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
October 2025

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Electricity is essential to everyday living, powering different activities and circumstances, especially in households, from lights and appliances to connectivity. Electricity powers nearly every aspect of home living, being the most used energy source and notable expense among Filipino households, with a 94.8% usage rate based on the Philippines Statistics Authority (2023). During frequent power interruptions, Filipino households face severe impacts from frequent power interruptions including comfort issues and disruption of work and livelihoods. Many households rely on diesel generators as a temporary measure, but these are costly to run and contribute to noise and air pollution, indicating the need for other alternative measures for power sources.

According to Villamil et. al (2020), "The internet of things is an emerging technology that is currently present in most processes and devices, allowing to improve the quality of life of people." As IoT continues to revolutionize daily living, solar energy, powered by innovations such as photovoltaic (PV) panels, plays a crucial role in shaping the future of global energy. Photovoltaic solar energy is rapidly becoming a key player in the global energy transition. This surge in demand and innovation paves the way for a more sustainable future, making solar energy a central focus in the race for renewable solutions. As highlighted by Sampaio and González (2017), "The capture of solar energy through photovoltaic (PV) panels to generate electricity has emerged as one of the most promising markets in renewable energy." In response to this, many systems utilize off-grid renewable energy; systems such as solar power systems are designed to provide electricity. This aligns with the study of Ramly, Jamal, Abd Ghafar, and Babu (2019), who highlighted that the "Emergency Portable Solar Power Supply is a product that uses a renewable energy source (sunlight) as the main source of electricity."

Today's solar power systems offer many benefits. The technologies mentioned above can contribute to addressing key issues in the Philippines. They aim to reduce the impact of frequent power interruptions and emergencies, while promoting scalable renewable energy innovations for affected communities. Additionally, it contributes to sustainable energy systems by addressing the unique reliability challenges of off-grid and disaster-prone areas in the region.

According to an article by Albay (2025), In the Philippines, the average Filipino household experiences 28 electricity supply interruptions in a year, due to frequent outages caused by plant breakdowns based on a report. The sudden or frequent power interruptions force households and businesses alike to rely on costly diesel generators as a backup power source. In August 2025, the National Grid Corporation of the Philippines (NGCP) reported an unscheduled power interruption affecting Camiguin and Misamis Oriental, which are home to 92,808 and 956,900 households based on the Philippine Statistics Authority (2020). The outage left thousands of households and businesses without power, mostly relying on diesel generators and various power sources. Addressing this gap in reliable energy access is crucial to providing communities with an affordable, sustainable power alternative and reducing the impacts of sudden interruptions.

Recent efforts to adapt solar-powered power supply systems show potential but face limitations. For instance, Gozano et al. (2023) designed a solar-based portable power supply with a modular battery pack. However, the portable power supply was shown capable of only supplying a lower energy load, such as charging mobile phones, mobile lighting and small auxiliary loads such as a small AM/FM radio. There were also shortcomings, such as the short lifespan of AC power whenever the battery pack reaches a certain voltage drop.

Innovations in solar-powered power supply systems offer a promising solution to these challenges. Bhatti et al. (2024) developed a portable solar station with integrated battery management and load monitoring system, having a power output of 200 W, and a 2x2 array of 50 W solar panels to provide electricity for basic necessities, in times of power interruptions due to natural disasters. Similarly, the study by Ramly et al (2019) designed a portable solar power supply for emergency situations, supplying electricity up to 100W at one time, and utilizing Arduino Uno with Bluetooth module and voltage sensor to get the voltage readings integrated into a mobile application. The said system lasted for two days without the need for charging. Despite these innovations, current solar-powered power supply systems still face limitations, such as low energy capacity, short battery lifespan, and restricted support for higher power loads.

To bridge these gaps, this study proposes a solar-powered rental station for detachable power sources with a 2x2 solar panel array for energy harvesting, a LiFePO4 battery for reliable storage, and an inverter for AC power conversion. The system integrates an ESP32 microcontroller, integrating IoT mechanisms to manage operations, with GPS for location tracking and GSM for communication. A coin-slot mechanism with a solenoid lock ensures secure access, while a mobile app provides real-time monitoring of battery charge levels and system status. The compact and user-friendly design offers a sustainable solution for communities affected by frequent power interruptions.

1.2 Statement of the Problem

Air pollution is among the Philippines' most critical environmental issues, primarily caused by the use of fossil fuels. The Philippines' reliance on fossil fuels for electricity generation, particularly coal, contributes to elevated levels of air pollution. In 2025, coal accounted for approximately 52.7% of the country's electricity generation, while natural gas contributed 20.1%. This dependence on fossil fuels leads to the emission of pollutants that adversely affect air quality and public health. (LowCarbonPower, 2025).

Electricity is a necessity for modern life. In Camiguin (served by CAMELCO) and certain parts of Misamis Oriental (served by MORESCO 2), the local community frequently experiences unscheduled power interruptions, occurring multiple times a week. This issue is consistent with research indicating that power interruptions are common in developing countries (Ibañez, 2024; Taniguchi, 2019), such as the Philippines, particularly in rural areas (Ibañez, 2024; Ali, 2016). These interruptions not only hinder productivity but also affect daily comfort in many households, making them very inconvenient and a source of frustration.

Despite the availability of off-grid setups, power banks, and small gasoline generators, these options are often limited by cost, power capacity, or environmental sustainability. Furthermore, the reliance on fossil-fueled alternatives poses safety risks and contributes to pollution. In response, the government encourages a shift away from fossil fuel energy sources (Koons, 2024) and promotes the use of renewables, as outlined in the policy framework provided for in Republic Act (RA) No. 9513 or the "Renewable Energy Act of 2008". Hence, there is a growing need for technological systems, such as solar-powered systems, to align with sustainability mandates. Studies show that the transition to greater use of renewables has wide-ranging implications (Villanueva, 2021), underscoring the importance of integrating supportive technologies into local environmental strategies.

Solar-powered systems have been introduced either as portable power supplies or as charging stations, yet existing systems face multiple limitations. Many of these are only capable of supplying low-energy loads, such as charging mobile phones, providing mobile lighting, or powering small auxiliary devices like AM/FM radios (Gozana et al., 2023). Additionally, the average cost of an off-grid setup is high (Boodoo, 2024), making it unaffordable for many households. Research also shows that solar-powered systems are commonly installed within the premises of the college campus (Catalan et al., 2019), but have not been widely initiated for communal purposes (Catalan et al., 2023).

Furthermore, a notable gap exists in security, as many systems lack sufficient measures to prevent delinquent users from tampering with or vandalizing the system. These gaps, along with the promotion of solar-powered coin-operated charging stations in remote and island barangays, are highlighted by Catalan et al. (2023), as these areas often face significant challenges in power accessibility.

Given these limitations, there is a clear need for an innovative solar-powered rental system that is both affordable and scalable, while providing reliable energy access for households and public areas affected by frequent and unscheduled power interruptions. This study aims to design and develop a solar-powered rental station with detachable power sources, offering a sustainable and user-friendly alternative to conventional backup solutions, while also addressing the need for improved security features.

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 portable power 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 portable power station 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 portable 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 solar-powered portable power source. This system ensures the community residents can use essential household appliances and stay connected during power interruptions, improving their daily lives and overall comfort.

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 real-time 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.

- 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.

