need for alternative, sustainable power sources.

Research has proven that solar-powered systems offer a reliable and eco-friendly power source. Catalan et al. (2023) developed a solar-powered coin-operated mobile charging station designed that provides off-grid charging for mobile devices through photovoltaic panels and integrated battery storage. Their study emphasized the system's effectiveness in extending energy access to remote and island communities, particularly in locations where electricity is limited. Moreover, Catalan et al. (2023) also emphasized the importance of incorporating additional security features to ensure the consistent and reliable operation of such systems over time. Similarly, photovoltaic (PV) solar energy is becoming a key player in the global energy transition, providing renewable and scalable energy solutions (Sampaio & González, 2017; Ramly, Jamal, Abd Ghafar, & Babu, 2019).

Technology also plays a vital role in improving such systems. According to Villamil et al. (2020), the Internet of Things (IoT) is an emerging technology present in many devices and processes, improving quality of life. Integrating IoT with solar energy systems enables smart monitoring, management, and accessibility. Rental-based systems can further improve affordability and accessibility. Thakur (2021) illustrated that a car rental system efficiently manages transactions, user data, and resources through database-driven modules and web-based interfaces. Applying similar principles to energy rentals allows automation of verification, monitoring, and payment processes through an IoT-based application. In support of this, Gavera et al. (2024) highlighted the relevance of the ESP32 as a powerful microcontroller for developing efficient and stable sensor networks, enhancing sustainability and resource efficiency. Combining these innovations can maximize utilization, enhance system functionality, and promote sustainable energy access for communities affected by frequent power interruptions.

In the Philippines, the average household experiences 28 electricity supply interruptions per year due to outages caused by plant breakdowns (Albay, 2025). In August 2025, the National Grid Corporation of the Philippines (NGCP) reported an unscheduled power interruption affecting Camiguin and specific parts of Misamis Oriental, which together house over sixty-thousand households (Philippine Statistics Authority, 2020). During such outages, reliance on diesel generators and other temporary energy sources underscores the inadequacy of existing solutions and the urgent need for reliable, affordable, and sustainable alternatives.

Recent efforts in solar-powered portable power supply systems show promise but still face limitations. Innovations have been made, such as Gozano et al. (2023) designing a solar-based portable power supply capable of charging small devices but with limited capacity and short battery life. Bhatti et al. (2024) developed a portable solar station with a 200 W output and load monitoring, while Ramly et al. (2019) created a 100 W portable solar power supply for emergencies that could last two days. Despite these advancements, existing systems still encounter issues related to energy capacity, battery lifespan, and limited support for higher power loads.

To address these gaps, this study proposes a solar-powered rental station with detachable power sources, powered by a solar panel for energy harvesting, a $LiFePO_4$ battery for reliable storage, and an inverter for AC power conversion. The system integrates an ESP32 microcontroller with IoT mechanisms to manage operations, while GPS and GSM modules provide real-time location tracking, communication, and monitoring of rented units, serving as additional security features of the system. A coin-slot mechanism with a solenoid lock ensures secure access, while the mobile application allows users to view available rental slots, check pricing based on the detachable power source's charge percentage, and manage user verification through SMS-based phone number confirmation. The application also stores the user's account information and available credits for future transactions. The compact and user-friendly design offers a sustainable solution for communities affected by frequent power interruptions, effectively bridging the gap in affordable and reliable energy access.

1.2 Statement of the Problem

Communities in various parts of the Philippines continue to face challenges in accessing stable electricity. In provinces such as Camiguin (served by CAMELCO) and specific parts of Misamis Oriental (served by MORESCO II), residents experience frequent and unscheduled power interruptions multiple times a week. These power outages cause inconvenience to households, affect business operations, and disrupt the productivity of local communities. Consistent and stable access to electricity remains a persistent challenge, especially in rural and island areas.

Although alternatives such as off-grid systems, portable power banks, and small gasoline generators are available, they often prove costly, limited in capacity, or unsustainable in the long term. The use of fossil-fueled generators also raises safety and environmental concerns, which contradict current efforts toward cleaner and more sustainable energy sources.

Solar-powered systems have been introduced as alternatives, yet most existing systems can only supply limited power to small devices such as mobile phones, lamps, or AM/FM radios. Many of these systems are installed within college campuses and are not designed for community accessibility. In addition, the absence of security and monitoring mechanisms makes these systems prone to theft.

To address these challenges, this study aims to answer the following research questions:

1. How can a solar-powered rental station with detachable power sources be designed to provide a sustainable and user-friendly energy solution for communities experiencing frequent power interruptions?

2. How can the proposed system overcome existing limitations in solar-powered portable power solutions, specifically lower energy load, limited battery capacity, restricted support for higher loads?
3. How can a secure coin-operated or mobile application-based mechanism be developed to regulate and monitor the rental and return of detachable power units?
4. How can GPS and GSM technologies be integrated to enhance tracking, monitoring, and communication of rented power sources?
5. To what extent can the developed prototype address issues of affordability, accessibility, and sustainability compared to existing backup power solutions?

1.3 Objectives of the Study

In view of the above stated problem, the following objectives are:

1.3.1 General Objectives

- To design and develop a solar-powered rental station with detachable power sources that are rented to serve as a sustainable and user-friendly solution for supplying electricity, specifically intended for communities experiencing frequent and unscheduled power interruptions.

1.3.2 Specific Objectives

- To design the system architecture for the power source that integrates photovoltaic panels, energy storage, and a power inverter, ensuring sufficient capacity for powering small-to-medium scale appliances.
- To develop a functional prototype of the rental power station with a detachable power source, with a secure coin-operated or app-based access mechanism for rental use.
- To integrate GPS and GSM modules to support real-time location tracking, communication, and monitoring of rented units.

1.4 Significance of the Study

This project benefits a diverse range of stakeholders including:

1.4.1 Community Residents: Community residents will benefit from continuous access to electricity through the detachable power source. This system ensures the community residents can use essential household appliances and stay connected during power interruptions.

1.4.2 Environment: This study contributes to environmental sustainability by promoting the use of solar energy, a renewable resource, instead of relying on fossil-fueled generators. The system reduces carbon emissions and pollution, aligning with global sustainability goals.

1.4.3 Future Researchers: Future researchers will find this study helpful because it gives important information on how to create solar-powered portable charging systems with features like GPS tracking, coin/app payment, and monitoring.

1.4.4 SDG 7: Affordable and Clean Energy: This system provides support in giving people access to energy that is affordable, reliable, and environmentally friendly by offering a solar-powered rental station that provides communities, especially those often experiencing blackouts, with a clean and low-cost source of electricity.

1.4.5 Industry, Innovation, and Infrastructure: This helps achieve the goal of improving systems, creating new technologies, and building stronger infrastructure by using modern technologies, as well as solar energy, which helps in creating innovative solutions that give communities a reliable energy option during power interruptions.

1.5 Scope and Limitations

1.5.1 Scope

- Design a solar-powered portable power station with detachable power sources for communities in Camiguin and selected areas in Misamis Oriental, which face frequent power interruptions.
- Integrate photovoltaic panels, energy storage, and a power inverter to run small-to-medium scale appliances.
- Implement coin-operated or app-based access for renting the power sources.
- Incorporate GPS and GSM modules for real-time location tracking and communication, ensuring efficient monitoring of rented units.

1.5.2 Limitations

- Geographic coverage limited to Camiguin and selected areas in Misamis Oriental.
- Not capable of operating high-demand power appliances due to limited power capacity.
- Cannot charge electric vehicles (e.g., Tesla) because required input is far higher than the system can supply.

- Deployment limited to suitable sites: Only for selected areas that both (a) frequently experience power interruptions and (b) have adequate sunlight; performance is poor where solar access is obstructed (c) inoperable in areas without Internet connectivity

- Coins only: The coin-operated mechanism does not accept paper bills.

- No physical change: The system does not dispense change; any excess payment/remaining balance is credited to the user's mobile application account.

- Weather-dependent operations: The system cannot operate during extreme weather, such as typhoons to protect users and equipment from potential damage

1.5.3 Definition of Terms

- Internet of Things (IoT) - A network of physical devices, such as sensors, appliances, and power sources, connected to the internet, enabling them to collect, send, and receive data for remote monitoring, control, and management.

- Solar Energy - Energy that is harnessed from sunlight using technologies such as photovoltaic (PV) panels, which convert sunlight into electricity, which is used to power the portable power sources.

- Fossil Fuel - Natural energy sources such as coal, oil, and natural gas, derived from the remains of ancient plants and animals, that are burned to produce energy but contribute to environmental pollution and climate change due to the emission of greenhouse gases.

- Photovoltaic (PV) Panels - Solar panels that convert sunlight into electricity, serving as the primary source of power generation for solar-powered systems.

- Auxiliary load - The secondary electrical components that support the operation of the system, such as controllers, sensors, and communication modules. In this study, this includes the ESP32, GPS and GSM modules, coin-slot mechanism, solenoid lock, and other low-power electronics.

- Portable Power Station - Compact, mobile units that provide electrical power for charging devices or operating appliances, often powered by renewable sources like solar energy and designed to be easily transported or moved.

- Small-to-Medium Scale Appliances - Electrical devices that consume relatively low to moderate power, typically ranging from 10 watts up to around 800 watts during normal operation.

- High-Demand Power Appliances - Devices that require significantly high power, usually 800 watts to more than 3000 watts, and often cause large spikes in household electrical load.
- Renewable Energy - Energy derived from natural resources that are replenished on a human timescale, such as sunlight, wind, and geothermal heat, which are harnessed to produce electricity in an environmentally sustainable manner.
- Off-grid power system - A power system that operates independently from the main electricity grid, using renewable energy sources like solar or wind to provide electricity in areas without access to centralized power.
- Solar harvesting - The process of capturing sunlight using solar panels or other solar technologies and converting it into usable electrical energy, typically for storage in batteries or direct use.
- Power Interruption - A temporary loss or disruption of electrical power, often due to faults, maintenance, or other technical issues in the power grid, affecting the availability of electricity to households or businesses.

CHAPTER 2

REVIEW OF RELATED LITERATURE

This chapter highlights related projects or studies that offer valuable insights to the researchers, serving as a foundation for the development of the study.

2.1 Theoretical Background

This study is anchored on three major theories: the Rental System Theory, the Sustainable Energy and Portable Power Theory, and the Wireless Communication and Positioning Theory (GPS and GSM Modules). Together, these theories explain the technological and operational principles underlying the development and functionality of the Kuryenta system, a coin-operated detachable power rental station designed to provide accessible, sustainable, and flexible energy solutions to users.

2.1.1 Rental System Theory

The Rental System Theory provides the conceptual basis for automating resource access and transactions through integrated digital and physical mechanisms. Thakur (2021) describes how an online rental platform enables users to register, reserve, and manage bookings remotely, transforming manual rental procedures into efficient, automated workflows. Applied to the Kuryenta system, this theory explains the combined use of a mobile application and on-station hardware (coin slot and solenoid mechanism) to control access to detachable power units. Users register and select an available slot via the application, then complete the physical payment at the station; the system computes the rental fee dynamically, based on the detachable unit's remaining battery percentage, and upon successful payment, actuates the solenoid to release the unit for a fixed rental duration. The integration of automated payment, real-time availability, and credit-storage mechanisms embodies core principles of rental system theory by increasing operational efficiency, ensuring transparent transaction management, and improving user convenience. These features align with Thakur's (2021) emphasis on system integration, automated database updates, and user-centred service delivery in modern rental platforms

2.1.2 Sustainable Energy and Portable Power Theory

The Sustainable Energy and Portable Power Theory supports the selection and design of renewable, off-grid power solutions and portable energy storage for resilient, community-oriented services. Recent implementations of coin-operated solar charging stations demonstrate how photovoltaic energy harvesting coupled with integrated storage batteries can provide continuous, low-maintenance charging services with commercial and emergency applications (Catalan et al., 2023). Complementing this, Gozano et al. (2023) provide empirical evidence for the design and deployment of portable, modular battery packs charged by solar panels, including component sizing (PV, inverter, charge controller), battery configuration, and performance monitoring via Arduino data logging, to reliably serve remote communities. Applying these principles to Kuryenta justifies the use of detachable battery with an onboard inverter and supports design decisions such as panel and battery sizing, battery management (BMS/modularity), and performance validation protocols. Together, these studies reinforce key theoretical aspects of the Kuryenta system: energy sustainability (solar charging), adaptability (modular/detachable units and inverter capability for low–medium appliances), operational resilience (off-grid emergency use), and evidence-based system sizing and monitoring for effective, user-centered portable power delivery.

2.1.3 Wireless Communication and Positioning Theory (GPS and GSM Modules)

The Wireless Communication and Positioning Theory serves as the foundation for the integration of the Global Positioning System (GPS) and

Global System for Mobile Communication (GSM) modules within the proposed system. This theory emphasizes the use of satellite-based navigation and mobile communication technologies to enable real-time tracking, monitoring, and data transmission over long distances. According to San Hlaing, Naing, and San Naing (2019), the integration of GPS and GSM enables efficient and continuous monitoring of mobile assets by acquiring geographic coordinates and transmitting them via wireless networks to designated users or databases.

In the context of this study, the theory supports the functionality of tracking and monitoring the location of detachable power sources within the rental system. The GPS module gathers real-time location data, while the GSM module transmits these coordinates to the mobile application and administrative system. Through this process, users and administrators are able to monitor the deployed power units, ensuring accountability, operational transparency, and user security. This theoretical foundation highlights the importance of wireless connectivity and geolocation in developing intelligent systems that enhance mobility, accessibility, and user convenience in portable power management.

