

**KURYENTA: SOLAR-POWERED RENTAL STATION WITH
DETACHABLE POWER SOURCES**

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TABLE OF CONTENTS

	Page No.
TITLE PAGE	i
TABLE OF CONTENTS	ii
LIST OF TABLES	v
LIST OF FIGURES	vi
Chapter 1. INTRODUCTION	1
1.1 Background of the Study	1
1.2 Statement of the Problem	5
1.3 Objectives of the Study	7
1.3.1 General Objectives	7
1.3.2 Specific Objectives	8
1.4 Significance of the Study	8
1.5 Scope and Limitations	10
1.5.1 Scope	10
1.5.2 Limitations	10
1.5.3 Definition of Terms	11
Chapter 2. REVIEW OF RELATED LITERATURE	14
2.1 Theoretical background	14
2.2 Conceptual Framework	15
2.2.1 Schematic Diagram	17
2.3 Review of Related Studies	21
2.3.1 Design of a Solar-Based Portable Power Supply with Modular Battery System for the Du-magat Tribe in Norzagaranay, Bulacan	21
2.3.2 Construction of a Portable Solar Power Supply for Household Appliances	22
2.3.3 Emergency Solar Portable Power Supply	23
2.3.4 Portable Solar-Station with Integrated Battery Management and Load Monitoring System	23
2.3.5 Solar Powered Mobile Power Bank Systems	24

2.3.6	Multiport Universal Solar Power Bank	26
2.3.7	Portable Power Supply Design with 100 Watt Capacity	27
2.3.8	Design and Development of Portable StandAlone Solar Power Generator	28
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	29
2.3.10	Development of a Low Cost Portable Hydro and Wind Power as Emergency Power Source	30
2.3.11	Development of Portable Solar Storage Device	31
2.3.12	Renewable Energy from Solar Panels: A Study of Photovoltaic Physics and Environmental Benefits	32
2.3.13	Power Consumption of Household Appliances	33
2.3.14	Electricity Distribution and Supply Authority	34
2.3.15	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	36
2.3.16	Solar-Powered Coin-Operated Mobile Charging Station for Sustainable Energy Access and Resilience	37
2.3.17	Synthesis	39
	Chapter 3. METHODOLOGY	42
3.1	Research Design and Procedure	42
3.1.1	Research Setting	43
3.1.2	Data Collection	44
3.1.3	Data Gathering Procedure	45
3.1.4	Data Finding Analysis	46
3.1.5	User Definition	47
3.1.6	System Requirements	47
3.2	Technical Design Workflow	49

3.2.1	System Architecture	49
3.2.2	Flowchart	51
3.2.3	Solar Energy Harvesting	53
3.2.4	Energy Conversion DC to AC	53
3.2.5	Power Monitoring	54
3.2.6	GPS Tracking	55
3.2.7	Context Level Diagram	56
3.2.8	Data Flow Diagram	58
3.2.9	Use Case Diagram	60
3.2.10	Activity Diagram	63
3.2.11	3D Design	65
3.2.12	Mobile App	66
3.2.13	Materials and Cost	72
3.2.14	Performance Testing	72
3.2.15	Usability Testing	73
APPENDICES	75

LIST OF TABLES

No.	Table	Page No.
1	System Requirements	47
2	Hardware Components and Cost	72

LIST OF FIGURES

No.	Figure	Page No.
2.1	IPO Model	14
2.2	Process flow on how the system operates	15
2.3	Research Variables and Their Relationships	17
3.1	The Waterfall Model	42
3.2	Map of Camiguin and Misamis Oriental	43
3.3	System Architecture	49
3.4	System Flowchart	51
3.5	Conversion of Sunlight into Electrical Energy using PV Panels and a Charge Controller	53
3.6	Battery DC power converted to AC output via Inverter.	53
3.7	ESP32 measures battery voltage and displays data on LCD	54
3.8	ESP32 receives real-time location data from GPS satellites using GSM Module	55
3.9	Context Level Diagram	56
3.10	Data Flow Representation of the Solar-Powered Rental Station System	58
3.11	Use Case Diagram	60
3.12	Activity Diagram of the Community Resident	63
3.13	Three Dimensional Representation of the System	65
3.14	Welcome Page	66
3.15	Sign n Screen	67
3.16	Sign Up Screen	68
3.17	User Home Screen	69
3.18	Renting Screen	70
3.19	Admin Home Screen	71
3.20	Admin Manage Users Screen	71

List of Equations

No.	Equation	Page No.
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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 sus-

tainable 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 gaso-

line 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 so-

lar 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

Figure 2.1

IPO Model

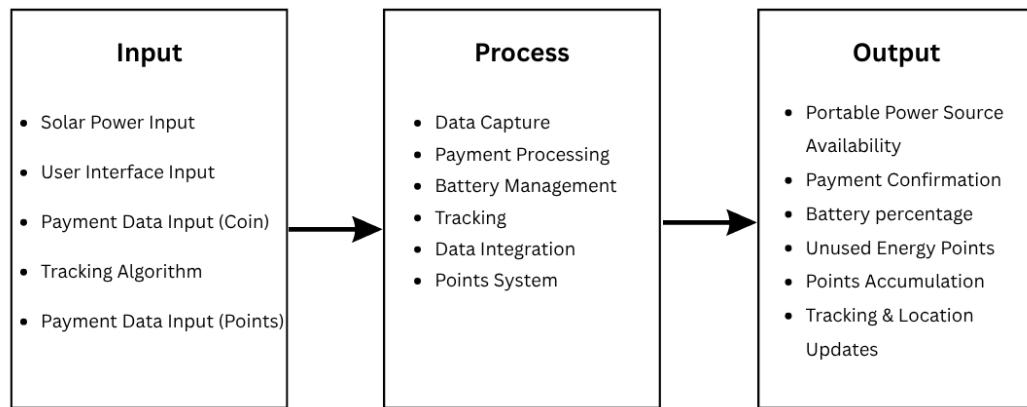


Figure 2.1 explains how the solar-powered rental station works from input to output. Inputs are what the system receives: solar energy that charges the main batteries, user actions on the screen or buttons, coins or points used for payment, and location data from GPS/GSM for tracking. The system then

processes these inputs. It captures the user's choice, checks and records the payment, manages the batteries by charging them and checking their levels, and updates each unit's location. It also combines all this information so everything stays in sync, and it runs the points feature so unused energy can turn into rewards.