- 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

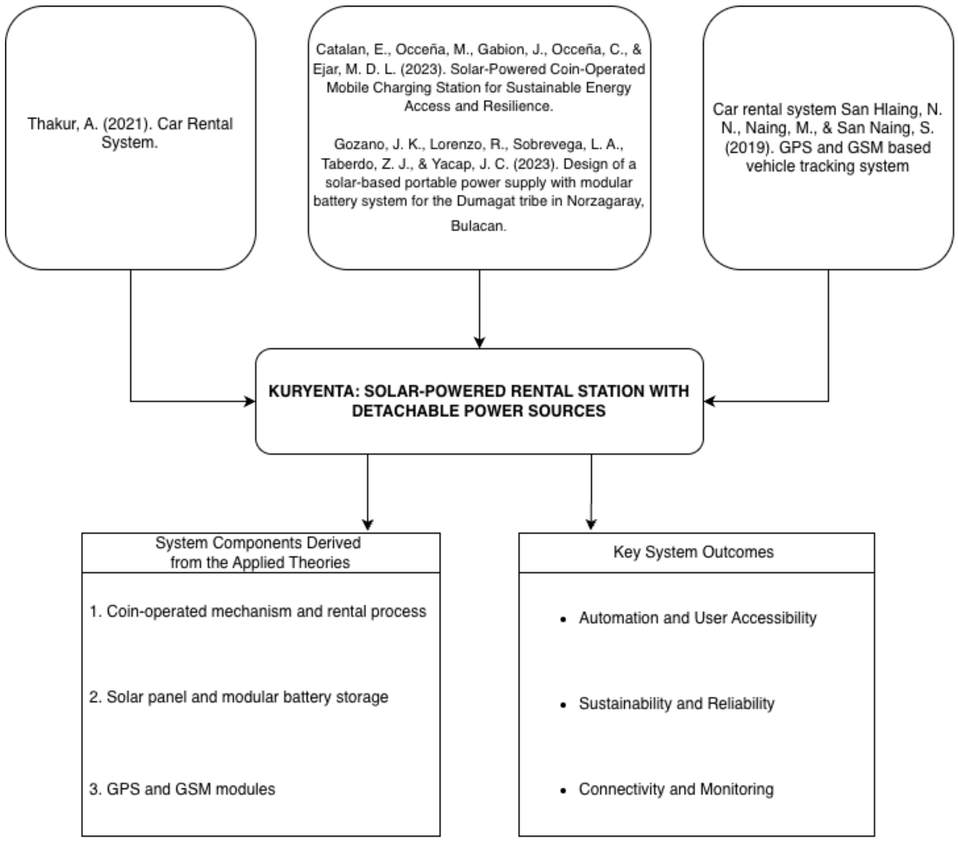


Figure 2.1 illustrates the Theoretical Framework of the study, showing how the Rental System Theory (Thakur, 2021), Sustainable Energy and Portable Power Theory (Catalan et al., 2023; Gazano et al., 2023), and Wireless Communication and Positioning Theory (San Haing et al., 2019) collectively form the 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

a. Variables

- **Independent Variables (IV)**

  Coin, Application, GPS Module, GSM Module, Power (Detachable), Stored Credit (Application)

- **Dependent Variables (DV)**

  Power (Detachable), User Information, User Verification, Location, Notification, Stored Credit (Application)

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.

- **Application** – The mobile interface that allows users to create accounts, manage stored credits, and process payments through app-based transactions.

- **GPS Module** – A component responsible for gathering the real-time location of the detachable power source.
- **GSM Module** – Facilitates wireless communication between the portable power station, the administrator and user by transmitting system data such as location, status updates, and notifications.
- **Power (Detachable)** – Refers to the removable power supply module that delivers electrical energy. It enables portable and flexible energy management, allowing the system to monitor power consumption during rental operations. Any remaining or unused power from the detachable unit is recorded by the system and converted into stored credit within the application, promoting efficient utilization of energy resources.
- **Stored Credit (Application)** – The virtual balance maintained within the mobile application, representing prepaid user credits used to initiate or extend power rentals.

Dependent Variables

- **Power (Detachable)** – The energy made available after the insertion of a coin or use of stored credits.

- **User Information** – Data collected from the application used to identify and manage user accounts.
- **User Verification** – The process of authenticating users before allowing access to the system.
- **Location** –The real-time position of the detachable power source, determined by the GPS and GSM modules.
- **Notification** – System-generated alerts sent via GSM to inform users or administrators of system activities.
- **Stored Credit (Application)** – The system's record of remaining power or credit balance available for rental use.

c. Relationship of Variables

The independent variables directly influence the dependent variables.

- **Coin → Power (Detachable)**

  The insertion of a coin activates the rental mechanism, enabling the user to access and utilize the detachable power source.

- **Application → User Information / User Verification**

  The application serves as the primary medium for collecting user data and verifying credentials to ensure legitimate access and secure transactions.

- **GPS Module → Location**

  The GPS module provides continuous monitoring of the detachable power unit's position, allowing administrators to track and ensure its proper use.

- **GSM Module → Notification / Location**

  The GSM module transmits the collected location data and system alerts, ensuring reliable communication between the power station, the user, and the administrator.

- **Power (Detachable) → Stored Credit (Application)**

  The detachable power supply unit provides electrical energy during system operation. The system monitors power consumption throughout the rental period, and any remaining or unutilized power from the detachable source is automatically converted into stored credit within the application. This process ensures efficient power utilization while linking the physical energy supply to the user's virtual credit balance.

- **Stored Credit (Application) → Power (Detachable)**

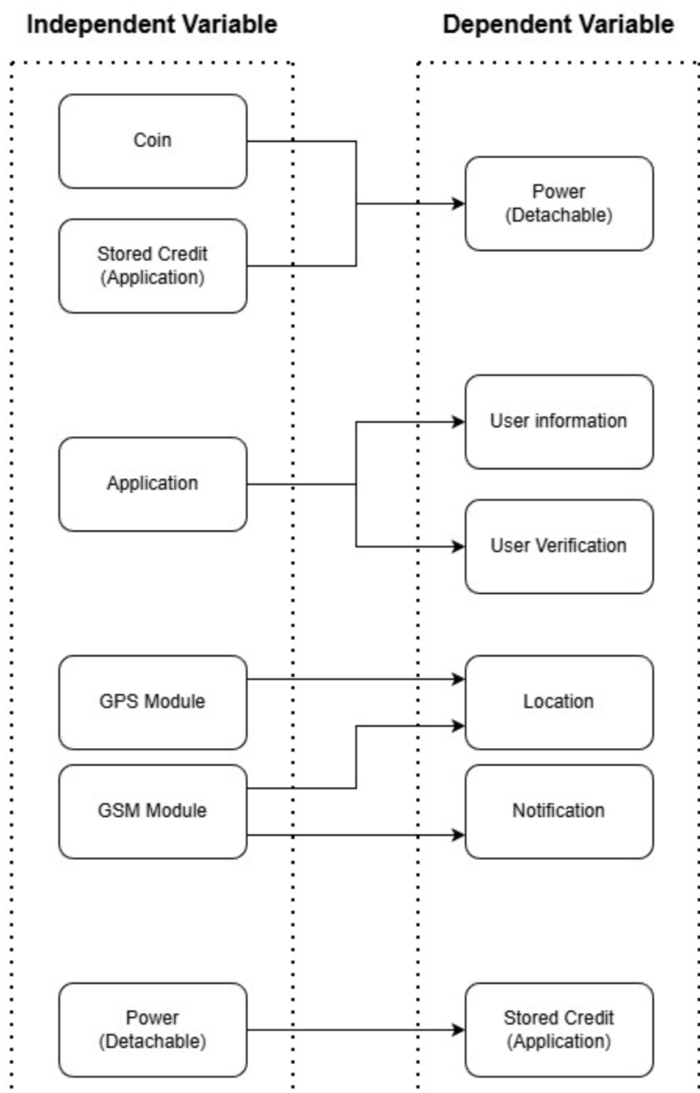
  The user's available stored credit within the application determines eligibility for rental access, thereby authorizing or restricting power usage based on remaining balance.