2.1.4 Integration of Theories

All three theories collectively form the foundation of this study. The Rental System Theory provides the framework for automating the process of accessing, reserving, and paying for detachable power units through a combination of digital applications and physical mechanisms, ensuring efficient and user-centered rental transactions. The Sustainable Energy and Portable Power Theory establishes the system's grounding on renewable and off-grid energy utilization, promoting sustainability and operational resilience through solar-powered charging and modular battery storage. Meanwhile, the Wireless Communication and Positioning Theory supports the integration of GPS and GSM modules that enable real-time monitoring, data transmission, and location tracking of the detachable power sources. Together, these theories support the development of KURYENTA: Solar-Powered Rental Station with Detachable Power Sources, a coin-operated, GPS-enabled, and solar-powered system designed to deliver accessible and sustainable portable energy solutions to users.

Figure 2.1

Theoretical framework

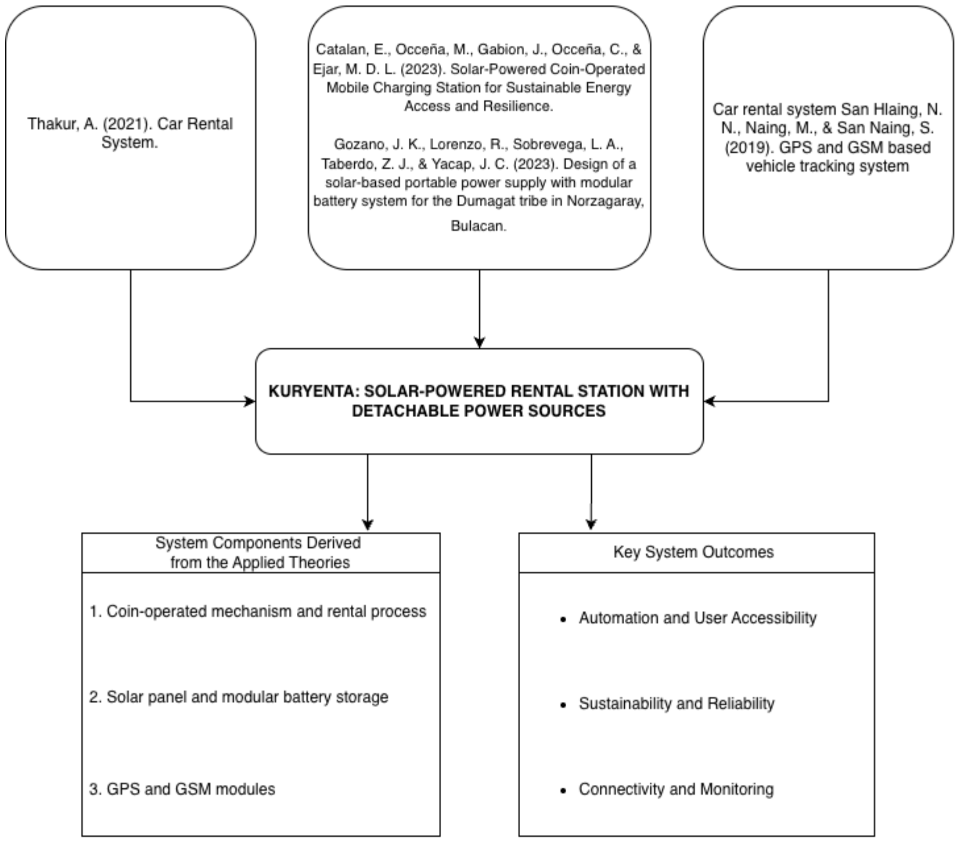


Figure 2.1 illustrates the Theoretical Framework of the study, showing how the Rental System Theory (Thakur, 2021), Sustainable Energy and Portable Power Theory (Catalan et al., 2023; Gazano et al., 2023), and Wireless Communication and Positioning Theory (San Haing et al., 2019) collectively form the conceptual basis of KURYENTA: Solar-Powered Rental Station with Detachable Power Sources.

These theories complement one another in explaining the system's core components, automation, sustainability, and connectivity, thereby providing a coherent theoretical foundation for its design and development.

2.2 Conceptual Framework

The conceptual framework of the study illustrates how the inputs and actions in the solar-powered rental station with detachable power sources affect its outcomes. Independent variables influence the system's performance, and the dependent variables show the results of these inputs. This framework explains how user actions and system conditions determine power delivery, user verification, location tracking, notifications, and credit rewards. It provides a clear structure for understanding and evaluating how the proposed system works.

a. Variables

- **Independent Variables (IV)**

  Coin, Credit, Distance, Signal, Unused Power

- **Dependent Variables (DV)**

  Power, Location, Notification, Credit

b. Formal Definition of Variables

Independent Variables

- *Coin* – Serves as the physical input medium that activates the system's rental process through coin insertion, enabling users to access the detachable power source.
- *Credit* – The amount of digital money or balance that a user has in their account (through the mobile app). The user can use this balance to pay for renting the detachable power source.
- *Distance* – The spatial measurement between the rental station and the portable power source as tracked by the GPS module.
- *Signal* – The communication strength and reliability between the system's GPS and GSM modules. It affects the accuracy of data transmission, notifications, and location tracking.
- *Unused Power* – Refers to the remaining electrical energy stored in the detachable power source after it has been rented and used by the user. This remaining power is measured based on the battery's remaining capacity percentage when returned. The system uses this value to calculate the amount of credit or reward that will be given to the user through the mobile application

Dependent Variables

- *Power* – The amount of electrical energy stored and supplied by the solar-powered battery system. It determines the duration and capacity of electricity available for users during rental operations.

- *Location* – The position of the rented portable power source as monitored by the GPS module. It indicates where the unit is located during operation.

- *Notification* – Refers to the alerts sent to the user via the GSM module. It notifies the user one hour before the allotted 12-hour usage period ends and informs them to return the item if the time exceeds the 12-hour limit. Notifications are then sent at 10-minute intervals until the item is returned.

- *Credit* – Refers to the digital value or reward points that the user earns in the mobile app after returning the rented detachable power source. The credit amount is calculated based on how much unused power remains in the device upon return.

c. Relationship of Variables

The independent variables directly influence the dependent variables.

- *Coin* → *Power*

  Inserting a coin activates the rental process, allowing the user to access the detachable power source. The available power supplied by the system depends on a valid coin being inserted,

- *Distance* $\rightarrow$ *Location*

  The measured distance of the detachable power source from reference points or the base station affects the GPS-based location tracking. The reported location depends on this spatial relationship, as distance influences the precision of GPS signals.

- *Signal* $\rightarrow$ *Location*

  The strength of the GPS signal affects the accuracy and reliability of location tracking.

- *Signal* $\rightarrow$ *Notification*

  The GSM signal strength determines how effectively the system can send alerts and messages to the user.

- *Unused Power* $\rightarrow$ *Credit*

  The amount of unused power remaining in the portable battery after a rental session determines the credit returned to the user through the application.

- *Credit* $\rightarrow$ *Power*

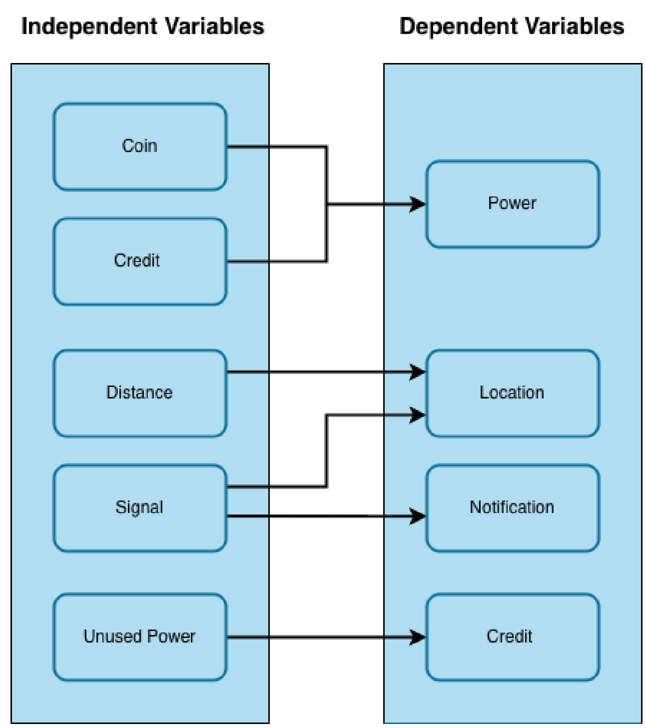
  The credit available in a user's account can be used to pay for the rental, which then activates the detachable power source.

2.2.1 Schematic Diagram

Figure 2.2 below presents the independent and dependent variables, along with their relationship.

Figure 2.2

Variable relation



2.3 Review of Related Studies

This part highlights related projects or studies that offer valuable insights to the researchers, serving as a foundation for the development of the study.

2.3.1 Design of a Solar-Based Portable Power Supply with Modular Battery System for the Dumagat Tribe in Norzagaray, Bulacan

Access to reliable and sustainable energy is a critical issue in many rural and indigenous communities. One such community is the Dumagat tribe in Norzagaray, Bulacan, where there is a notable lack of access to electricity despite the usage of electronic devices like phones. Addressing this issue requires innovative solutions that not only meet their energy demands but also ensure sustainability and accessibility.

In this context, Gozano et al. (2023) conducted a study on a solar-powered portable power supply designed to provide the Dumagat Tribe with basic energy needs. This system incorporated a solar panel, a modular battery pack, and an inverter, aimed at powering low-energy devices and addressing the tribe's electricity needs. Using an Arduino data logger, the study measured the charging and discharging rates of the system, showing promising results while also identifying areas for improvement, such as the need for higher-capacity batteries and more efficient solar panels.

2.3.2 Construction of a Portable Solar Power Supply for Household Appliances

Oluwasegun et al. (2018) developed a portable solar power supply system designed to power household appliances, offering a sustainable, eco-friendly alternative to traditional non-renewable energy sources. The system consists of a solar panel, a charge controller, a 12V lead-acid battery, a pure sine wave inverter, and an Arduino phase for voltage monitoring. The system was tested with household appliances such as a 300W electric blender and a 300W electric kettle, demonstrating its ability to provide reliable power. The solar panel efficiently converts sunlight into electricity, which is stored in the battery for use when solar energy is unavailable, providing a continuous energy supply.

The portable solar power system was able to power household appliances effectively, with minimal voltage drop during use, ensuring its practicality and dependability. By using solar energy, the system reduces electricity costs and promotes environmental sustainability by lowering greenhouse gas emissions. The use of a pure sine wave inverter ensures stable and high-quality power for sensitive appliances. Oluwasegun et al. (2018) concluded that this system offers a cost-effective, clean energy solution for households, though further enhancements are needed to support higher electrical loads for more extensive applications.

2.3.3 Solar-Powered Coin-Operated Mobile Charging Station for Sustainable Energy Access and Resilience

The increasing demand for sustainable and accessible energy has driven innovations that utilize renewable sources to meet electricity needs in both urban and rural areas. The study by Catalan et al. (2023) aimed to develop a solar-powered, coin-operated mobile charging station designed to provide continuous off-grid power using photovoltaic (PV) technology. Employing a developmental research approach, the researchers designed, fabricated, and tested a prototype equipped with solar panels and an integrated storage battery system capable of charging multiple mobile devices for both commercial and emergency purposes. The results demonstrated that the charging station effectively powered various mobile gadget models with no compatibility issues, maintained stable operation even under limited sunlight, and offered cost efficiency through its low maintenance and sustainable design. Furthermore, the system contributed to reducing carbon emissions and supported the green technology initiatives of Guimaras State University. It was concluded that the solar-powered charging station is a practical and eco-friendly innovation that promotes energy resilience in communities affected by power outages. The study recommended installing such systems in strategic locations for communal purposes and remote areas, integrating security features to prevent misuse, and conducting further research to enhance its technological design and promote the widespread adoption of renewable energy solutions.

2.3.4 Emergency Solar Portable Power Supply

The "Emergency Portable Solar Power Supply" study by Ramly et al. (2019) explored the development of a portable solar power system designed to provide electricity in areas without reliable grid access, particularly during power outages. The system utilizes solar photovoltaic (PV) technology to convert sunlight into electricity, which is stored in a battery for later use. Key components of the system include solar panels, batteries, charge controllers, inverters, and a microcontroller with Bluetooth functionality for remote monitoring. The study emphasizes the importance of sizing the solar panels and batteries properly to ensure a consistent energy supply, particularly in off-grid or emergency situations. By harnessing renewable solar energy, the system reduces reliance on fossil fuels and contributes to environmental sustainability. The solar panels used in the system have an efficiency rating of around 15-18%.

2.3.5 Portable Solar-Station with Integrated Battery Management and Load Monitoring System

Abdur et al. (2024) describe the development of a portable solar-powered station designed for disaster response, offering a 200W output using a 2x2 array of 50W solar panels. The system integrates a battery management system (BMS) and load monitoring mechanism (LMM), providing power for essential needs such as lighting, mobile device charging, and medical equipment in emergency situations. Replacing diesel generators reduces environmental pollution and noise, offering a sustainable, clean energy solution in areas with limited infrastructure. Its compact design allows easy transportation to disaster zones, making it an effective tool for providing reliable power where it's needed most.

The system also features an MPPT solar charge controller, optimizing energy efficiency and extending battery life by preventing overcharging and undercharging. The design incorporates Nanton YIDA YD-W50 Monocrystalline solar panels and a 12V 80Ah lead-acid battery, ensuring reliable energy storage. Abdur et al. (2024) conclude that this portable solar station provides a cost-effective, low-maintenance, and environmentally sustainable alternative to traditional diesel generators, making it a practical solution for disaster-prone regions.

2.3.6 Solar Powered Mobile Power Bank Systems

Solar-powered mobile charging systems offer a sustainable solution for powering devices during power interruptions and disasters. The research by Agarwal et al. (2016) focuses on a Solar-Powered Portable Power Bank designed for mobile phones, using solar energy to charge a battery, which in turn provides power through a USB port. This system is particularly useful in disaster events and remote areas with limited electricity. The system utilizes two 6V solar panels to charge a 12V battery, with a microcontroller monitoring the battery's charge level and controlling relay circuits to ensure safe charging. LEDs display the battery charge level, offering a user-friendly interface for monitoring.