After processing, the system produces clear outputs that users and operators can see. It shows which portable power sources are available to rent, confirms that the payment went through, and displays the battery percentage of each unit before checkout. It also updates the user's points, both the unused-energy points earned and the total points saved, and keeps the tracking information current, so rented units can be monitored in real time. This flow makes the station easy to use, transparent, and secure.

2.2 Conceptual Framework

Figure 2.2
Process flow on how the system operates

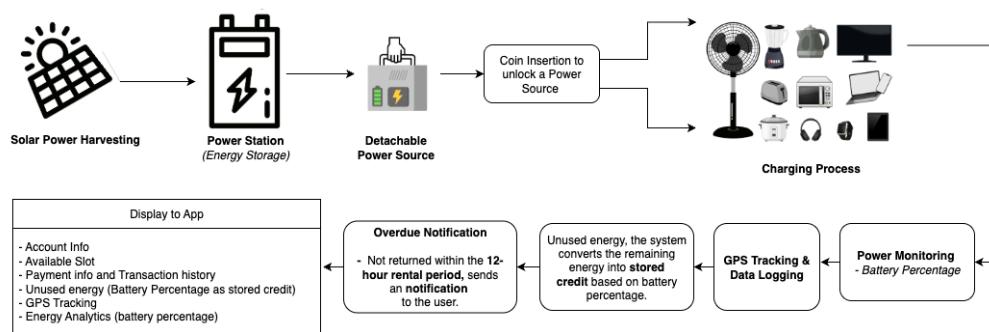


Figure 2.2 illustrates the step-by-step process of how the proposed system functions, beginning with energy harvesting and ending with user access to the detachable power source. The process starts when photovoltaic (PV) panels capture solar energy and convert it into electricity. This electricity is then stored in the LiFePO₄ battery, ensuring a reliable and long-lasting power supply. To make the stored energy usable for different devices, the system employs an inverter, which converts the direct current (DC) from the battery into alternating current (AC). Next, the ESP32 microcontroller, integrated with IoT mechanisms, monitors and manages the flow of energy. Through this control unit, real-time data such as battery charge level and system status can be tracked. Supporting modules such as GPS (for location tracking) and GSM (for wireless communication) enhance the monitoring and management of the system, particularly for rented power sources. For the rental mechanism, the system is equipped with a coin slot or app-based access system that unlocks the detachable power source through a solenoid lock. Once accessed, the user can rent and carry the power source for portable use, such as charging appliances or gadgets during power interruptions. The accompanying mobile application provides the renter with real-time updates on the battery level, usage duration, and system availability. Lastly, once the power source is returned, the system resets and recharges through solar harvesting, making it

ready for the next user. This cyclical process ensures that the system remains sustainable, user-friendly, and reliable for communities experiencing frequent and unscheduled power interruptions.

2.2.1 Schematic Diagram

Figure 2.3
Research Variables and Their Relationships

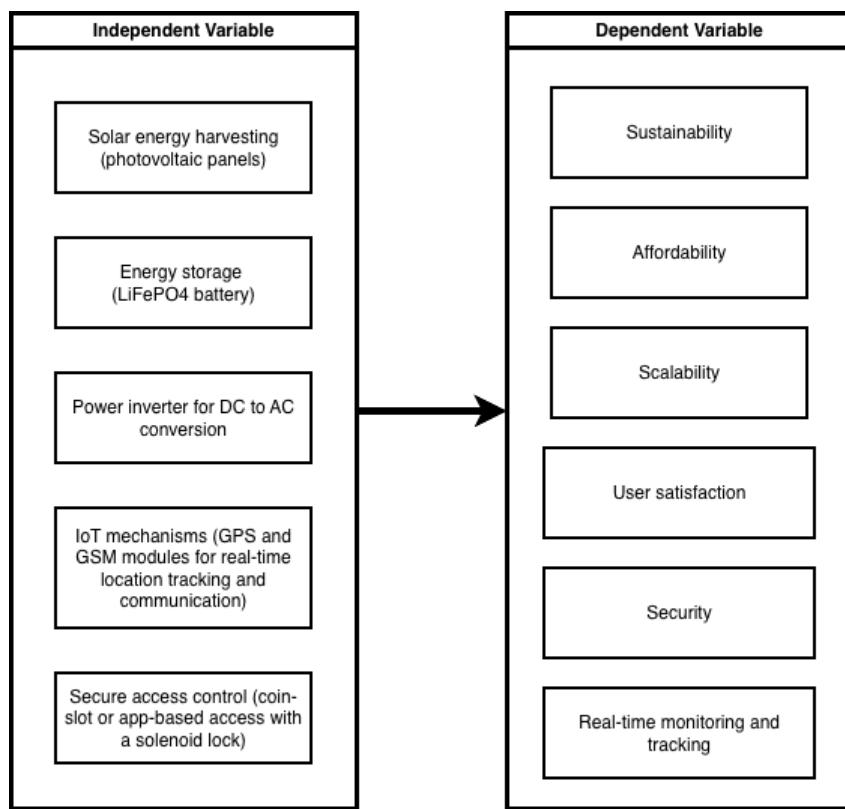


Figure 2.3 presents the independent and dependent variables, along with their relationship. The system integrates photovoltaic (PV) panels for solar energy harvesting, a process that involves capturing sunlight and con-

verting it into usable electrical energy. The harvested solar energy is then stored in a LiFePO₄ battery. Once stored, the direct current (DC) energy stored in the LiFePO₄ battery is converted into alternating current (AC) by the power inverter. This conversion is essential since most household appliances and devices operate on AC power. Through this process, the system ensures a stable and usable power supply for various common electrical loads. The system also incorporates a GPS module, which continuously gathers satellite signals to provide real-time location data. This enables effective tracking and monitoring of the rented power sources. Simultaneously, the GSM module facilitates communication between the system and the administrator by transmitting data through cellular networks. It allows the system to send notifications, updates, and alerts to users in real time. To regulate user access, the system employs a secure payment mechanism. Before using the power source, users must make a payment through a coin-slot or app-based interface. Once payment is verified, the solenoid lock releases the detachable power source, ensuring that only authorized users can access it.