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

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 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

2.3.4 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.

2.3.5 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 Abdur et al. (2024) 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. Abdur et al. (2024) 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.

2.3.6 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.

2.3.7 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.

2.3.8 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.

2.3.9 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.

2.3.10 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.

2.3.11 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.

2.3.12 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.

2.3.13 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 farmers and fisherfolk 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.

2.3.14 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, Occeña, Gabion, Occeña, and Ejar (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.

2.3.15 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 LiFePO4 (Lithium Iron Phosphate) batteries which is a better alternative. According to EDSA (2024) and Zakri et al. (2021), LiFePO4 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 LiFePO4 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 real-time 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 real-time 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 2x2 solar panel array, LiFePO4 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 LiFePO4 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

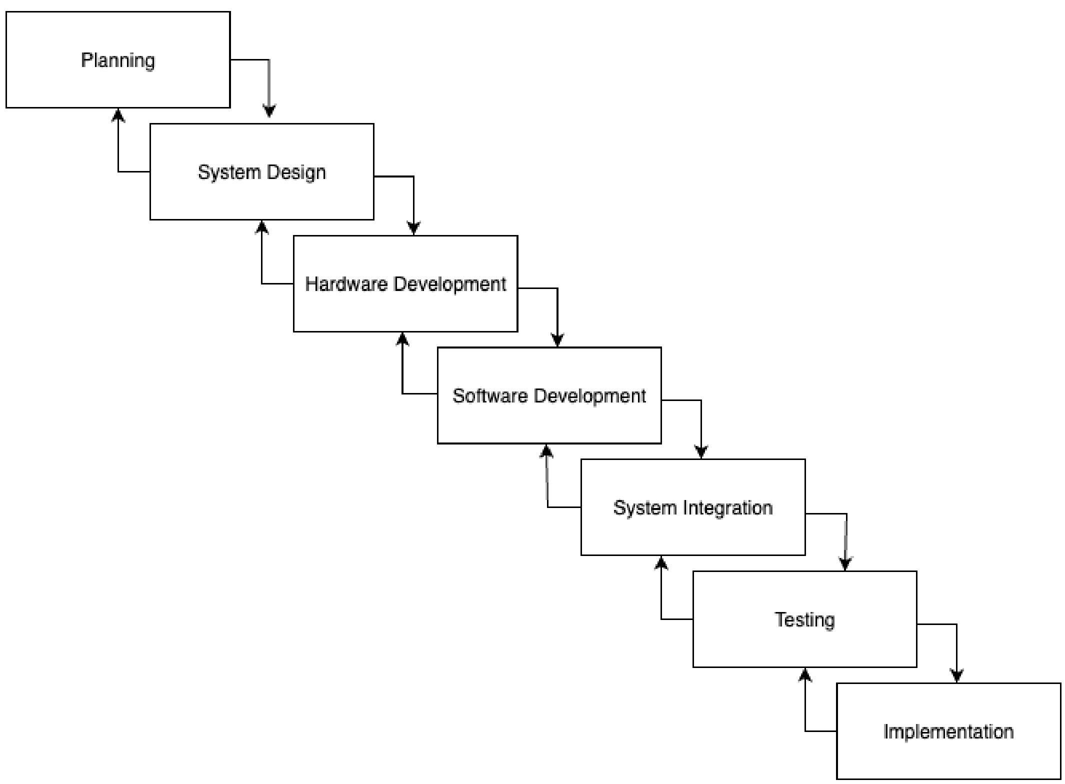
METHODOLOGY

In this chapter, the researchers detail the methodology employed to conduct the study, providing a comprehensive overview of the research design, data collection, and analytical procedures.

3.1 Research Design and Procedure

Figure 3.1

The Waterfall Model

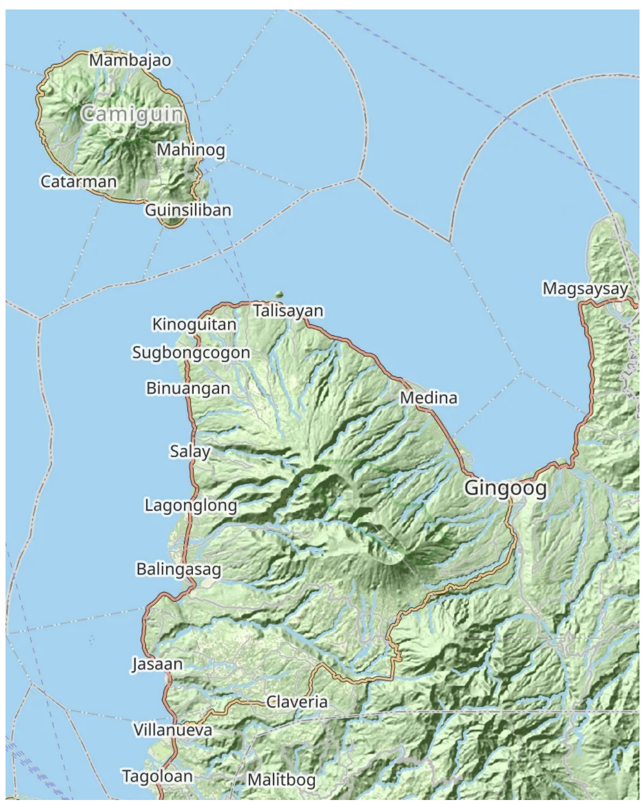


In Figure 3.1, the system creation process is illustrated, utilizing a modified waterfall model. This systematic approach consists of several key stages, commencing with requirements gathering and followed by requirements analysis, hardware development, software development, system design, integration, 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 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 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.
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.