The proposed system has multiple advantages, including reducing reliance on traditional power sources and providing a reliable charging solution in emergencies. It addresses environmental concerns by utilizing renewable energy, minimizing pollution compared to conventional power generation methods. The microcontroller ensures efficient charge flow and protects the system from damage caused by overcharging or voltage fluctuations. Agarwal et al. (2016) conclude that for optimal performance, the system requires direct sunlight and proper placement of the solar panels. The design can be improved by enhancing its portability and ensuring better protection for the mobile devices and battery, making it a practical and eco-friendly alternative to traditional charging methods.

2.3.7 Multiport Universal Solar Power Bank

Altelmessani et al. (2024) introduce the concept of a Multiport Universal Solar Power Bank, designed to harness solar energy for a portable power supply. This device aims to address critical needs in emergency situations and recreational activities like camping, especially in remote areas where access to electricity is limited. Equipped with solar panels for efficient energy absorption, the power bank offers both DC and AC outputs, making it versatile enough to charge a wide range of electronic devices. The project emphasizes the importance of sustainability, using renewable resources to reduce reliance on non-renewable energy sources and provide a reliable, eco-friendly power source.

The system is capable of powering various appliances, including small household electronics, portable fans, lights, and mobile devices, with an AC output of up to 400W and a battery capacity of 20,000mAh. It also incorporates safety features to protect against overcharging, overheating, and other risks, ensuring both user safety and device longevity. The study highlights the project's compact and lightweight design, making it ideal for on-the-go use, such as in emergencies or outdoor activities. By focusing on energy independence and environmental sustainability, the project contributes to reducing environmental impact while offering a reliable and versatile energy solution

2.3.8 Portable Power Supply Design with 100 Watt Capacity

Zakri et al. (2021) developed a portable solar power supply design with a 100W capacity, aimed at providing sustainable energy in areas with limited electricity access. The system utilizes solar cells and a transformer to store energy in batteries with capacities of 20Ah, 60Ah, and 100Ah. The solar-powered generator can charge devices like lamps, laptops, LED televisions, and fans, supporting electrical loads under 100 watts for up to 12 hours. The system includes a Solar Charge Controller (SCC) to prevent overcharging, ensuring battery safety and longevity. The design is portable, easy to operate, and suitable for off-grid locations such as plantations or rural areas.

The tool's efficiency depends on the battery capacity and weather conditions. For example, charging the 20Ah battery takes about 5 hours under optimal sunlight, while larger batteries (60Ah and 100Ah) require more than one day to fully charge. This design is versatile, offering both AC and DC outputs, and is equipped with an LCD for voltage display, as well as safety features such as overcharge protection. Zakri et al. (2021) conclude that this portable power supply offers a practical, environmentally friendly solution for off-grid applications, with the flexibility to charge batteries via solar energy or electrical sources.

2.3.9 Design and Development of Portable StandAlone Solar Power Generator

Prathiba et al. (2020) developed a portable, standalone solar power generator designed to replace diesel generators with a sustainable, eco-friendly solution. The system integrates a solar panel, a battery, a bidirectional buck-boost converter, and an inverter, all supported by a Maximum Power Point Tracking (MPPT) algorithm for optimal efficiency. The generator provides a green energy source to meet load requirements and stores excess energy in a battery for use when solar energy is unavailable. The bidirectional converter enhances battery charging efficiency and ensures regulated DC voltage output, while the MPPT algorithm maximizes power extraction from the solar panel to improve overall system performance.

The portable solar generator utilizes a bi-directional converter and MPPT to achieve high efficiency, allowing it to charge and discharge a 12V lead-acid battery. The system is capable of powering both DC and AC loads, using a push-pull full-bridge inverter to drive AC devices. The system is designed for off-grid applications, including emergency situations and areas without access to electricity. The study emphasizes the system's compact design, cost-effectiveness, and potential for use in relief camps and remote locations. The project demonstrates a practical and portable renewable energy solution for sustainable power generation in diverse applications, especially in areas with limited access to the grid.

2.3.10 A solar-powered multi-functional portable charging device (SPMFPCD) with internet-of-things (IoT)-based real-time monitoring—An innovative scheme towards energy access and management

Rehman et al. (2024) propose a solar-powered multi-functional portable charging device (SPMFPCD) with IoT-based real-time monitoring, designed to address the growing need for reliable and versatile energy solutions across various sectors, including transportation, communication, and emergency services. The device integrates a highly efficient solar panel, a charge controller, sensors, and an IoT module for real-time monitoring of power parameters. This innovative system supports diverse applications, such as emergency medical device charging, outdoor adventures, disaster management, and public spaces. The IoT capabilities provide continuous monitoring, ensuring efficient operation and proactive maintenance, enhancing the reliability and scalability of the system.

The study emphasizes the significance of integrating advanced technologies, such as IoT-driven battery energy storage system (BESS) health monitoring, to optimize the performance and lifespan of the system. The study also conducted an economic and environmental impact assessment, showing the feasibility and sustainability of widespread SPMFPCD deployment. The proposed system demonstrated competitive cost-effectiveness, with a low cost of electricity and minimal annual operating costs. The integration of renewable energy sources like solar power and the IoT-based health monitoring system positions the SPMFPCD as a promising solution for providing accessible, environmentally friendly energy in various settings, highlighting its potential to contribute to sustainable energy management and community empowerment.

2.3.11 Renewable Energy from Solar Panels: A Study of Photovoltaic Physics and Environmental Benefits

Jaiswal (2023) provides an in-depth analysis of solar energy's growing role in the global energy transition, focusing on its environmental, economic, and technological advantages. The study highlights that global solar photovoltaic (PV) capacity reached about 1,059 gigawatts by 2021, reflecting rapid adoption and its significant contribution to reducing greenhouse gas emissions. Technological advancements, such as bifacial and perovskite solar cells, have increased the efficiency and affordability of solar power, making it more accessible. The research also stresses the importance of supportive policies and regulatory frameworks in promoting solar energy deployment.

The environmental benefits of solar power are significant, with Jaiswal (2023) noting that solar energy could reduce up to 80% of greenhouse gas emissions by 2050. Additionally, the integration of solar energy with energy storage systems is essential for improving reliability and addressing challenges related to intermittency. The study concludes that solar energy plays a crucial role in achieving sustainable development, reducing climate change impacts, and driving economic growth. With ongoing technological advancements and effective policies, solar power is set to be a key component of the future energy system.

2.3.12 Power Consumption of Household Appliances

Power consumption patterns in households are significantly influenced by the frequency and duration of appliance usage. Pulvera (2021) found that household appliances such as televisions, electric fans, and refrigerators are among the most frequently used devices, contributing considerably to total electricity consumption. The results revealed that the television set operates for an average of forty-four (44) hours per week, followed by the electric fan with fifty-one (51) hours, and the refrigerator with one hundred five (105) hours of usage weekly. These appliances are commonly prioritized for their essential roles in providing comfort, entertainment, and food preservation within the household.

Pulvera (2021) further emphasized that electricity usage is affected by several factors, including low voltage supply, appliance wattage, power interruptions, standby power, and user behavior. Among these, user awareness and proper energy management play a crucial role in reducing unnecessary power consumption. The continuous use of high-demand appliances such as electric fans and refrigerators, especially in tropical climates like the Philippines, highlights the dependence of households on these devices for maintaining comfort during hot weather and ensuring food preservation. Consequently, understanding the frequency of appliance use helps identify energy-saving opportunities and promote consumer awareness.

2.3.13 Electricity Distribution and Supply Authority

Battery selection plays a critical role in optimizing the performance and sustainability of photovoltaic (PV) systems. According to the Electricity Distribution and Supply Authority (EDSA, 2024) under the Government of Sierra Leone, three major battery options are typically considered in solar power applications—Flooded Lead Acid, Sealed Lead Acid (SLA), and Lithium Iron Phosphate ($LiFePO_4$). The study highlighted that $LiFePO_4$ batteries are preferred for the Regional Emergency Solar Power Intervention (RESPITE) Project due to their superior efficiency, longevity, and environmental advantages.

$LiFePO_4$ batteries are generally more energy-efficient, allowing for greater energy utilization and reduced losses during charging and discharging. In contrast, SLA batteries exhibit lower efficiency, which can result in higher energy wastage. Additionally, $LiFePO_4$ batteries support a higher depth of discharge (DoD), enabling deeper energy use without significantly affecting their lifespan. This characteristic makes them more suitable for daily solar energy cycling compared to SLA batteries, which tend to degrade faster under similar conditions.

Another major advantage of $LiFePO_4$ technology is its longer cycle life. The EDSA (2024) report notes that $LiFePO_4$ batteries can endure more charge-discharge cycles before their performance diminishes, offering better long-term reliability. They also possess higher energy density, meaning they can store more energy in a smaller physical footprint—an important factor when space constraints exist in solar installations.

In terms of maintenance, $LiFePO_4$ batteries are maintenance-free, unlike SLA batteries which often require periodic electrolyte checks and refilling. While $LiFePO_4$ batteries have a higher upfront cost, they compensate with lower operational and maintenance expenses throughout their lifespan. From an environmental perspective, $LiFePO_4$ batteries are also less harmful and easier to dispose of or recycle compared to lead-acid types, which generate toxic emissions during recycling.

2.3.14 Assessing the Impact of Power Outages on Appliances of Farmers and Fisherfolks in Selected Barangays of Cawayan, Masbate, Philippines: Basis for a Proposed Extension Program

Frequent power interruptions have long been a challenge in rural communities, particularly among those who depend on electricity for household and livelihood activities. The study aimed to determine the impact of frequent power interruptions on the appliances and economic well-being of residents in selected barangays of Cawayan, Masbate. Employing a descriptive research design, the researchers gathered data from 266 respondents through paper surveys and face-to-face interviews to assess the frequency, duration, and effects of power interruptions. Findings revealed that almost all respondents experienced power interruptions lasting three to four hours, leading to increased electricity consumption and higher bills. Refrigerators and televisions were the most power-consuming appliances, and there was significant damage to appliances, especially bulbs, as well as disruptions to income-generating activities. The study results showed that many respondents had an annual income of less than ₱18,200, which was considered low and may have resulted in difficulty in paying high bills brought by power outages. All respondents relied on the power grid as their source of electricity, and power interruptions were a common occurrence. The data revealed that 97.7% of respondents experienced power interruptions, with 51.1% experiencing 3-4 hours of interruption. Almost all respondents claimed that power interruption increased their electric consumption and bill, and 56% were not satisfied with their electric bill when there was a power interruption. It was concluded that unreliable electricity supply and lack of maintenance significantly affect low-income households that rely solely on the power grid as their source of electricity. The study recommended strengthening local power infrastructure and promoting renewable energy education through a proposed extension project that trains communities in the use of solar energy as a sustainable and reliable alternative to the current power grid system. This helps reduce air pollution and climate change while building the capacity of farmers and fishers to adapt to these changes.

2.3.15 Synthesis

The reviewed literature highlights the progress made in solar-powered portable energy systems, especially for off-grid communities facing frequent power interruptions and power emergencies. Studies like those by Gozano et al. (2023), Oluwasegun et al. (2018), and Ramly et al. (2019) developed solar-based systems that integrated photovoltaic panels, charge controllers, batteries, and inverters. However, these systems often lacked sufficient energy storage capacity, limiting their ability to provide continuous power for communities that rely heavily on energy for daily appliances such as refrigerators and fans. Studies by Abdur et al. (2024) and Altelmessani et al. (2024) incorporated more advanced energy management through battery monitoring and load management systems but still did not fully address the integration of high-capacity energy storage and secure access for users. The gap in addressing these challenges highlights the need for a more efficient and accessible solar energy system for communities affected by power disruptions.

A significant gap in the existing literature lies in the choice of energy storage solutions. Many studies employed Lead-Acid batteries, which are still common in many solar power systems. For example, Oluwasegun et al. (2018)

used a 12V Lead-Acid battery, which is cheaper but comes with limitations, including lower efficiency, shorter cycle life, and higher maintenance requirements. Lead-Acid batteries are typically less efficient, with a cycle life of about 500 to 1,000 cycles. In contrast, the proposed system utilizes $LiFePO_4$ (Lithium Iron Phosphate) batteries which is a better alternative. According to EDSA (2024) and Zakri et al. (2021), $LiFePO_4$ batteries offer several advantages, including a much higher cycle life (more than 2,000 cycles), greater depth of discharge (DoD), and better overall efficiency, making them ideal for systems that undergo frequent charge-discharge cycles. These batteries are also more environmentally friendly and require less maintenance than their lead-acid counterparts. The $LiFePO_4$ battery selected for the proposed system offers reliable energy storage with a high energy density, ensuring longer-lasting and more sustainable power for the solar-powered rental station.

Additionally, a notable gap in the literature is the lack of secure, rental-based access mechanisms for solar energy systems. While studies like Catalan et al. (2023) explored solar-powered coin-operated charging stations, they primarily focused on mobile charging rather than integrated power solutions for household or community use. The current study addresses this gap by incorporating a coin-slot mechanism with a solenoid lock for secure, pay-per-use access, ensuring that only authorized users can access the stored energy.

Moreover, the integration of IoT-based monitoring through the ESP32 microcontroller, GPS, and GSM modules provides tracking of battery levels, usage statistics, and system status, which has not been fully explored in previous research. Rehman et al. (2024) highlighted the use of IoT for monitoring in solar-powered devices, but their research focused on charging stations for mobile devices rather than community-based energy solutions. The integration of a mobile app for monitoring battery charge levels and energy consumption ensures that users have full visibility into the system's performance.