The dependent variables represent the measurable outcomes influenced by the performance of the solar-powered rental station. Sustainability pertains to the system's capacity to maintain consistent and reliable operation over time through the use of renewable solar energy. It is evaluated based

on the efficiency of energy generation, storage, and utilization under varying environmental conditions. Affordability refers to the system's level of cost-effectiveness and economic accessibility, determining whether the rental fees, maintenance requirements, and operational expenses make it a viable and practical energy alternative during power outages. Scalability concerns the system's potential to be expanded, replicated, or adapted for use in various communities or environments without compromising its cost efficiency or operational performance. User satisfaction measures how end-users perceive the system's reliability, convenience, and overall usability. It is assessed through user feedback and usability evaluations focusing on accessibility, charging efficiency, and ease of operation. Security relates to the effectiveness of the system in safeguarding its physical components and digital data from unauthorized access, tampering, or misuse. Finally, real-time monitoring and tracking refer to the system's capability to collect, transmit, and present accurate and timely data on power usage, battery status, and equipment location through the integration of IoT modules. Collectively, these dependent variables define the system's efficiency, practicality, and long-term sustainability as an alternative energy source for communities experiencing frequent power interruptions.

The relationship between the independent and dependent variables focuses on how the proposed solar-powered rental station with detachable power

sources influences the system's overall effectiveness and performance. As the independent variable, the solar-powered rental station—integrating solar energy harvesting, energy storage, power conversion, Internet of Things (IoT) mechanisms, and secure access control—serves as the central technological concept of the study. The design and integration of these components are expected to affect several dependent variables, including sustainability, affordability, scalability, user satisfaction, security, and real-time monitoring. In this relationship, the independent variable represents the proposed system, while the dependent variables represent the measurable outcomes that determine its efficiency and practicality. Proper design and operation of the solar-powered rental station are assumed to enhance sustainability through stable energy generation and storage, promote affordability by minimizing operational costs, and enable scalability for broader deployment. Furthermore, the integration of IoT-based monitoring and secure access control is anticipated to improve user satisfaction, system security, and data accuracy. Overall, the conceptual framework illustrates that the system's effectiveness depends on how well the independent variable's components contribute to achieving reliable, sustainable, and user-oriented energy access during power interruptions.

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 mon-

itoring, 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 Development of a Low Cost Portable Hydro and Wind Power as Emergency Power Source

The study of low-cost portable hydro and wind power system as an emergency power source by Supardi et al. (2020) explored the development of a low-cost portable hydro and wind power system as an emergency power source. The system is designed to provide power for recharging essential equipment such as mobile phones, radios, and emergency lights, which are essential during prolonged outdoor activities or power outages. This system can be implemented in remote areas with fluctuating water flows, making it an ideal solution for communities with limited access to electricity. The study found that

the portable hydropower system, when coupled with wind power, could generate reliable electricity. These findings support the integration of renewable energy sources in off-grid locations, where accessibility to traditional power infrastructure is limited, and emphasize the importance of efficient turbine and generator design for portable power generation.

2.3.11 Development of Portable Solar Storage Device

Roslan et al. (2019) developed a portable solar storage (PSS) device designed to address the increasing demand for sustainable and portable power sources. The PSS is tailored for outdoor activities, such as hiking, camping, and climbing, providing a portable solution for charging electronic devices. The system uses a 12V or 18V solar panel to charge a battery with 98W of energy storage. During testing, the system showed charging rates of 16.086 W/h for the 12V solar panel and 13.35 W/h for the 18V panel, demonstrating the effectiveness of solar energy harvesting. The PSS was capable of recharging devices with capacities up to 10,000mAh, offering a reliable power supply for small electronic gadgets.

The study highlights the advantages of using solar panels for off-grid applications, noting that the PSS is ideal for areas with ample sunlight, such as Malaysia. The device's efficiency was calculated at 12.75%, with the sys-

tem capable of charging devices like phones, smartphones, and power banks. However, the study also found limitations in charging larger devices with the 12V solar panel. Roslan et al. (2019) concluded that while the PSS provides an environmentally friendly and practical solution for outdoor power needs, further improvements in solar panel capacity and battery efficiency are needed to enhance its performance for higher power demands.

2.3.12 Renewable Energy from Solar Panels: A Study of Photo voltaic 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 photo voltaic (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.

2.3.13 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.

2.3.14 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.

LiFePO₄ 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, LiFePO₄ 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 LiFePO₄ technology is its longer cycle life. The EDSA (2024) report notes that LiFePO₄ 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, LiFePO₄ batteries are maintenance-free, unlike SLA batteries which often require periodic electrolyte checks and refilling. While LiFePO₄ batteries have a higher upfront cost, they compensate with lower operational and maintenance expenses throughout their lifespan. From an environmental perspective, LiFePO₄ batteries are also less harmful and easier to dispose of or recycle compared to lead-acid types, which generate toxic

emissions during recycling.

2.3.15 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 P18,200, 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.

2.3.16 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 ur-

ban 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.

2.3.17 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 require-

ments. 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.