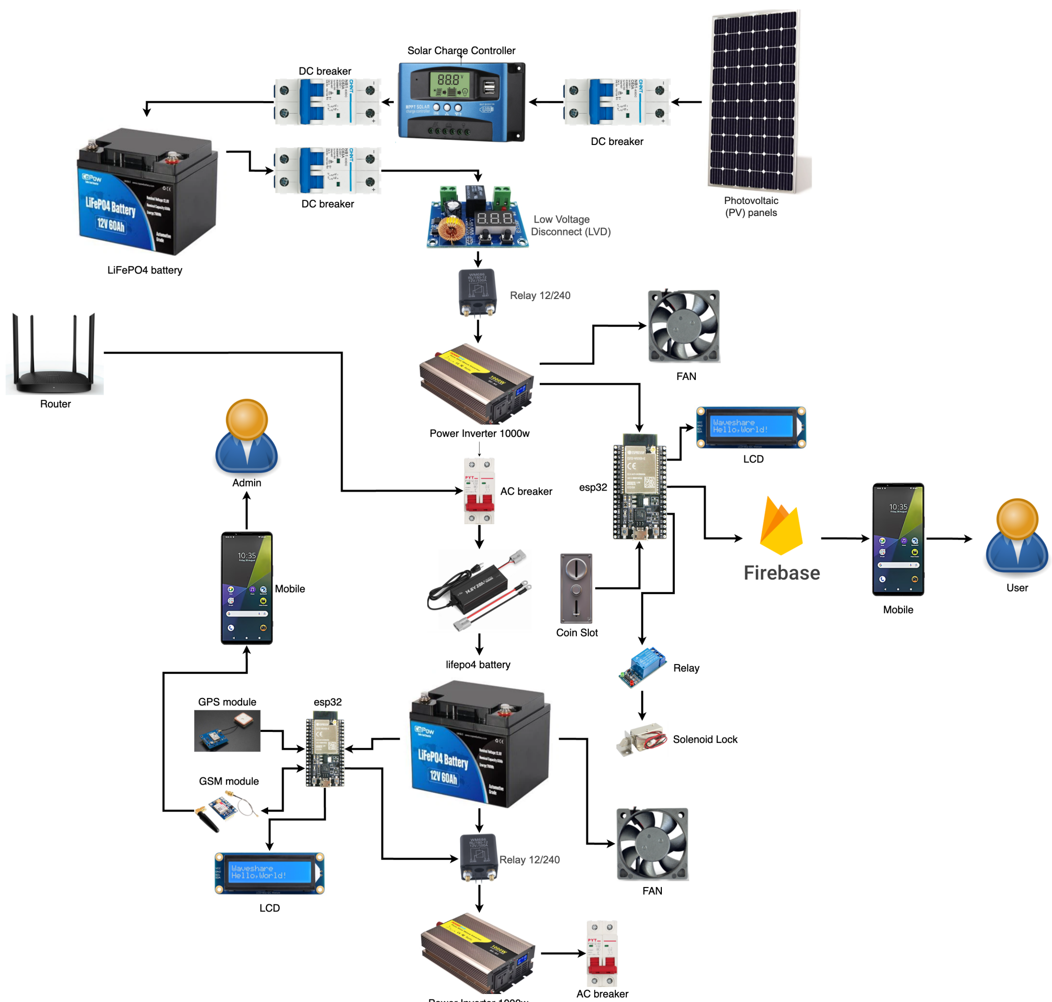
Category	System Requirement
	- The system shall continuously monitor and record the battery level, location, and usage duration of active rentals. - The system shall process the return of rented power sources by validating device ID, updating the database, and releasing the final transaction summary.
Output Requirements	- The system shall display rental confirmation details such as power source ID, rental duration, and current charge level. - The system shall provide real-time status updates on the mobile app, including remaining battery percentage, and device location. - The system shall generate notifications for payment confirmation, overdue alerts, and successful returns.
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 real-time 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.

3.2 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 Security - 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

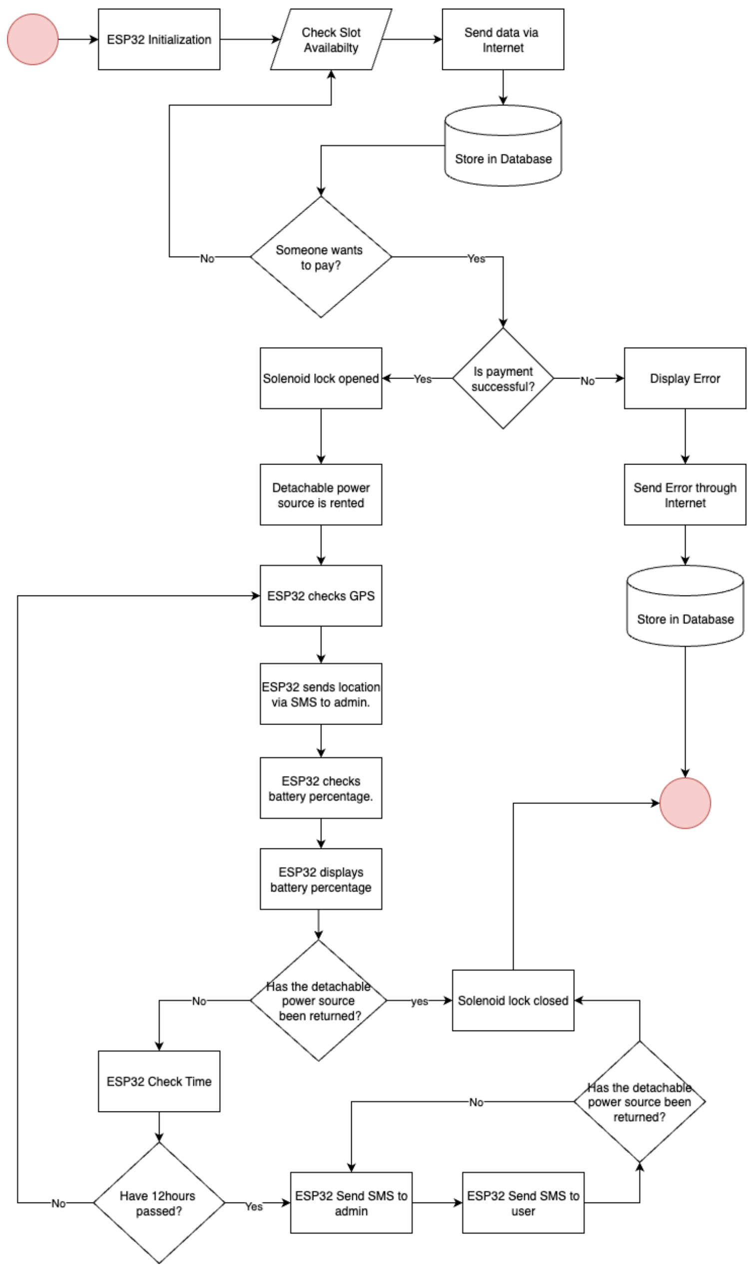


Figure 3.4 illustrates the overall process of the proposed Solar-Powered Rental Station with Detachable Power Sources. The process begins with the initialization of the ESP32, which activates system components and prepares communication protocols. The system first checks slot availability to determine 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.

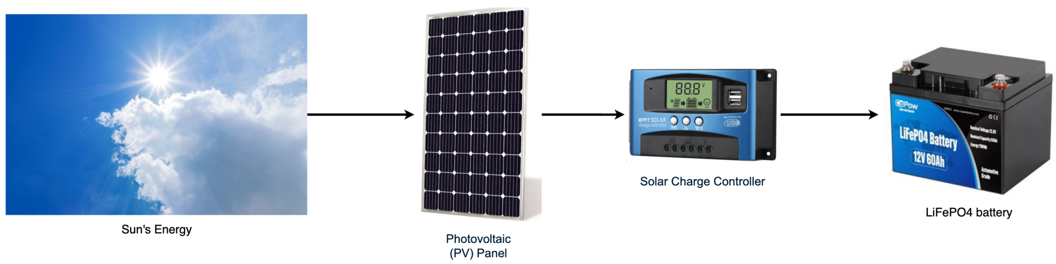
When a user intends to rent a power source, the system verifies if payment is successful. If confirmed, the solenoid lock opens, allowing the detachable power source to be accessed by the user. Once rented, the ESP32 continuously monitors the power source, including its GPS location and battery percentage, 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.