Furthermore, the proposed system's combination of a solar panel, $LiFePO_4$ battery, MPPT charge controller, and AC inverter ensures that the system is capable of powering small to medium-sized appliances, such as refrigerators and fans, which are commonly used in Filipino households as noted in the studies by Pulvera (2021) and Masbate (2024). This integrated approach addresses a crucial need for accessible and reliable energy solutions in communities that frequently face power interruptions. The system's scalability and eco-friendly design, driven by high-capacity $LiFePO_4$ batteries, secure rental features, and smart monitoring systems, provide a comprehensive solution that builds on existing research while filling the gap in accessible and sustainable solar energy solutions for off-grid communities.

CHAPTER 3

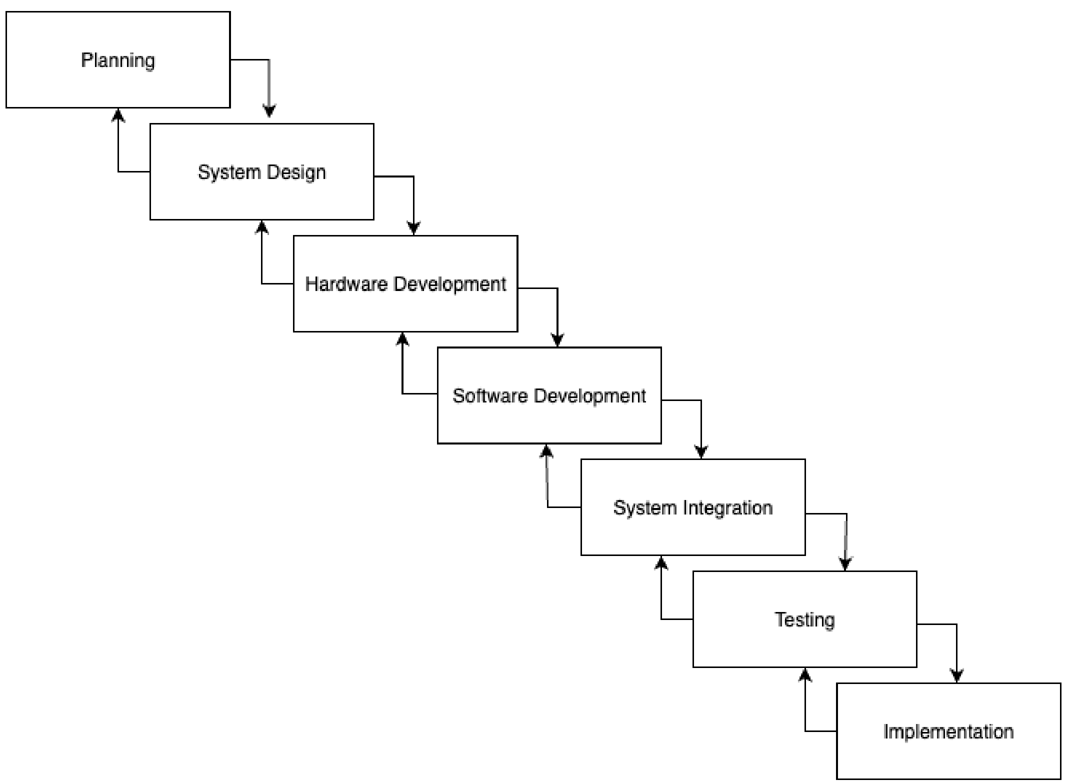
METHODOLOGY

In this chapter, the researchers outline the methodology employed to conduct the study, providing a comprehensive overview of the research design, technical design workflow, and analytical procedures.

3.1 Research Design and Procedure

Figure 3.1

The Waterfall Model

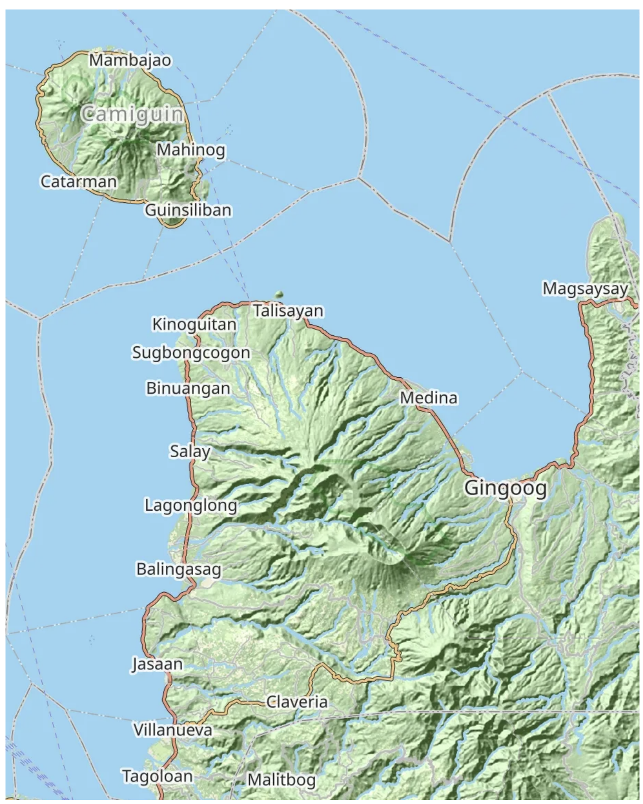


In Figure 3.1, the system creation process is illustrated, utilizing a modified waterfall model. This systematic approach consists of several key stages, commencing with requirements gathering and followed by requirements analysis, hardware development, software development, system design, integration, and testing & evaluation. This procedural framework acts as a guiding path for researchers to achieve the study's intended objectives.

3.1.1 Research Setting

Figure 3.2

Map of Camiguin and Misamis Oriental



The research will be conducted in selected areas of Camiguin and Misamis Oriental, regions in the Philippines that are known for frequent and unscheduled power interruptions. These areas are served by CAMELCO (Camiguin Electric Cooperative) and MORESCO II (Misamis Oriental Electric Cooperative II), both of which experience regular power outages, particularly during peak hours. This issue disrupts daily activities, especially in community centers, educational institutions, and local businesses that rely on electricity for mobile devices, lighting, and small appliances.

3.1.2 Data Collection

The research team will gather data from both primary and secondary sources. For the primary data, first-hand interactions will be conducted with community residents, power supply providers, and solar energy experts. Community residents, as the primary users of the solar-powered rental station, will provide information on the demand for portable power sources, willingness to adopt a solar-powered system, and feedback on system usability and effectiveness in addressing power interruptions. Power supply providers, such as local electric cooperatives like CAMELCO and MORESCO 2, will provide data on the frequency of power interruptions, challenges in accessing reliable energy, and the overall energy demand in the community. Insights from solar energy experts will focus on technical aspects of solar power systems, including optimal photovoltaic panel configurations, energy storage solutions, and power inverter specifications.

Secondary sources will include academic papers, case studies, industry reports, and other literature related to solar energy, portable power stations, and renewable energy systems. These sources will provide a theoretical foundation and context for the study, ensuring that both practical relevance and technical feasibility are considered in developing the solar-powered rental station system.

3.1.3 Data Gathering Procedure

To obtain relevant qualitative data for the study, a series of in-depth interviews will be conducted with selected community residents using purposive sampling. The interviews will focus on understanding residents' experiences with frequent power interruptions, the challenges they encounter during interruptions, and their perceptions of a solar-powered rental station with detachable power source as an alternative energy source. These discussions will also explore their reliance on backup power systems and their willingness to adopt renewable energy solutions. Participants will be purposively selected, particularly those who frequently experience power interruptions, depend on electricity for livelihood activities, and have expressed interest in solar technology. Combined with qualitative tools, this approach will ensure a comprehensive understanding of the community's energy needs, user expectations, and potential areas for improving the design and implementation of the solar-powered rental station system.

3.1.4 Data Finding Analysis

The analysis of the collected data will lead to several important findings. The first will reveal that community residents frequently experience power interruptions that disrupt both household and livelihood activities. These interruptions will highlight common challenges related to the reliability, cost, and accessibility of backup power solutions. Residents will express concerns about their dependence on the unstable power grid and the lack of affordable alternatives during interruptions. The analysis will also uncover the community's openness to adopting a solar-powered rental solution, recognizing its potential to provide a more sustainable and reliable energy source. Feedback from interviews and discussions will emphasize the need for practical improvements to the proposed system, such as flexible payment options (coin- or app-based), increased power capacity, and user-friendly accessibility. These insights will be vital in assessing the system's feasibility and refining its design to ensure it effectively addresses the residents' energy needs.

3.1.5 User Definition

After the planning phase, the system's users were identified. For this study, the Community Resident is defined as follows:

Community Resident - A person residing in a local community who is actively involved or has access to the portable power sources during power interruptions or emergencies.

3.1.6 System Requirements

Table 1: System Requirements

Category	System Requirement
Input Requirements	- The system shall collect user information during account registration through designated input fields in the mobile application. - The system shall accept user login credentials such as username and password for authentication. - The system shall accept rental requests, including power source selection, rental duration, and payment method (coin-based or app-based). - The system shall receive telemetry data from each power source, including battery percentage, GPS location, and rental status through the GSM module. - The system shall receive telemetry data from each power source, including battery percentage, GPS location, and rental status through the GSM module.

Continued on next page

Table 1 – continued from previous page

Category	System Requirement
Process Requirements	- The system shall process rental transactions by verifying payment completion before authorizing power source access. - The system shall generate and transmit an access token or unlock code to the power source upon successful rental approval. - The system shall continuously monitor and record the battery level, location, and usage duration of active rentals. - The system shall automatically send an SMS notification via GSM one hour before the allotted 12-hour usage period ends, and if the user exceeds the 12-hour limit, it shall continue sending overdue alerts every 10 minutes until the item is returned. - The system shall process the return of rented power sources by validating device ID, updating the database, and releasing the final transaction summary. - The system shall calculate credit earned for users based on unused power and reflect the updated balance in the users mobile application account.
Output Requirements	- The system shall display rental confirmation details such as power source ID, rental duration, and current charge level. - The system shall provide updates on the detachable power source, provide user logs, and notify the admin whenever a new account is created. - The system shall generate the location of the rented power source using the GSM module. - The system shall generate notifications on the mobile app, including GPS location, and rental time remaining. - The system shall calculate the unused power of the returned detachable power source and convert it into a credit stored in the user's mobile app.

Continued on next page

Table 1 – continued from previous page

Category	System Requirement
Control Requirements	- The system shall implement user authentication and authorization mechanisms to restrict access to registered users only. - The system shall validate all rental and payment data to ensure that only completed and legitimate transactions are processed.
Performance Requirements	- The system shall maintain fast response time during login, payment processing, and rental activation to ensure a smooth user experience. - The system shall provide monitoring and synchronization of power source data through reliable GSM and IoT communication. - The system shall ensure continuous operation and high availability to prevent service interruptions during rentals.

3.1.7 Calculation Requirements

Load Analysis

Table 2: Load Consumption

Load	Quantity	Power	Hours/Day	Daily Consumption
Electric Fan	1	75 W	5	370 WH
Mobile Phone Charger	1	20 W	5	100 WH
Auxiliary Load	1	5 W	5	25 WH
Total				**500 WH**

The schedule of load includes three main loads, namely the electric fan, the mobile phone charger, and a 5W auxiliary load. Each load is multiplied by its hours of operation, and their products are summed to obtain the total watt-hour daily consumption.

All calculations are done in accordance to PEC (Philippine Electrical Code 2017).

Battery Sizing

- **Detachable Power Source:**

$$\text{Battery Capacity} = \left(\frac{\text{Total Daily Consumption}}{\text{System Voltage}}\right) + \text{ESP32 Consumption} \tag{1}$$

This equation determines the required battery capacity for the detachable power source. The total daily load consumption in watt-hours is divided by the 12V system voltage to convert the value into ampere-hours. The consumption of the ESP32 microcontroller (0.858 Ah), which continuously operates for system monitoring, is then added. This computation ensures that the detachable power source can sustain both the primary load and the microcontroller's operational requirements. Please refer to Appendix A for the detailed computation.

- **Station:**

$$\text{Battery Capacity} = (\text{BCDPS} + 35\%) + \text{ESP32 Consumption} \tag{2}$$

This equation is used in sizing the battery of the main station. It begins with the computed battery capacity of the detachable power source and adds 35% to account for system losses, such as wiring resistance, power conversion inefficiencies, and charging losses. The ESP32's consumption (0.858 Ah) is also included to ensure that the main station battery can support all monitoring and control operations. Please refer to Appendix A for the detailed computation.

- **Panel Sizing:**

$$\text{PV Power} = \frac{\text{Total Daily Consumption}}{\text{Sun Peak Hours}} \tag{3}$$

This equation calculates the required power rating of the solar panel. The total daily energy consumption (500 Wh) is divided by the available sun peak hours (3.5 hours, based on PEC 2017) to determine the power output needed to fully recharge the battery each day. The computed value of approximately 142.86W is rounded up to a 200W solar panel for practical and technical considerations. Please refer to Appendix A for the detailed computation.

- **Inverter Sizing:**

Table 3: Inverter Sizing

Load	**Power**	**Power Surge**	**With Power Surge**
Electric Fan	75 W	3	225 W
Mobile Phone Charger	20 W	1	20 W
Auxiliary Load	5 W	1	5 W
Total			**250 W**

$$\text{Inverter Size} = \text{Total Power Consumption} + 20\%\text{Allowance} \tag{4}$$

This formula is used to determine the appropriate inverter size. After calculating the total power requirements of all connected loads, including surge components such as the electric fan, a 20% allowance is added to ensure that the inverter can safely handle fluctuations and temporary increases in power demand. With a total of 250W, the system requires a 300W pure sine wave inverter. Please refer to Appendix A for the detailed computation.