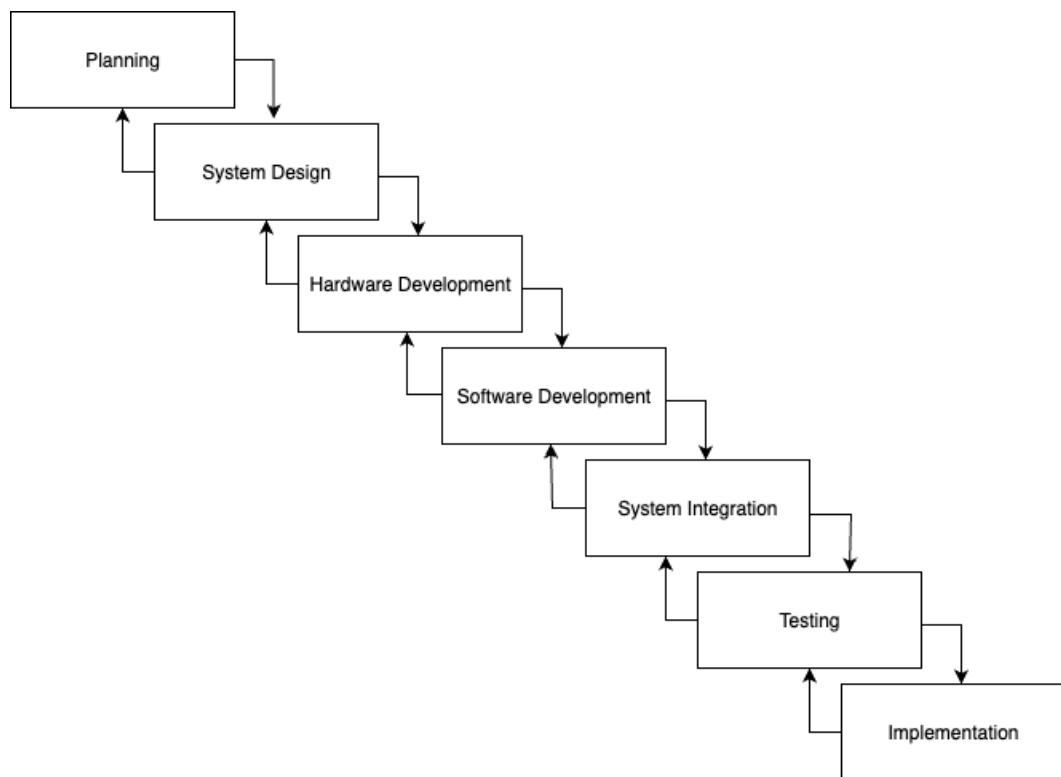
CHAPTER 3

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	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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
	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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

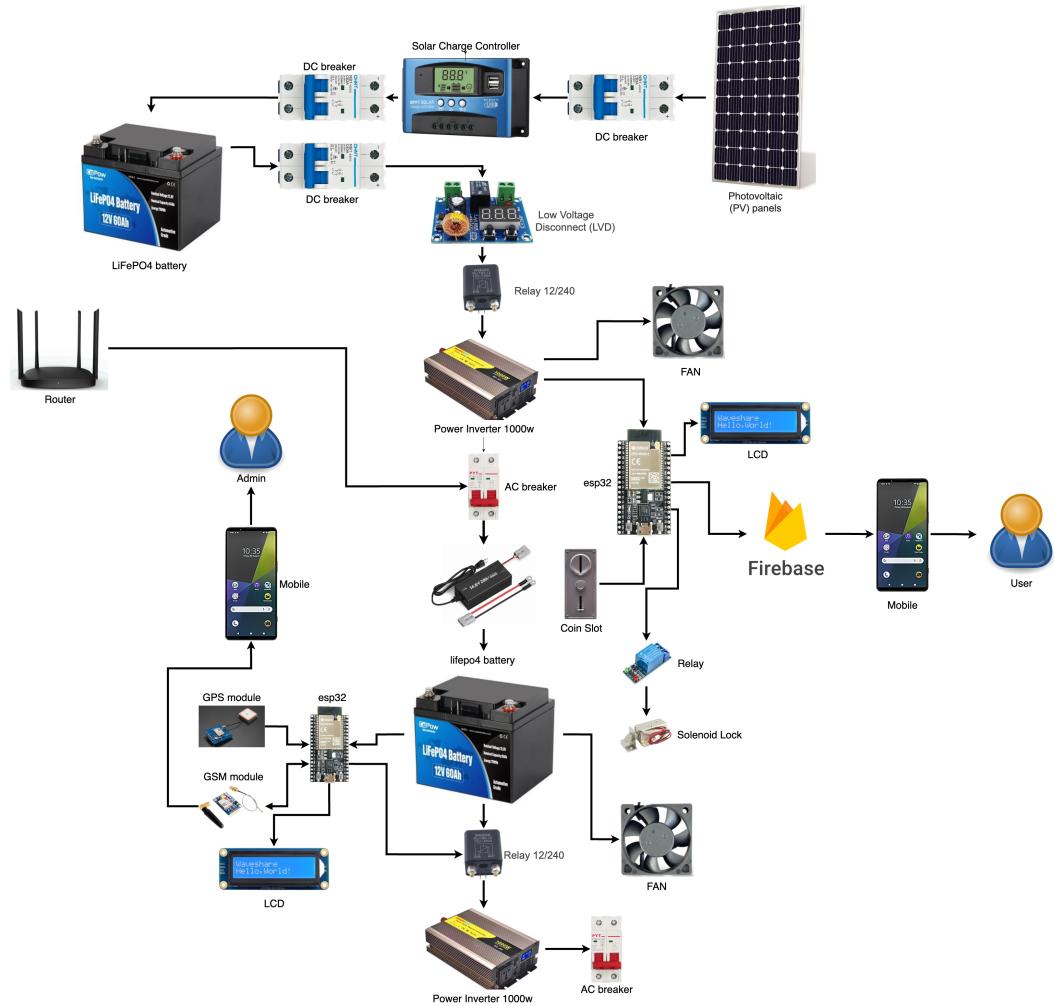


Figure 3.3 illustrates the architecture of the KuRyenta system, a solar-powered, coin-operated, GPS-enabled portable power source. The diagram

shows how solar energy is captured by the photovoltaic panels and stored in a LiFePO₄ battery through the solar charge controller. The stored energy is then converted into usable AC power by the power inverter, which is accessible to the user via a coin-operated access system.