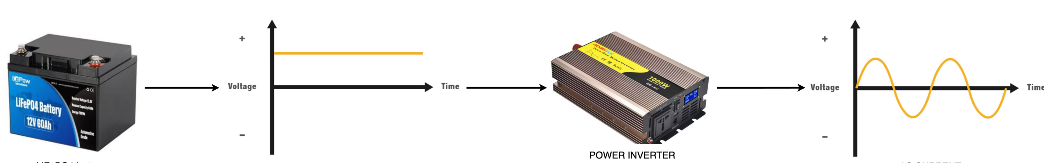
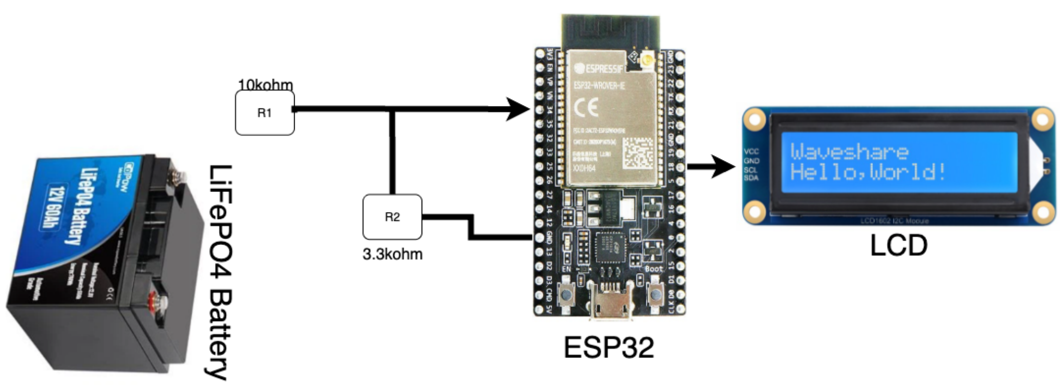


Figure 3.6 shows the process of converting direct current (DC) into alternating current (AC). The stored energy in the $LiFePO_4$ battery is passed through a power inverter, and the inverter transforms the DC from the battery into AC power, which can be used to power household appliances such as fans 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 in real time. 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 real-time location data from GPS satellites using GSM Module

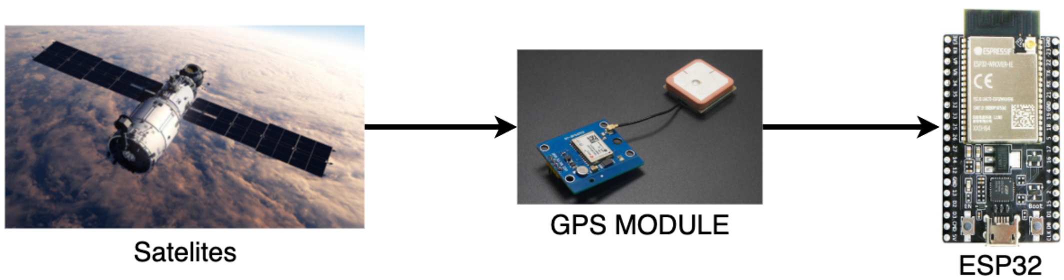
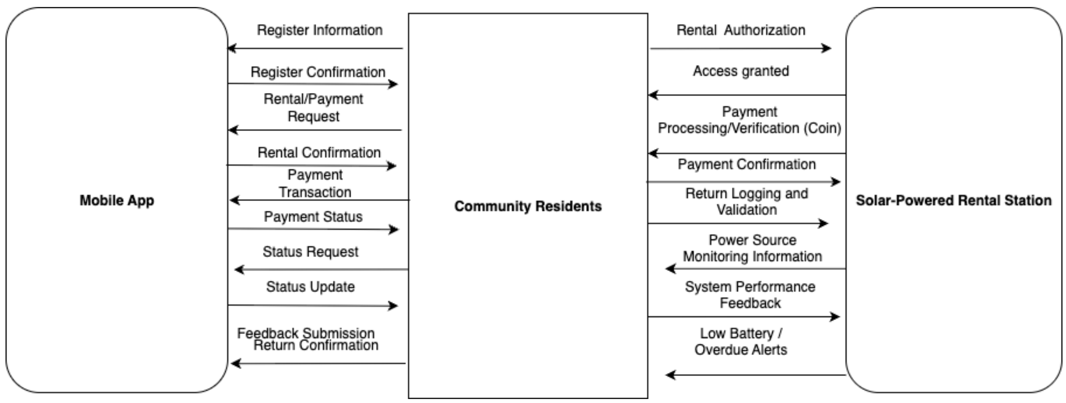


Figure 3.8 shows the GPS tracking system used to monitor the location of the detachable power source. A GPS module, connected to the ESP32 microcontroller, receives signals from satellites to determine the geographical location of the system. This real-time location data is essential for tracking and 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



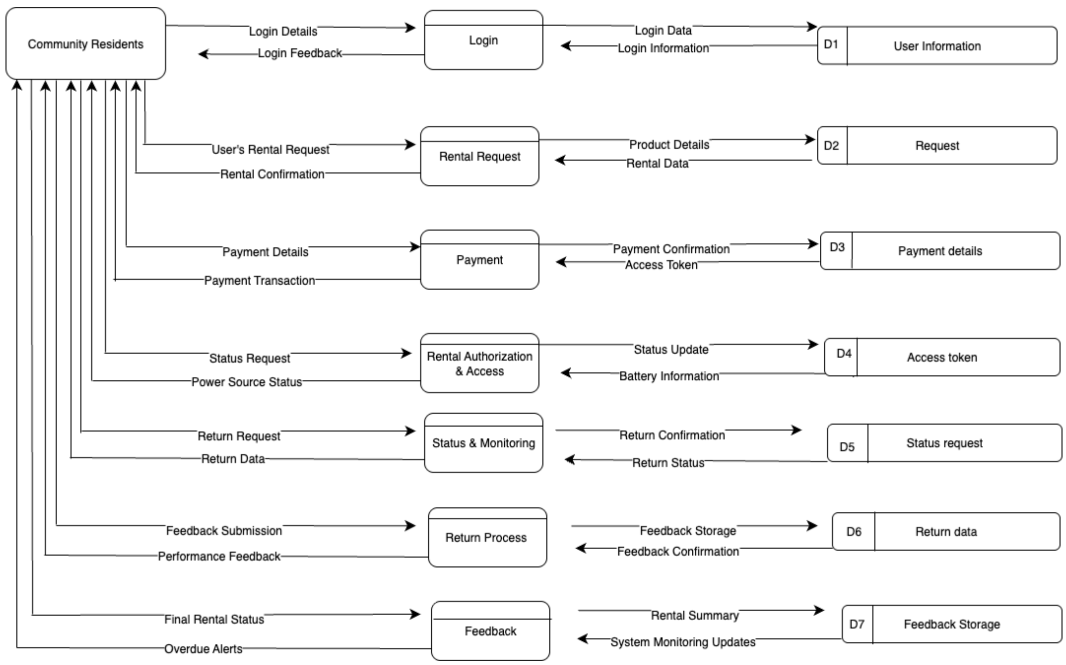
This Figure 3.9 illustrates the Context Level Diagram of the system. The Mobile App serves as the primary interface through which Community Residents interact with the Solar-Powered Rental Station. The Community Resident starts by providing their registration information via the Mobile App, which sends this data to the system. Once registered, the system sends back a registration confirmation and the Mobile App allows users to proceed with rental/payment requests. The Mobile App then facilitates payment transactions where the Community Resident can complete the payment either through a coin-based mechanism or an app-based method. Once the payment transaction is successfully completed, the Mobile App receives a payment confirmation from the System, ensuring the rental is validated. The Community Resident can then use the Mobile App to check the system status, such as battery levels, power source availability, or the remaining rental time. After use, the Community Resident sends a return request via the Mobile App, which then communicates with the System to confirm the power source return. The System logs the return and ensures the process is validated, signaling the completion of the rental session. Additionally, the Mobile App allows the Community Resident to submit feedback on their experience with the service.