- **Solar Charge Controller Sizing:**

$$I_{cc} = \frac{\text{Total PV Power}}{\text{System Voltage}} \tag{5}$$

This equation determines the required rating for the solar charge controller. Dividing the total solar panel wattage (200W) by the system voltage (12V) yields the expected charging current supplied to the controller. The computed value of 16.67A is rounded upward to select a 20A MPPT charge controller, ensuring safe and efficient power regulation. Please refer to Appendix A for the detailed computation.

- **Breaker Sizing:**

  a. Panel - SCC

  $$\text{Circuit Breaker} = 11.85A \times \text{Over Radiance Factor} \times \text{Safety Factor} \tag{6}$$

  This equation is used to determine the appropriate circuit breaker rating between the solar panel array and the Solar Charge Controller (SCC). The value 11.85A represents the short-circuit current (Isc) of the solar panel system. Multiplying by the Over Radiance Factor and the Safety Factor provides an adjusted current value that accounts for sudden increases in sunlight intensity and unexpected current surges. After substituting the given parameters in the complete computation, the calculated value results in a 20A circuit breaker rating, which is the recommended protection size between the solar panel and the SCC. This ensures safe operation by preventing overheating, protecting the solar wiring, and avoiding damage to system components. Please refer to Appendix A for the detailed computation.

b. SCC - Battery

$$\text{Circuit Breaker} = \frac{\text{Total Array Wattage}}{\text{Battery Bank Nominal Voltage}} \times \text{Safety Factor} \tag{7}$$

This equation sizes the circuit breaker between the Solar Charge Controller (SCC) and the battery bank. The total wattage of the solar panel array is divided by the system's nominal battery voltage to determine the expected charging current that will flow from the SCC into the battery during operation. A Safety Factor is then applied to account for possible current variations during charging, ensuring that the system remains protected from overload. After substituting the system values into the calculation, the resulting breaker rating requirement is 20A, which provides proper protection during charging while maintaining safe operating conditions for the battery bank. This recommended 20A circuit breaker prevents overheating and electrical damage by limiting excessive current flow into the battery storage system. Please refer to Appendix A for the detailed computation.

c. Battery - Power Inverter

$$\text{Circuit Breaker} = \frac{\text{Power Inverter}}{\text{Battery Bank Nominal Voltage}} \tag{8}$$

This equation determines the appropriate circuit breaker rating between the battery bank and the power inverter. The power rating of the inverter (in watts) is divided by the nominal battery voltage (in volts) to calculate the maximum current drawn during inverter operation when supplying AC loads. This calculated current serves as the basis for selecting a circuit breaker capable of protecting both the inverter and battery system during high-demand usage. After substituting the specified system values into the equation, the resulting breaker requirement is 80A, which is the recommended rating to ensure sufficient protection from overcurrent conditions that may occur when connected appliances operate at maximum load capacity. This breaker rating prevents damage to the inverter and battery by interrupting excessive current flow and maintaining safe operating conditions. Please refer to Appendix A for the detailed computation.

d. Inverter - Load (AC Breaker)

$$\text{Circuit Breaker} = \frac{\text{Safety Load}}{\text{Inverter Voltage Output}} \times \text{BBNV} \tag{9}$$

This equation sizes the AC circuit breaker located between the inverter and the connected load. The Safety Load represents the maximum expected power consumption of the AC appliances connected to the inverter. Dividing this value by the inverter's AC output voltage converts the load into current, representing the expected amperage during operation. The result is then multiplied by the battery bank nominal voltage to account for conversion losses and variations in real operating conditions. Based on the system values used in the computation, the required AC breaker rating is 4A, which provides sufficient protection by interrupting excessive current that could damage connected appliances or the inverter output circuitry. This calculated breaker size ensures safe and reliable system performance under normal and peak load operations. Please refer to Appendix A for the detailed computation.

- **Wire Sizing:**

$$\text{Voltage Drop Index} = \frac{\text{Amperes} \times \text{Wire Length (Feet)}}{\text{Voltage} \times \text{Percent Voltage Drop}} \tag{10}$$

This equation is used for determining the appropriate wire size needed to safely and efficiently handle electrical current within the system. The Voltage Drop Index (VDI) is calculated based on four factors: the current in amperes, the wire length, the system voltage, and the allowable percentage of voltage drop. Higher current flow or longer cable distance increases the VDI value, which indicates the need for a thicker wire in order to minimize electrical resistance and heat generation. Selecting the correct wire size ensures that voltage loss is controlled, system performance remains efficient, and the overall electrical design operates safely without risk of overheating or component failure.

a. Panel - SCC

   Panel to Solar Charge Controller = 10AWG

   The first VDI calculation was performed for the wire connection between the solar panel and the Solar Charge Controller (SCC). Given the operational current and wire distance in this segment, the computed VDI value resulted in 3.52. Based on standard VDI wire reference charts, a value of 3.52 corresponds to the use of 10 AWG wire, which provides sufficient conductivity and prevents excessive voltage reduction over the cable length. This ensures that power harvested from the solar panel is efficiently delivered to the SCC with minimal losses. Please refer to Appendix A for the detailed computation.

b. SCC - Battery

Solar Charge Controller to Battery = 10AWG

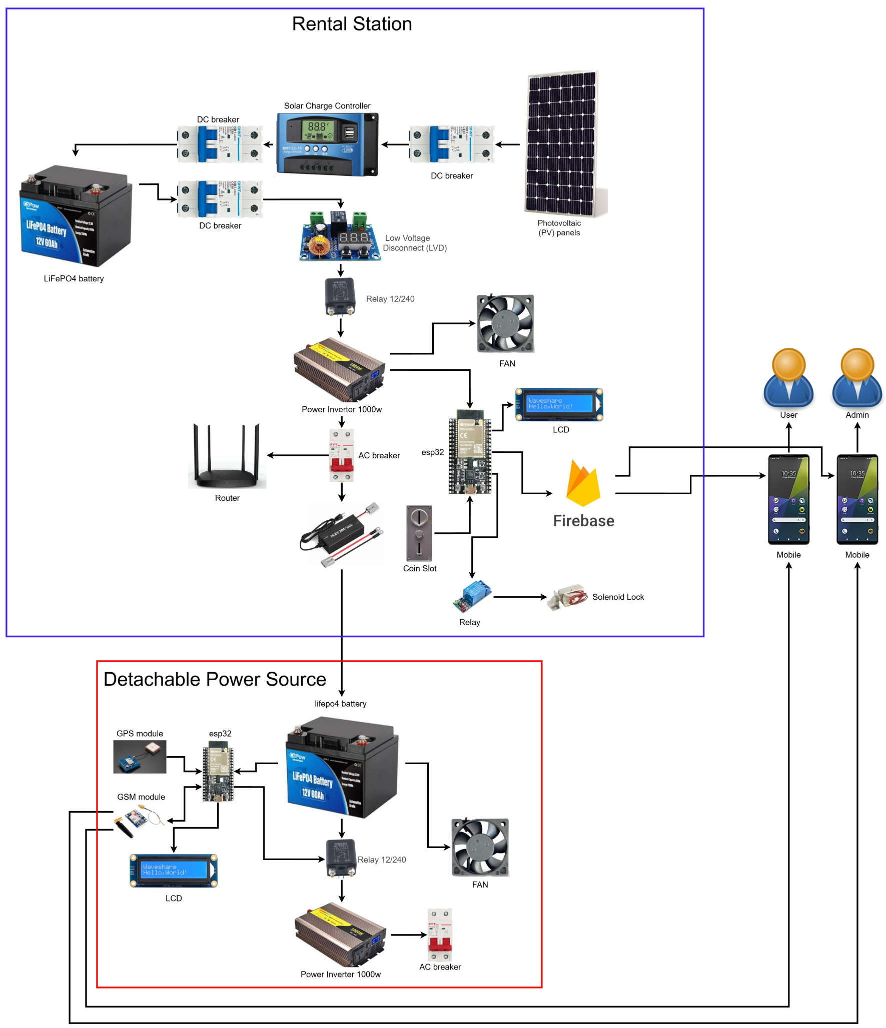
The second VDI calculation was conducted for the wire connection between the Solar Charge Controller (SCC) and the battery bank. Using the specified current, distance, system voltage, and allowable voltage drop percentage, the computed VDI value for this segment is 3.125. Similar to the previous result, this VDI value also aligns with the requirement for 10 AWG wire, ensuring safe current handling capacity and controlled voltage drop. The consistent selection of 10 AWG wire across both connection points maintains electrical balance and reliability throughout the charging circuit. Please refer to Appendix A for the detailed computation.

3.2 Technical Design Workflow

3.2.1 System Architecture

Figure 3.3

System Architecture



The Figure 3.3 illustrates the overall architecture of the solar powered rental station with a detachable power source. The system is designed to harvest solar energy, convert it to usable power, and provide access to users through various interfaces and technologies.

- *Solar Energy Collection and Storage* - PV panels capture solar energy, which is stored in a $LiFePO_4$ battery through a solar charge controller and DC breakers for protection.
- *Energy Conversion* - The stored DC power is converted to AC using a power inverter to supply household appliances.
- *User Interface and Control* - The ESP32 microcontroller connects with a mobile app via a router and Firebase, allowing users to monitor battery levels and manage rental requests.
- *Power Access and Management* - A coin slot and relay control access to the power source, while an LCD displays real-time system status.
- *GPS Tracking and Securit*y - A GPS and GSM module track the power source's location, ensuring security and preventing theft.
- *Admin Control* - Admins can monitor and manage the system through a mobile interface, overseeing usage and system health.

This system is designed to provide a sustainable, secure, and user-friendly power source solution for communities, utilizing solar energy and modern IoT technologies for enhanced management and accessibility.

3.2.2 Flowchart

Figure 3.4

System Flowchart

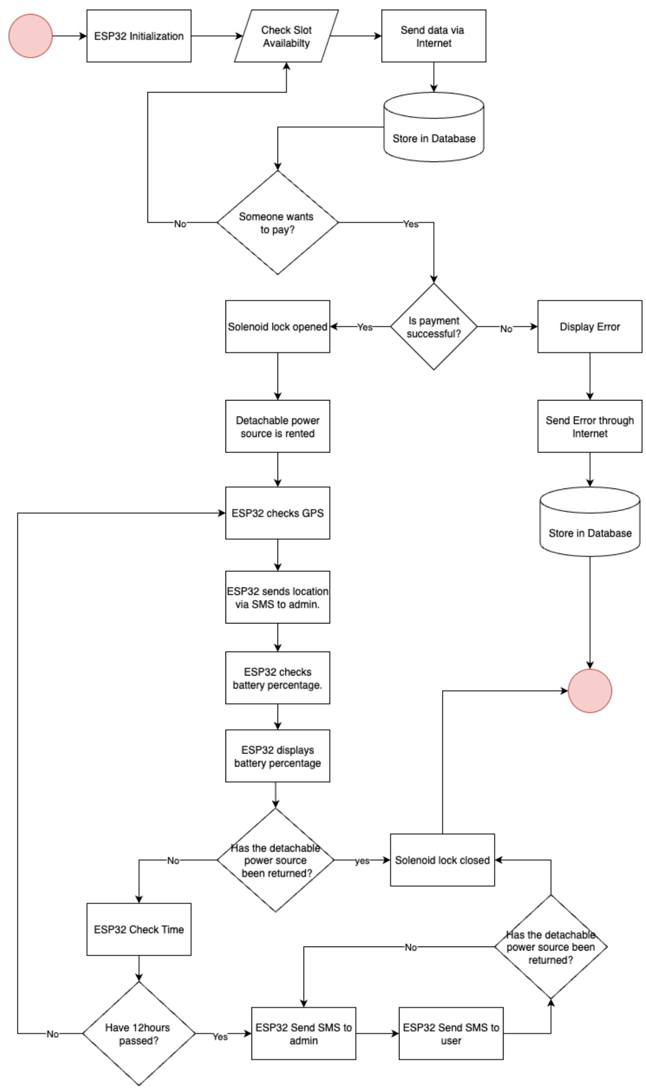


Figure 3.4 illustrates the overall process of the proposed Solar-Powered Rental Station with Detachable Power Sources. The process begins with the initialization of the ESP32, which activates system components and prepares communication protocols. The system first checks slot availability to determine if a detachable power source is ready for use. Data from this process is transmitted through the internet and stored in a central database for monitoring purposes.

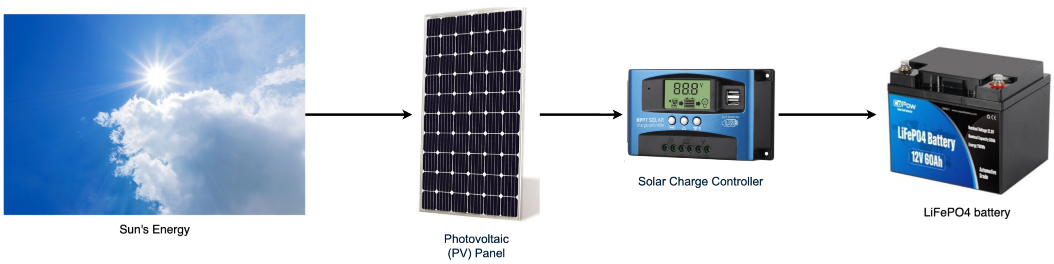
When a user intends to rent a power source, the system verifies if payment is successful. If confirmed, the solenoid lock opens, allowing the detachable power source to be accessed by the user. Once rented, the ESP32 continuously monitors the power source, including its GPS location and battery percentage, and sends the information to the administrator via SMS. This ensures proper tracking and security of the rented device.

The system also monitors whether the detachable power source is returned. If it remains unreturned after 12 hours, the ESP32 automatically sends reminder SMS notifications to both the user and the administrator. Upon return, the solenoid lock closes, securing the power source back in place. All key actions, including errors and system activities, are logged in the database for reference and analysis.