The ESP32 microcontroller manages the system's operations, integrating key components such as the GPS module for location tracking and the GSM module for communication with the admin. A coin slot and solenoid lock control the unlocking of the portable power sources, ensuring that users can access the power only after payment is made. The user can interact with the system through a mobile app that displays the battery's charge level and other important information. In essence, the KuRyenta system is designed to provide a sustainable and secure solution for portable power, incorporating solar energy, and coin-based access for a user-friendly and efficient experience.

3.2.2 Flowchart

Figure 3.4
System Flowchart

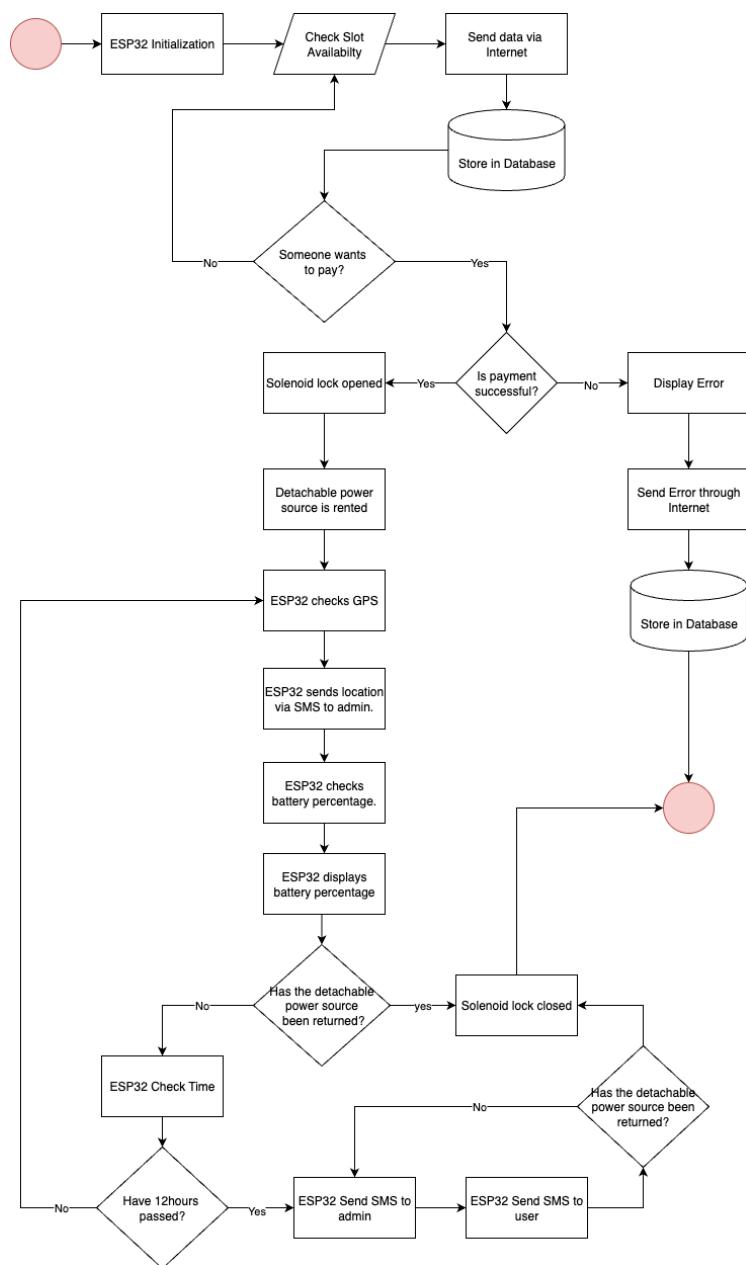


Figure 3.4 illustrates the overall process of the proposed Solar-Powered Rental Station with Detachable Power Sources. The process begins with the initialization of the ESP32, which activates system components and prepares communication protocols. The system first checks slot availability to determine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

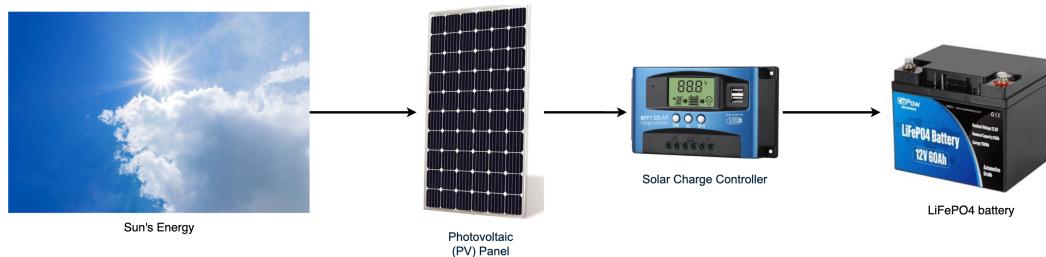
When a user intends to rent a power source, the system verifies if payment is successful. If confirmed, the solenoid lock opens, allowing the detachable power source to be accessed by the user. Once rented, the ESP32 continuously monitors the power source, including its GPS location and battery percentage, 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 LiFePO₄ 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.