On the other side, the System (the Solar-Powered Rental Station) manages the backend of the rental process. It verifies rental requests from Community Residents and authorizes them to rent a power source. It also handles payment processing, ensuring that the payment is verified before the rental is completed. Once payment is confirmed, the System updates the Mobile App with the confirmation. The System also monitors the rented power source, providing live monitoring information, such as the power source's battery level and available runtime. If the Community Resident fails to return the power source on time or if the power source is running low on battery, the System sends low battery or overdue alerts to both the Mobile App and the Community Resident, prompting them to take action.

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

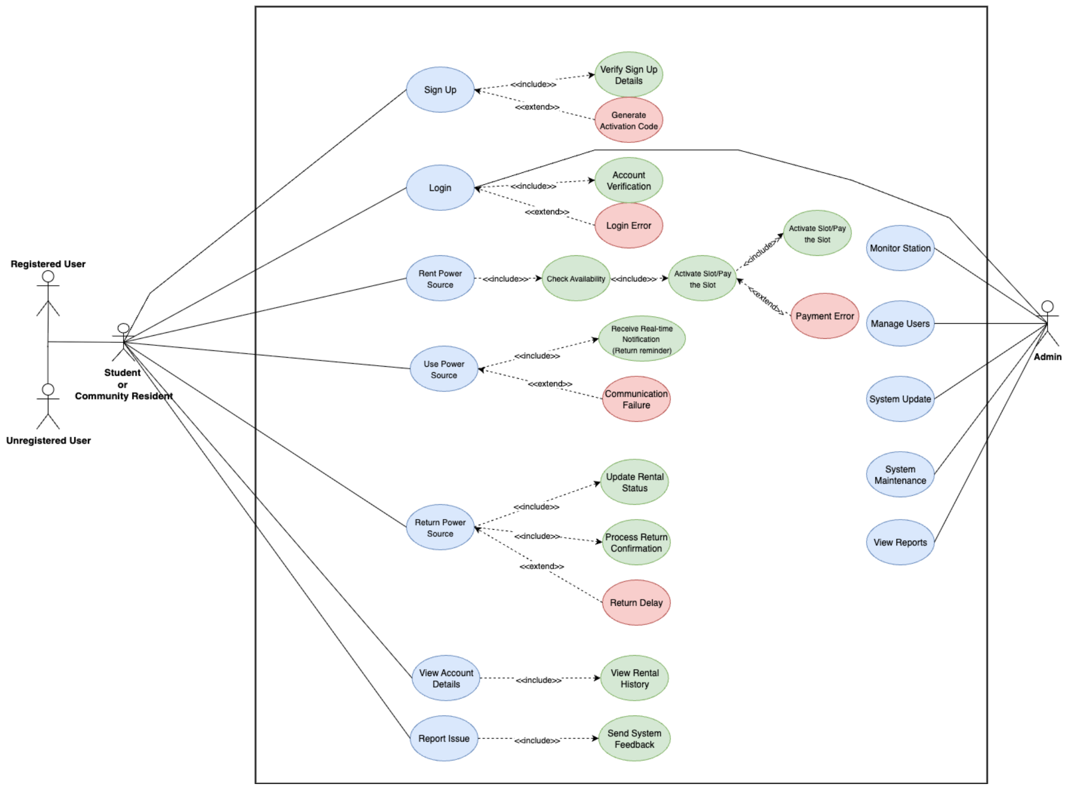


Figure 3.11 illustrates how different users and administrators interact with the system. It highlights the actions users can take and the roles of administrators. The Unregistered User is someone who has not yet signed up for the system. They can create an account by providing their details, which are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

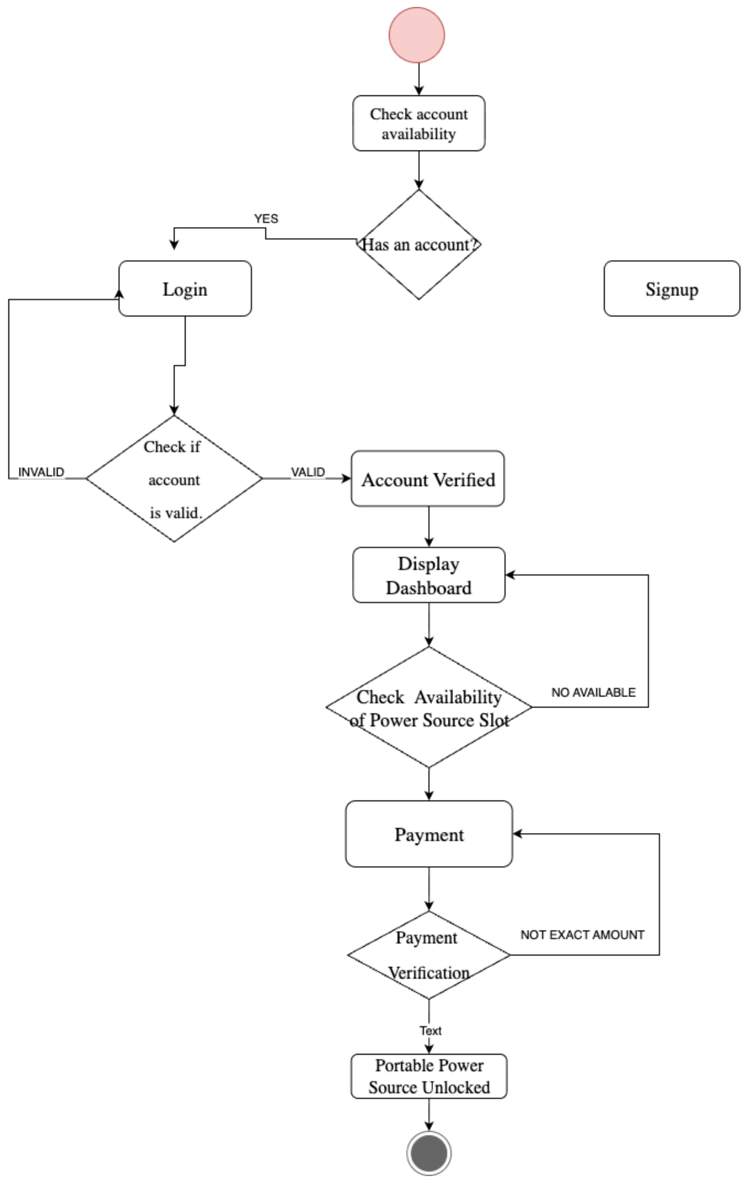


Figure 3.12 shows the step-by-step activity flow of the system from user login to unlocking the portable power source. The process begins with checking account availability. If the user already has an account, they proceed to the login step; otherwise, they must sign up first. After logging in, the system 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