3.2.3 Solar Energy Harvesting

Figure 3.5

Conversion of Sunlight into Electrical Energy using PV Panels and a Charge Controller



The Figure 3.5 illustrates the process of harvesting solar energy using photovoltaic (PV) panels. Solar energy is captured by the PV panels, which then convert sunlight into electrical energy. The energy is stored in a $LiFePO_4$ battery through a solar charge controller, ensuring proper charging and voltage regulation. This energy is stored for later use, contributing to the overall sustainability and efficiency of the system, enabling it to power devices even during periods of limited sunlight.

3.2.4 Energy Conversion DC to AC

Figure 3.6

Battery DC power converted to AC output via Inverter.

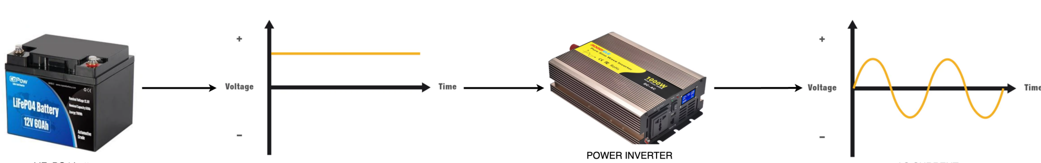
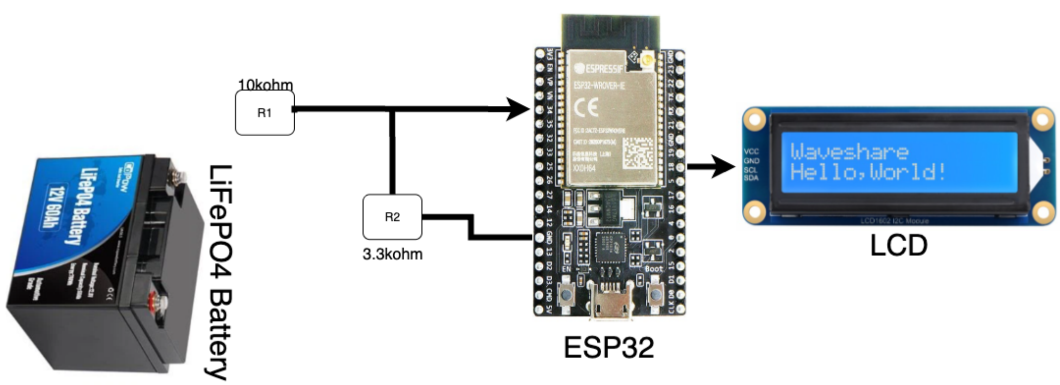


Figure 3.6 shows the process of converting direct current (DC) into alternating current (AC). The stored energy in the $LiFePO_4$ battery is passed through a power inverter, and the inverter transforms the DC from the battery into AC power, which can be used to power household appliances such as fans and other AC-powered devices. This conversion is essential for making the system compatible with common electrical appliances that require AC power for operation.

3.2.5 Power Monitoring

Figure 3.7

ESP32 measures battery voltage and displays data on LCD



The Figure 3.7 illustrates the power monitoring system used to keep track of the energy stored and consumed by the system. The $LiFePO_4$ battery is connected to an ESP32 microcontroller, which continuously monitors the battery's voltage and health, and the data collected is displayed on an LCD screen which allows users to view the battery's current status. This monitoring is vital for ensuring the system's efficiency and preventing over-discharge, ensuring long-term sustainability.

3.2.6 GPS Tracking

Figure 3.8

ESP32 receives location data from GPS satellites using GSM Module

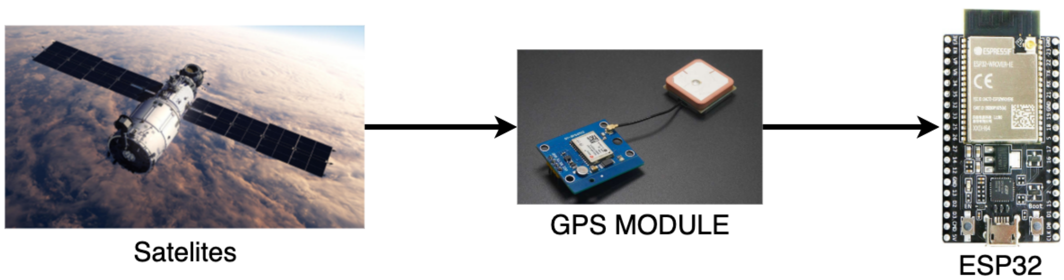
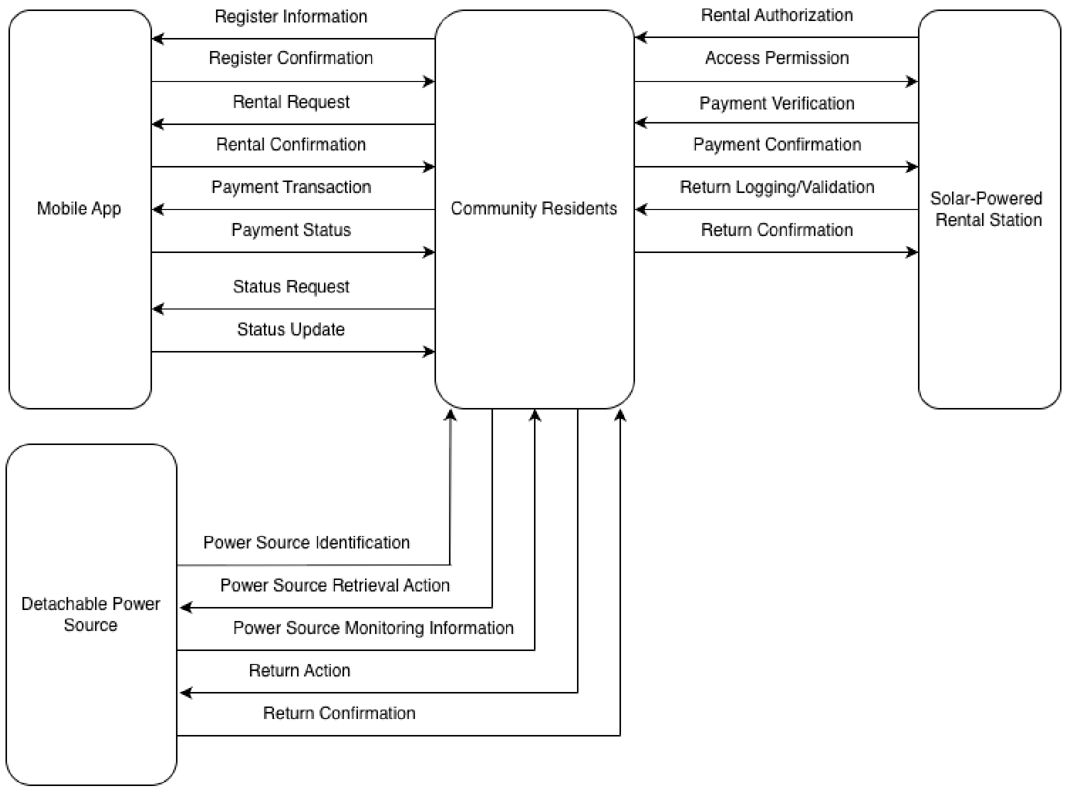


Figure 3.8 shows the GPS tracking system used to monitor the location of the detachable power source. A GPS module, connected to the ESP32 microcontroller, receives signals from satellites to determine the geographical location of the system. This location data is essential for tracking and managing the rental and use of the power sources, ensuring they are accessible to users and protected from theft or misuse. The GPS data is then sent to the system for further processing and user access.

3.2.7 Context Level Diagram

Figure 3.9

Context Level Diagram



This Figure 3.9 illustrates the complete interaction flow of the solar-powered rental system, showing how the Mobile App, Community Residents, Solar-Powered Rental Station, and the Detachable Power Source communicate with one another. The process begins with community residents using the mobile application to register their information, submit rental requests, process payments, and receive status updates. Once a rental request is made, the app sends the relevant information to the system, which then confirms the registration, validates the rental request, and updates the user about payment status and rental confirmation.

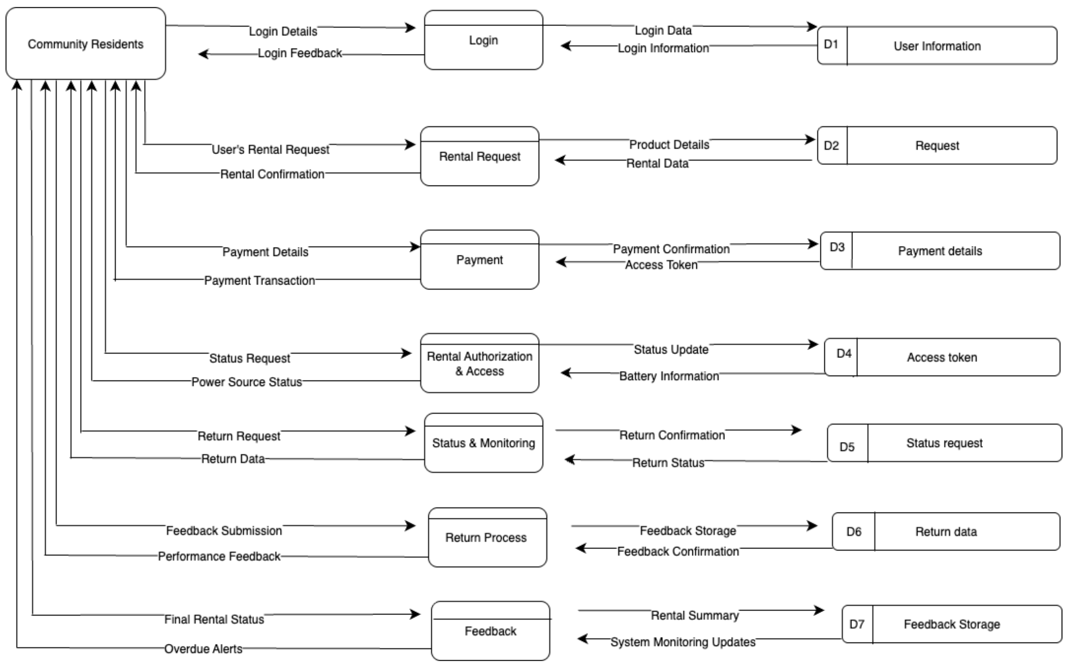
The interaction between the community residents and the solar-powered rental station focuses on physical access and transaction validation. The rental station authorizes the rental, verifies payment, and grants access permission for users to retrieve the detachable power source. Upon returning the device, the station logs and validates the return, ensuring that the power source is securely and correctly returned. The station then issues a return confirmation to the user, completing the rental cycle.

The detachable power source also communicates with the system to strengthen security and monitoring. It provides identification data, sends monitoring information such as location and usage status, and confirms both retrieval and return actions. These interactions ensure that the system can track each device, prevent unauthorized usage, and maintain accountability for each rental unit. Overall, the diagram presents a structured overview of how all components work together to support registration, rental, payment, monitoring, and return of the solar-powered power source in a seamless and secure manner.

3.2.8 Data Flow Diagram

Figure 3.10

Data Flow Representation of the Solar-Powered Rental Station System



The Figure 3.10 shows the complete process flow of the solar-powered rental station system, illustrating how community residents interact with the mobile application and system database. It begins with the login process, where residents input their login details, which are verified by the system. Once authenticated, the system provides feedback confirming successful login. After logging in, the user proceeds to make a rental request by selecting a power source and specifying the rental duration. The system responds with rental confirmation and product details. The user then moves to the payment process, where payment details are submitted through the app. The system validates the payment, sends a confirmation, and generates an access token that authorizes the user to unlock and use the detachable power source.

Once access is granted, the rental authorization and monitoring phase begins. The system continuously provides updates on the power source's status, such as battery level and remaining usage time, ensuring that the user can track energy consumption. When the rental period ends, the user then sends a return request, and the system verifies and confirms the return while updating the rental status. After returning the power source, the user proceeds to the feedback process, submitting performance feedback through the app. The system stores the feedback and confirms successful submission. After that, the system records the final rental summary and sends any overdue alerts if the power source is not returned on time. Overall, the diagram presents a clear and structured view of how the user's actions and system responses are linked throughout the entire rental transaction cycle, which is from login to feedback completion.