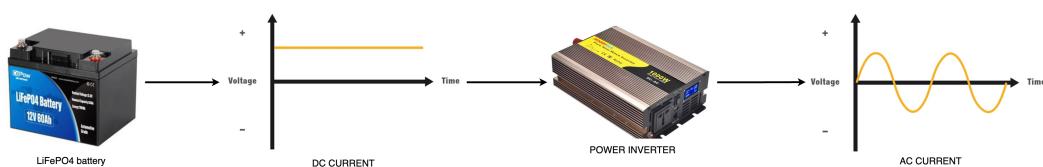
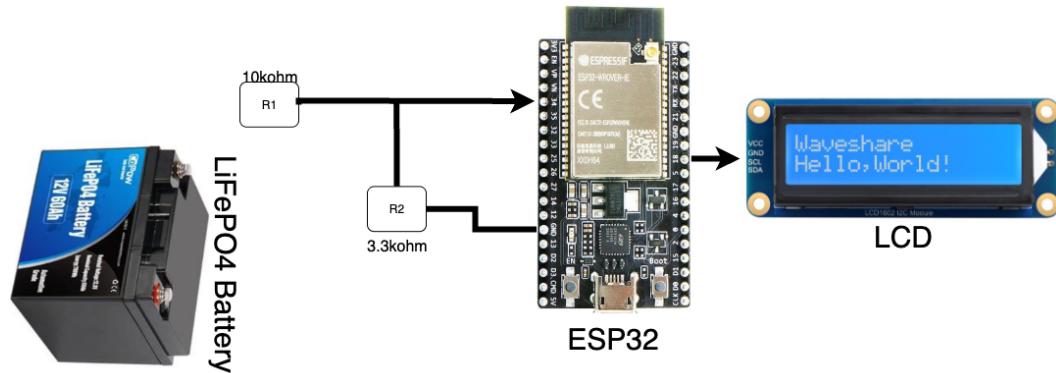


Figure 3.6 shows the process of converting direct current (DC) into alternating current (AC). The stored energy in the LiFePO₄ battery is passed through a power inverter, and the inverter transforms the DC from the battery into AC power, which can be used to power household appliances such as fans and 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 LiFePO₄ 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

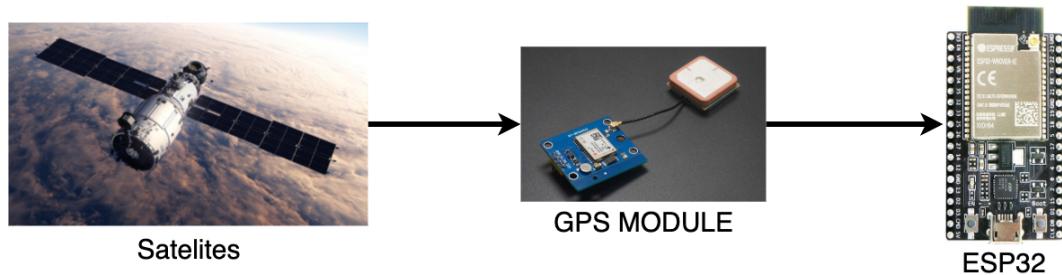
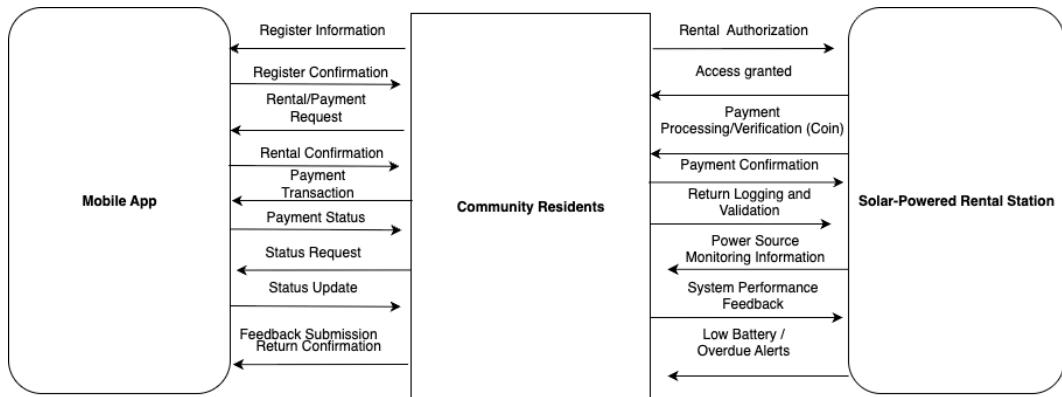


Figure 3.8 shows the GPS tracking system used to monitor the location of the detachable power source. A GPS module, connected to the ESP32 microcontroller, receives signals from satellites to determine the geographical location of the system. This real-time location data is essential for tracking and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

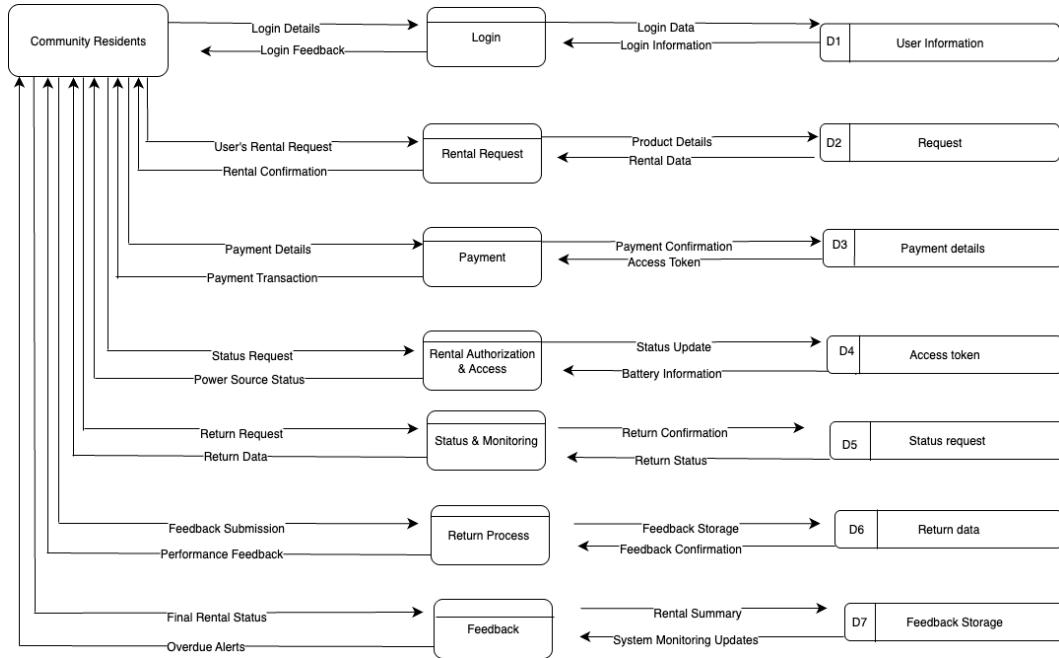
can then use the Mobile App to check the system status, such as battery levels, power source availability, or the remaining rental time. After use, the Community Resident sends a return request via the Mobile App, which then communicates with the System to confirm the power source return. The System 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 they input payment details and transaction information. The system returns payment confirmation and an access token. The rental authorization and access process handles status requests and power source status, providing updates and battery information. The status and monitoring process manages return requests and return data, providing confirmation and return status. The return process involves feedback submission and performance feedback, leading to feedback storage and confirmation. Finally, the feedback process provides final rental status and overdue alerts, and stores rental summary in feedback storage, which also receives system monitoring updates.