Figure 3.13

Three Dimensional Representation of the System

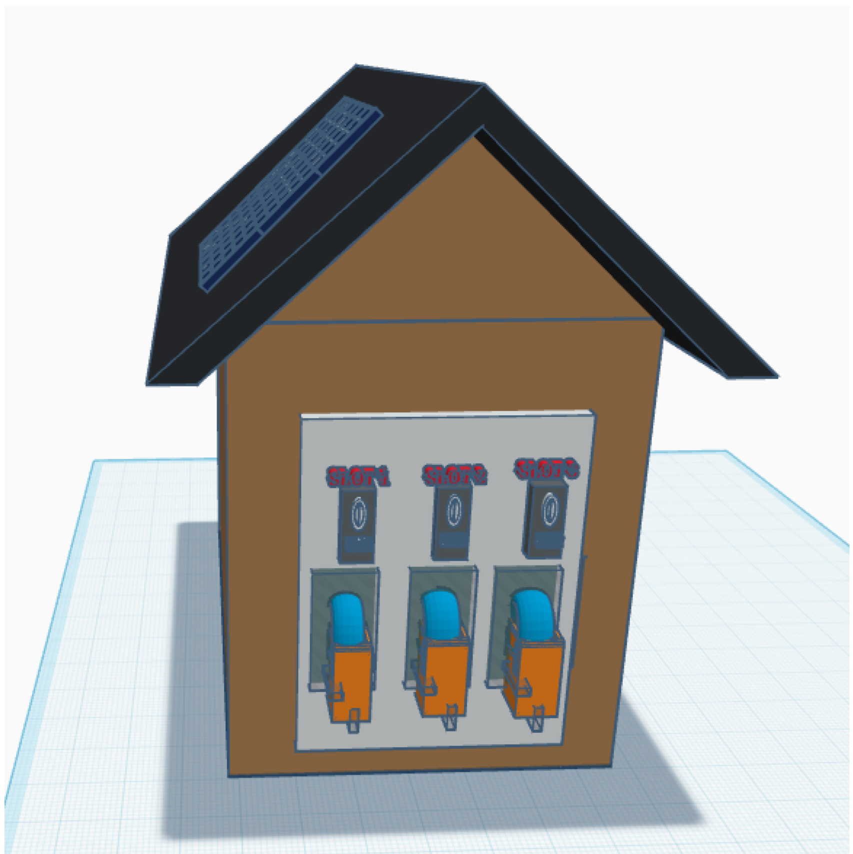
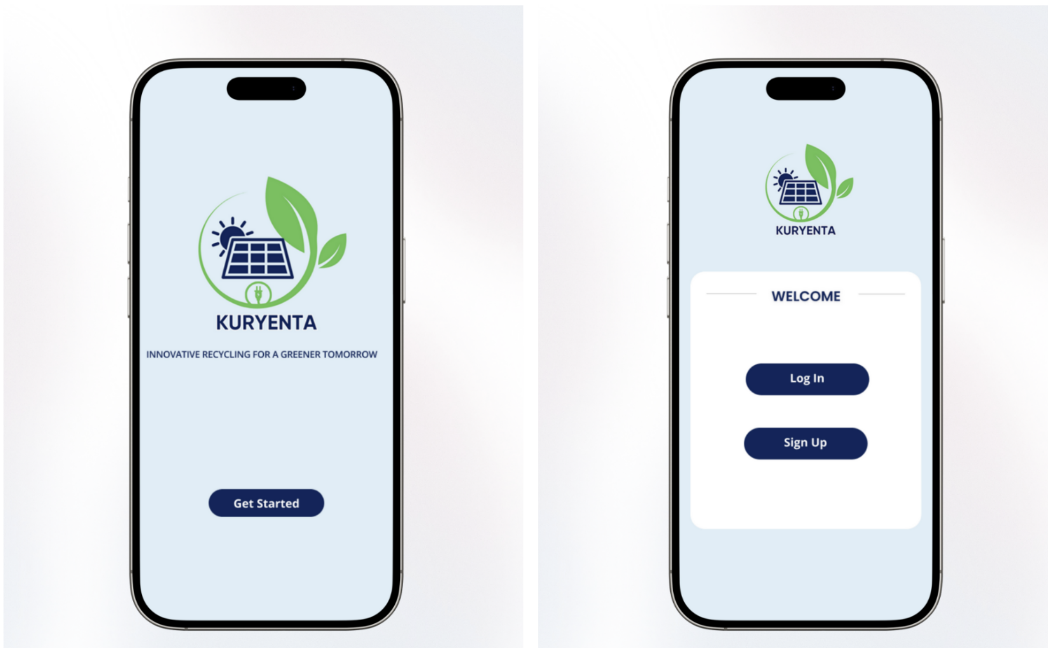


Figure 3.13 shows the 3D design of the system. It is a stationary power station powered by solar energy and contains three detachable power sources, each secured with a coin slot and solenoid lock.