3.2.9 Use Case Diagram

Figure 3.11

Use Case Diagram

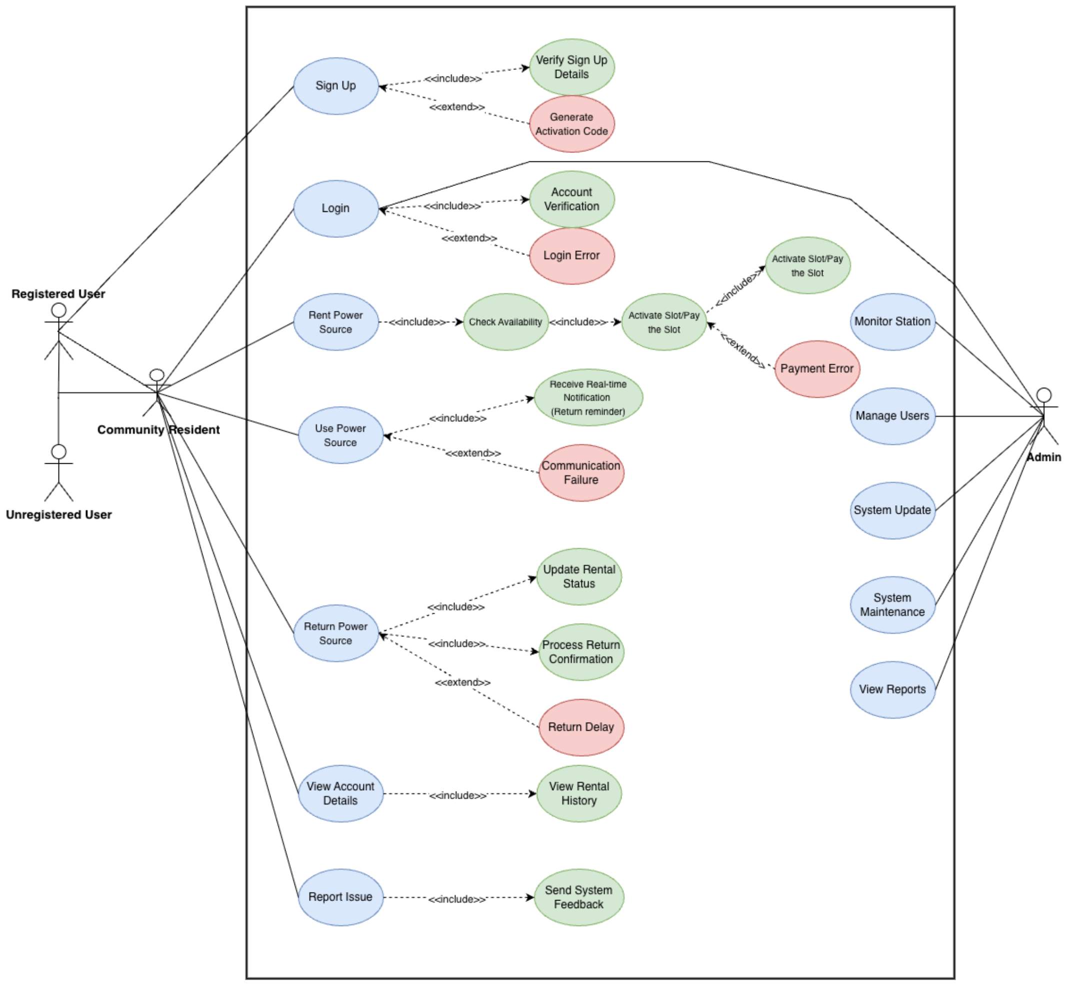


Figure 3.11 illustrates how different users and administrators interact with the system. It highlights the actions users can take and the roles of administrators. The Unregistered User is someone who has not yet signed up for the system. They can create an account by providing their details, which

are then verified by the system. If the details are correct, an activation code is generated for the user to complete the registration. After signing up, the user can log in to the system, but if there's an issue with the login, an error is displayed.

Once the Unregistered User becomes a Registered User after logging in successfully, they can perform more actions within the system. The user can rent a power source by checking its availability, paying for it, and activating the slot where the power source is stored. If there's a problem with communication during the rental process, the system handles this as an extended action. After using the power source, the user can return it, and the system confirms the return. If there's any delay in returning the power source, the system will manage this as well. Registered users also have the ability to view their account details and rental history, and they can report any issues or provide feedback through the system. The Admin plays a key role in overseeing the system. They can manage users, including adding or removing them from the system. The admin is also responsible for performing system updates and maintenance, ensuring the smooth operation of the system. Additionally, the admin can view various reports that provide insights into system performance and user activities.

The relationships in the diagram are shown through Include and Extend. Include means that one action is always linked to another. For example, signing up always includes verifying the user's details, and renting a power source includes checking availability and processing payment. Extend means that certain actions may trigger additional steps under specific conditions. For instance, if a payment fails, it will trigger the "Payment Error" action, or if the power source return is delayed, it will trigger the "Return Delay" action. In summary, this use case diagram provides an overview of how users and administrators interact with the system, covering key actions like renting and returning power sources, managing user accounts, and maintaining the system.

3.2.10 Activity Diagram

Figure 3.12

Activity Diagram of the Community Resident

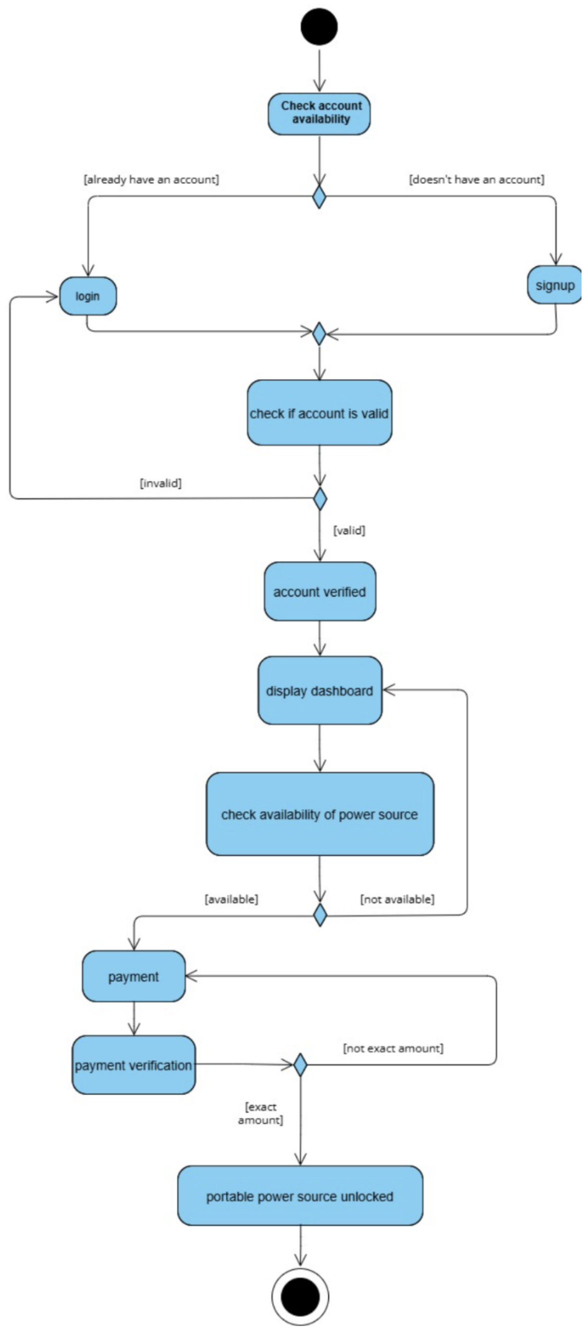


Figure 3.12 shows the step-by-step activity flow of the system from user login to unlocking the portable power source. The process begins with checking account availability. If the user already has an account, they proceed to the login step; otherwise, they must sign up first. After logging in, the system checks if the account is valid. If the account is invalid, the process returns to the login step. If valid, the system verifies the account and displays the dashboard. Next, the system checks if a power source slot is available. If no slot is available, the user remains on the dashboard until one becomes free. If a slot is available, the process continues to the payment step. The system then verifies the payment amount. If the amount entered is not exact, the process returns to the payment step. If the payment is correct, the portable power source is successfully unlocked, completing the process.

Overall, the diagram clearly shows how the user interacts with the system , which starts from account access, validation, and payment, up to unlocking the rented portable power source.

3.2.11 3D Design

The 3D representation shows the overall design of the detachable power source and the solar-powered rental station. It provides a clear visual of the system's shape and structure. The model illustrates how the different parts of the system are arranged in space, allowing a better understanding of the physical layout of the proposed system.

Figure 3.13

Front View of the Power Source – Three Dimensional Representation

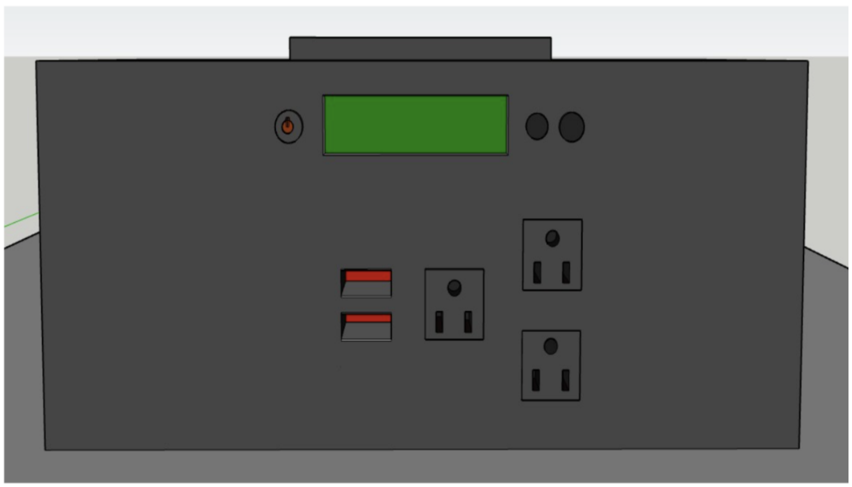


Figure 3.14

Aerial View of the Power Source – Three Dimensional Representation

Figure 3.15

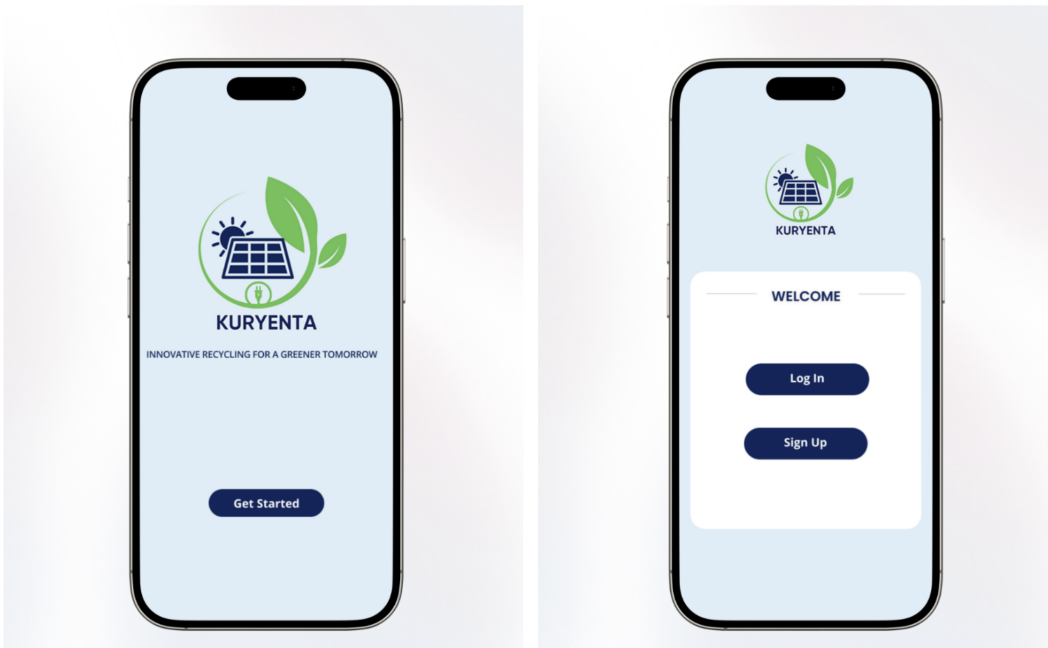
Three Dimensional Representation of the Rental Station of the Detachable Power Source

Figure 3.15 shows the 3D design of the system. It is a stationary power station powered by solar energy and contains three detachable power sources. The system has a single coin slot that controls access, and each detachable power source is secured with a solenoid lock.

3.2.12 Mobile App

Figure 3.16

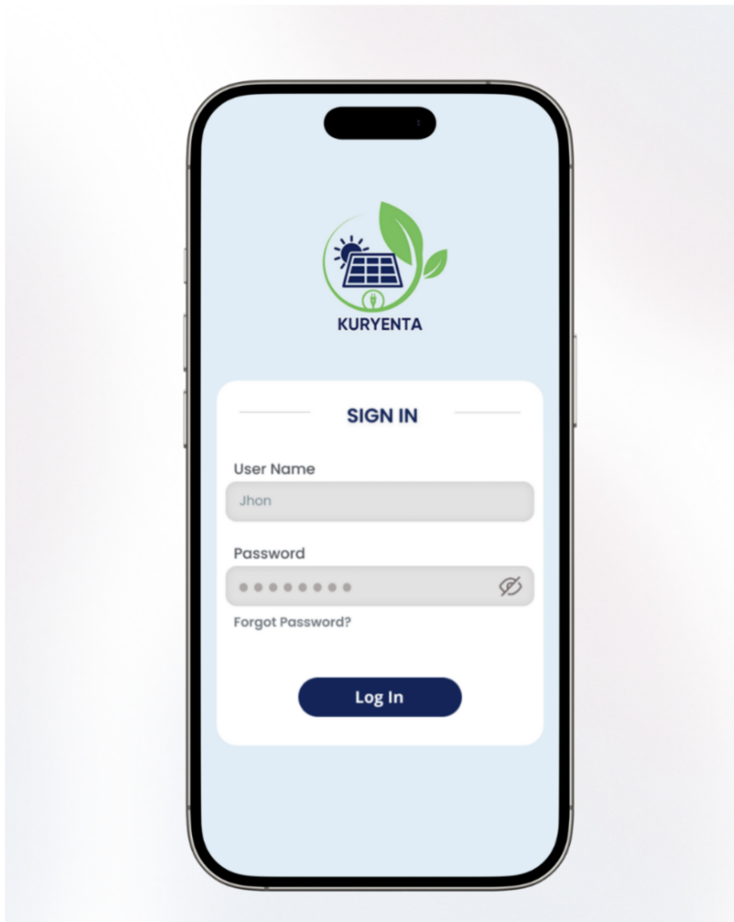
Welcome Page



The welcome interface presents the system logo and entry actions. The left panel shows a splash screen with a “Get Started” control; the right panel shows a gateway card offering Log In and Sign Up. This screen functions as the access point to the authentication flow.