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

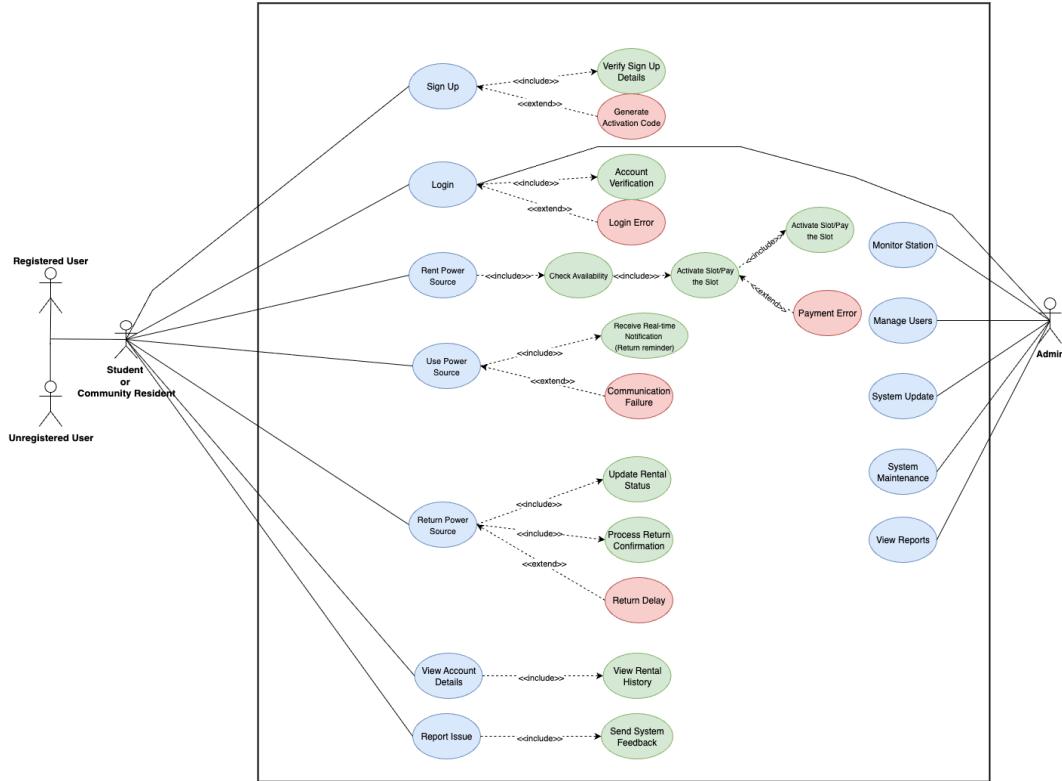


Figure 3.11 illustrates how different users and administrators interact with the system. It highlights the actions users can take and the roles of administrators. The Unregistered User is someone who has not yet signed up for the system. They can create an account by providing their details, which are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