3.2.12 Mobile App

Figure 3.14

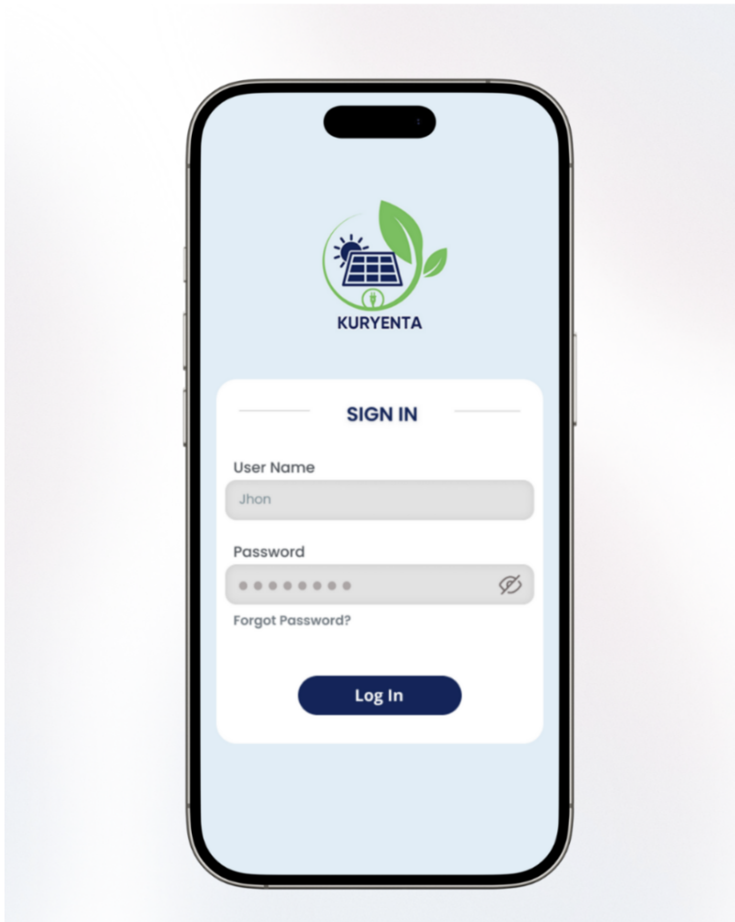
Welcome Page



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 3.15

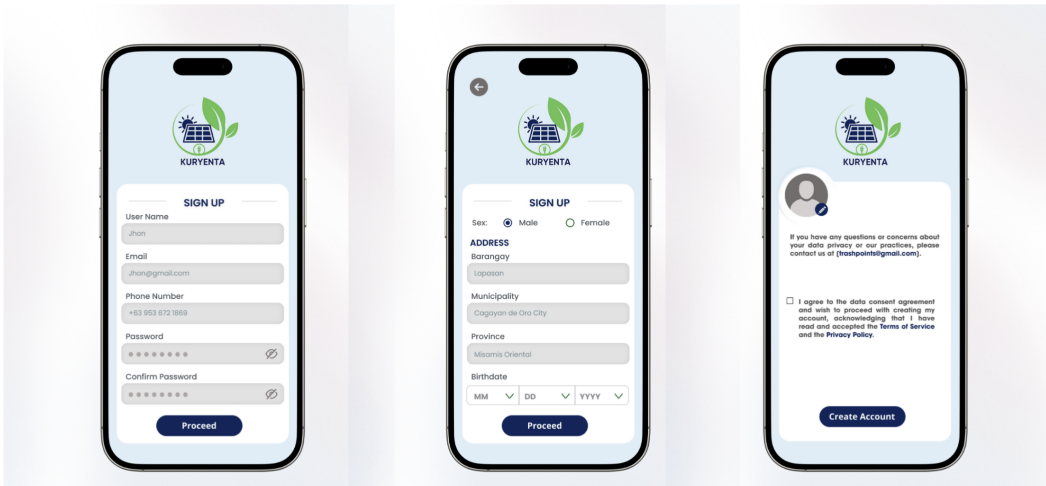
Sign n Screen



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 3.16

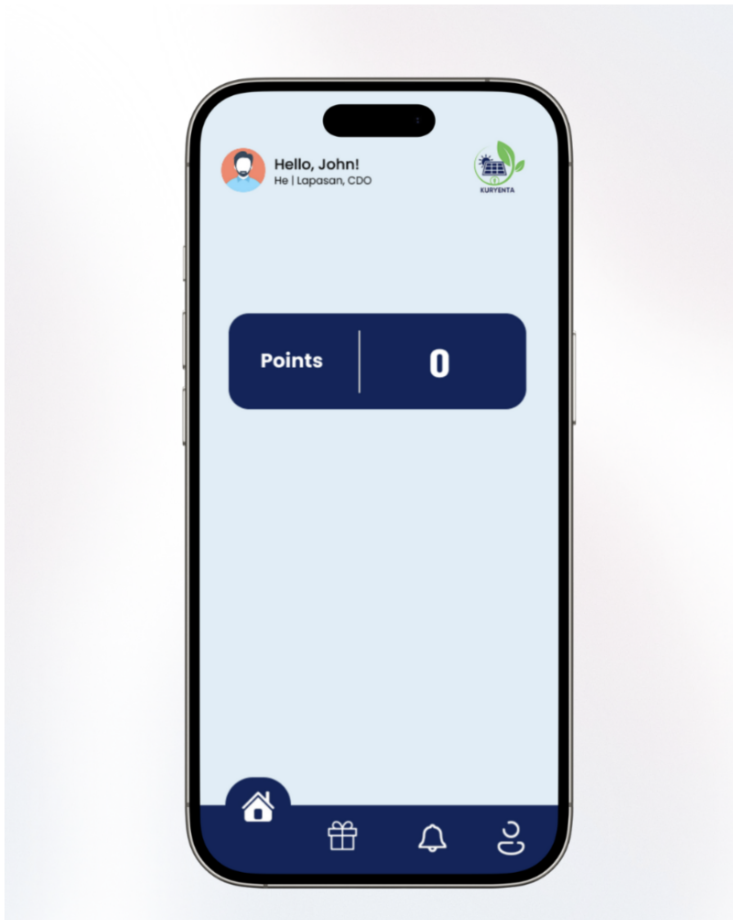
Sign Up Screen



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 3.17

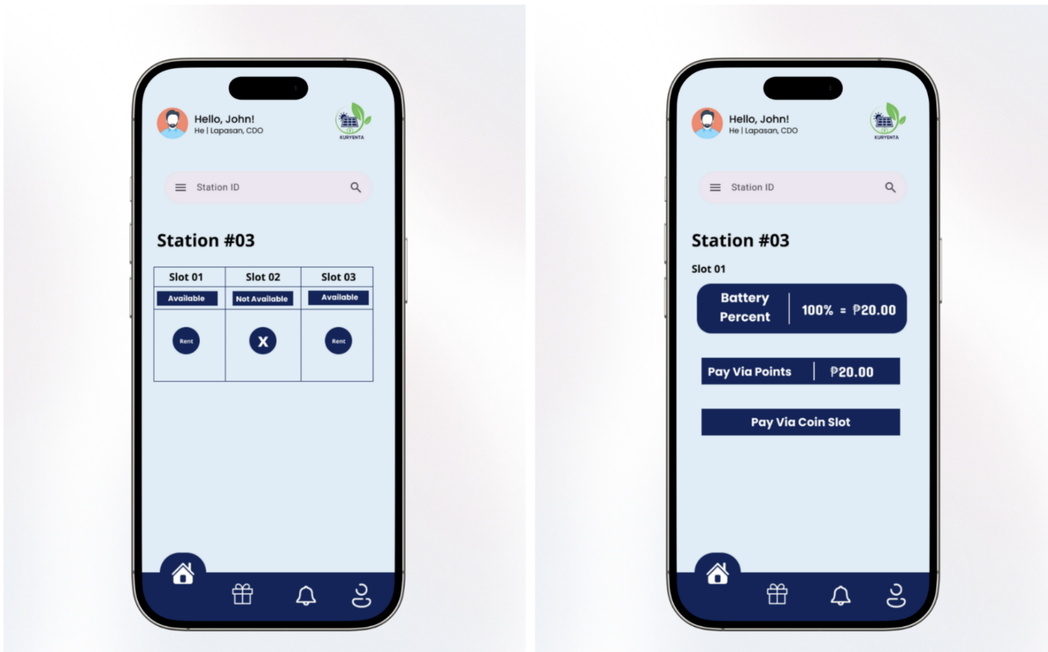
User Home Screen



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 3.18

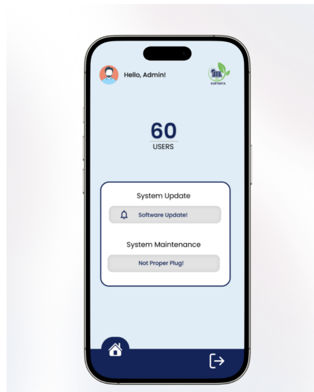
Renting Screen



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 3.19

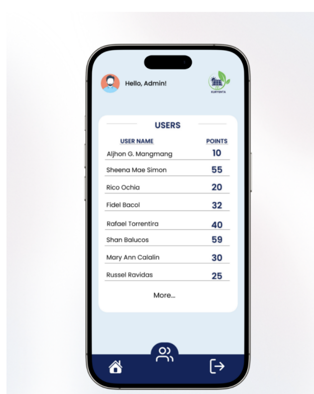
Admin Home Screen



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 3.20

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 2: 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.

APPENDICES