Figure 3.17

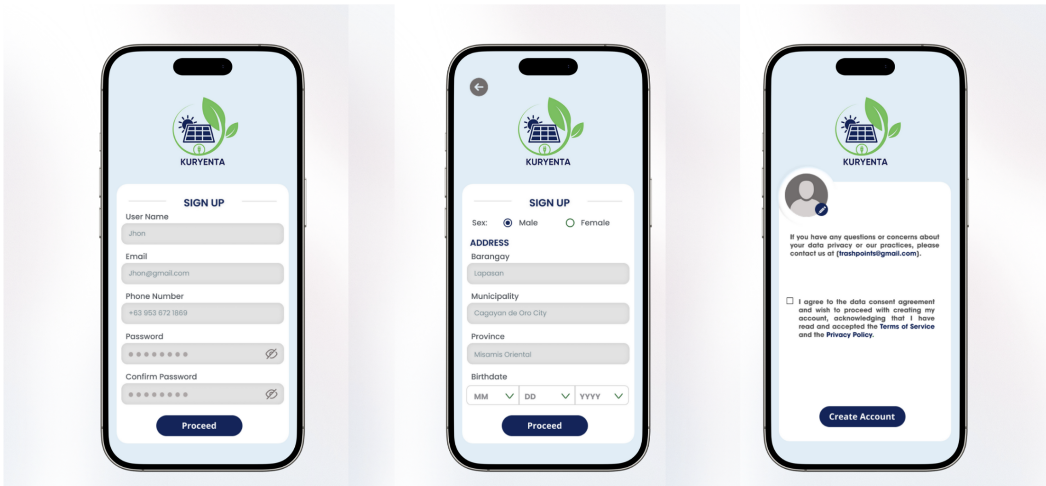
Sign n Screen



The sign-in interface collects the username and password with options to reveal the password and recover forgotten credentials. A primary Log In control initiates authentication for registered users. The design supports secure access to user functions.

Figure 3.18

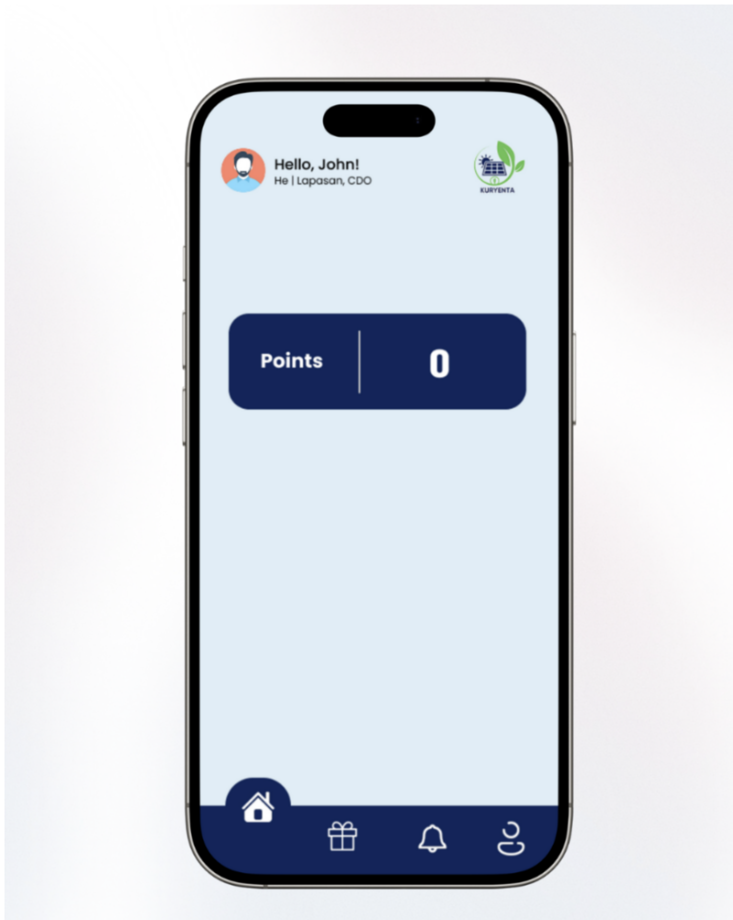
Sign Up Screen



Registration is implemented as a three-step process. Step 1 captures account credentials (username, email, phone number, password, and confirmation). Step 2 records profile and address data (sex, barangay, municipality, province, and birthdate). Step 3 presents a data-privacy notice and obtains consent to the Terms of Service and Privacy Policy before account creation.

Figure 3.19

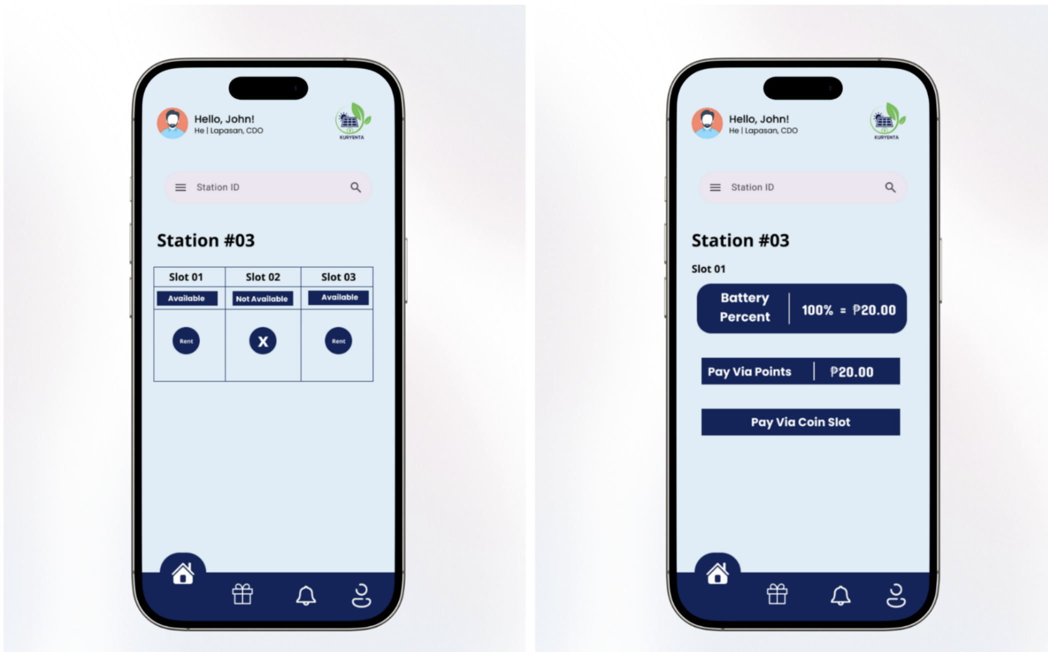
User Home Screen



The user dashboard displays a greeting header with location metadata and a card showing the current points balance. A bottom navigation bar provides access to core modules (home, rewards, notifications, and account/tools). This screen serves as the primary hub for user activities.

Figure 3.20

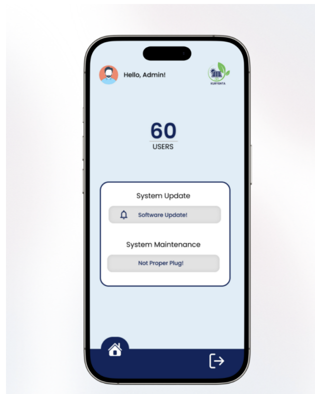
Renting Screen



The renting module allows search by Station ID and shows slot availability per station. Users select a slot and view its battery percentage with the corresponding price. Payment options include Pay via Points and Pay via Coin Slot, enabling transaction initiation.

Figure 3.21

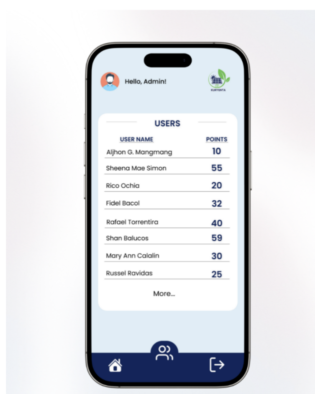
Admin Home Screen



The administrative dashboard reports the total number of users and provides status cards for system updates and system maintenance alerts. A bottom navigation enables movement to other administrative functions. This screen supports monitoring and operational control.

Figure 3.22

Admin Manage Users Screen



The user-management view lists registered users with their points balances. The list supports further exploration through a “More. . . ” action. This screen enables oversight of accounts for incentive tracking and administration.

3.2.13 Materials and Cost

Table 4: Hardware Components and Cost

Component	**Price**
Battery x 2	₱12,000.00
Solar Charge Controller	₱1,000.00
Solar Panel	₱2,500.00
Pure Sine Wave Inverter x 2	₱6,000.00
Lithium Battery Charger	₱500.00
Low Voltage Disconnect module	₱100.00
Coin Slot Facade	₱150.00
ESP32 x 2	₱400.00
DC breaker x 3 (Cable, Mounts)	₱100.00
Relay Module 12/ 240v x 2	₱240.00
Liquid Crystal Display (LCD) x 2	₱400.00
Relay	₱50.00
GPS module	₱200.00
GSM module	₱600.00
AC breaker	₱1,200.00
Solenoid lock	₱200
Router	₱1,500.00
Total	**₱27,140.00**

Table 2 shows the following materials that will be used in the study.

3.2.14 Standards and Guidelines Considered

The design and evaluation of the solar-powered rental station were guided by several internationally recognized standards to ensure safety, reliability, and environmental compliance.

- *ISO 9001 (Quality Management)* – Ensures proper documentation, and structured design of the system.
- *ISO 14001 (Environmental Management)* – Supports compliance with sustainable and eco-friendly practices.
- *ISO 9806 (Solar Energy Testing)* – Provides guidelines for evaluating the performance and durability of the solar charging component.
- *ISO 20653 (IP Ratings)* – Used to reference enclosure protection against dust and water for outdoor installation.
- *IEC 62133 (Battery Safety)* – Covers safety requirements for the LifePO4 battery used in the power source.
- *IEC 62368 (Electrical Equipment Safety)* – Provides safety guidelines for electronic components such as the inverter, charge controller, and communication modules.

APPENDICES

Appendix A

Step-by-Step Calculations

Detachable Power Source

The battery capacity for the detachable power source is calculated based on expected daily consumption and system voltage. The battery capacity is calculated as:

$$\begin{aligned}\text{Battery Capacity} &= \frac{\text{Total Daily Consumption}}{\text{System Voltage}} \\ &= \frac{500 \text{ Wh}}{12 \text{ V}} \\ &= 41.67 \text{ Ah} + 0.858 \text{ Ah} \\ \text{Battery Capacity} &\approx 43 \text{ Ah}\end{aligned}$$

Use: 50Ah $LiFePO_4$ Battery

Station

The station battery is sized to accommodate the detachable battery and additional reserve. Let BCDPS = Battery Capacity of Detachable Power Source.

The station battery is sized as:

$$\begin{aligned}\text{Battery Capacity} &= (\text{BCDPS} + 35\%) + 0.858\text{Ah}\\ &= 68.358\text{Ah}\\ \text{Battery Capacity} &\approx 70\text{Ah}\end{aligned}$$

Use: 70Ah $LiFePO_4$ Battery.

Panel Sizing

Solar panel power is calculated to meet the daily energy requirements within average peak sun hours.

$$\begin{aligned}\text{PV Power} &= \frac{\text{Total Daily Consumption}}{\text{Sun Peak Hours}}\\ &= \frac{500\text{Wh}}{3.5\text{h}}\\ &= 142.857\text{W}\\ \text{PV Power} &= 200\text{W}\end{aligned}$$

Use: 200W Solar Panel.

Inverter Sizing

The inverter is sized to handle the system load with a safety margin.

$$\text{Inverter Size} = 250W + 20\% \text{ allowance}$$

$$\text{Inverter Size} = 300W$$

Use: 300W pure sine wave inverter.

Solar Charge Controller Sizing

The charge controller current is selected based on PV array power and system voltage.

$$
\begin{aligned}
I_{cc} &= \frac{\text{Total PV Power}}{\text{System Voltage}} \\
&= \frac{200W}{12V} \\
&= 16.67A \\
I_{cc} &= 20A
\end{aligned}
$$

Use: 1 pc — MPPT 12V or 24V Auto Adapt 20A.

Breaker Sizing

Circuit breakers are sized to protect each part of the system.

a. Panel - SCC

$$
\begin{aligned}
\text{Circuit Breaker} &= 11.85A \times \text{Over Radiance Factor} \times \text{Safety Factor} \\
&= 18.5A \\
\text{Circuit Breaker} &= 20A
\end{aligned}
$$

b. SCC - Battery

$$\text{Circuit Breaker} = \frac{\text{Total Array Wattage}}{\text{Battery Bank Nominal Voltage}} \times \text{Safety Factor}$$
$$= \frac{200W}{12V} \times 1.25$$
$$\text{Circuit Breaker} = 20.8A$$

c. Battery - Power Inverter

$$\text{Circuit Breaker} = \frac{\text{Power Inverter}}{\text{Power Bank Nominal Voltage}}$$
$$= \frac{1000W}{12V}$$
$$= 83.33A$$
$$\text{Circuit Breaker} = 80A$$

d. Inverter - Load (AC Breaker)

BBNV = Battery Bank Nominal Voltage

$$\text{Circuit Breaker} = \frac{\text{Safety Load}}{\text{Inverter Voltage Output}} \times \text{BBNV}$$
$$= \frac{700W}{220V} \times 1.25V$$
$$\text{Circuit Breaker} = 3.98A$$

Wire Sizing

Wire sizes are determined to handle current and limit voltage drop.

a. Panel - SCC

$$\text{VDI} = \frac{10.85 \times 12}{18.5 \times 2}$$
$$= 3.53$$
$$\text{Wire Size} = 10AWG$$

b. SCC - Battery

$$\text{VDI} = \frac{20 \times 4}{12.8 \times 2}$$
$$= 3.125$$
$$\text{Wire Size} = 10AWG$$