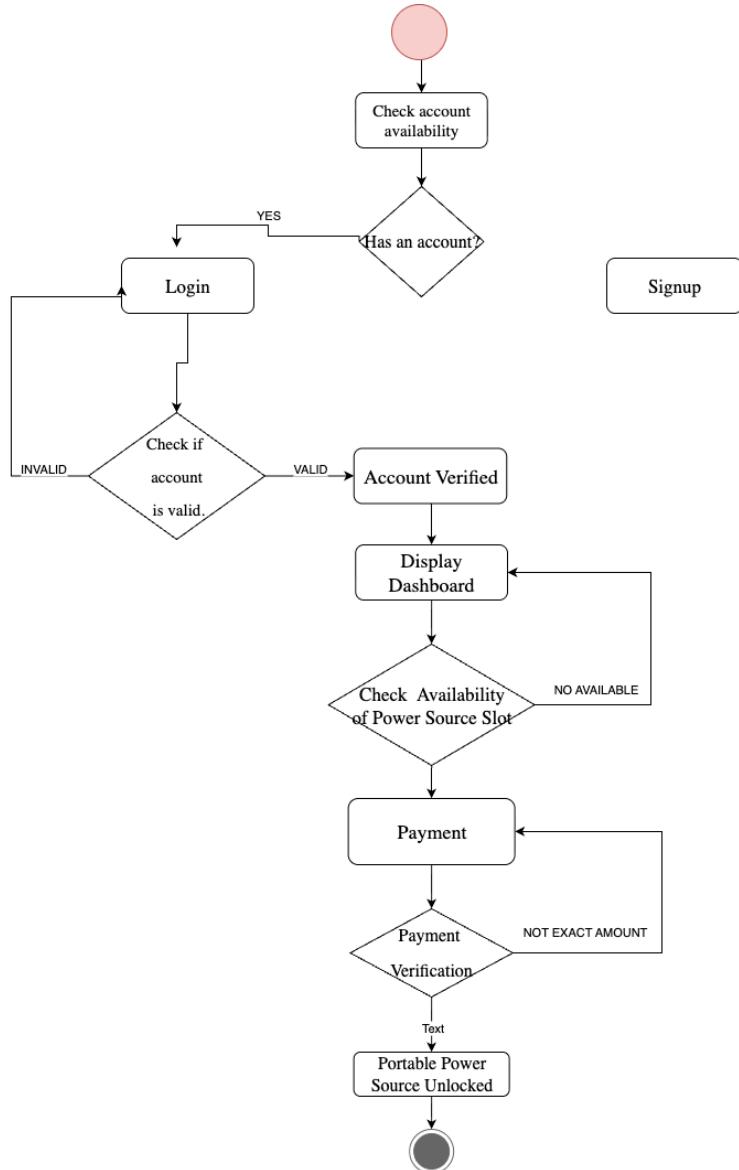


Figure 3.12 shows the step-by-step activity flow of the system from user login to unlocking the portable power source. The process begins with checking account availability. If the user already has an account, they proceed to the login step; otherwise, they must sign up first. After logging in, the system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

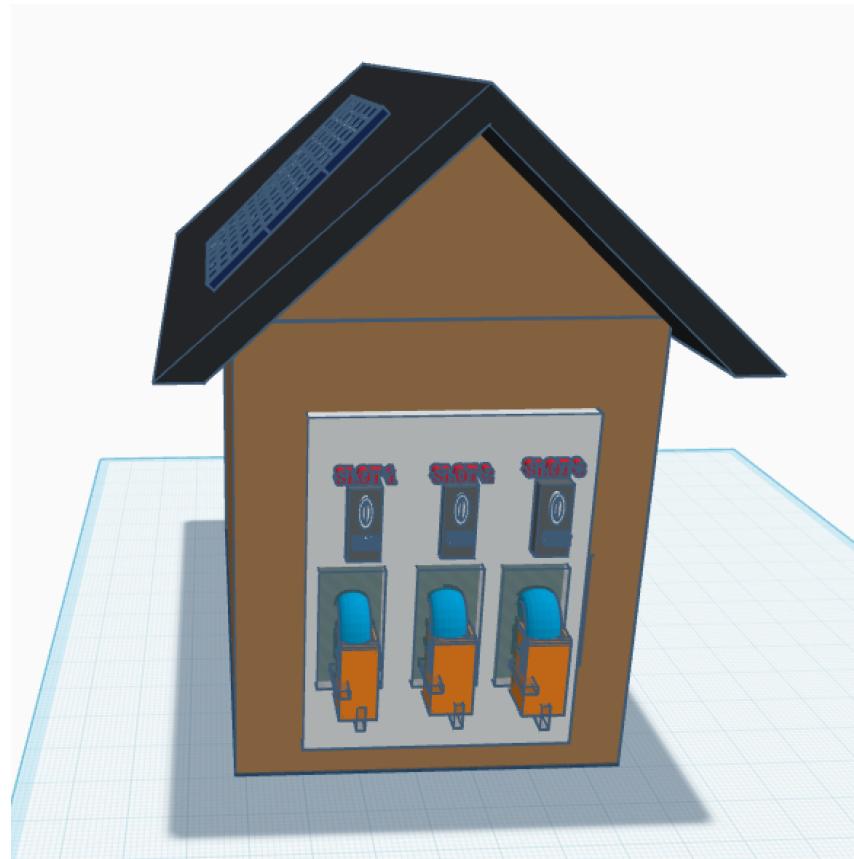
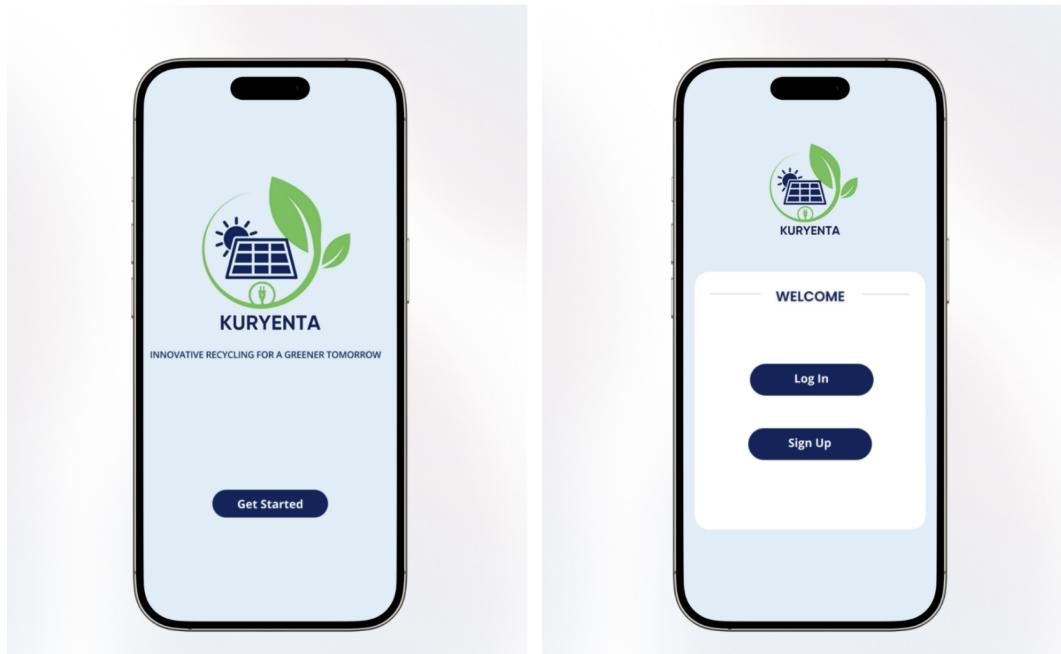


Figure 3.13 shows the 3D design of the system. It is a stationary power station powered by solar energy and contains three detachable power sources, each secured with a coin slot and solenoid lock.

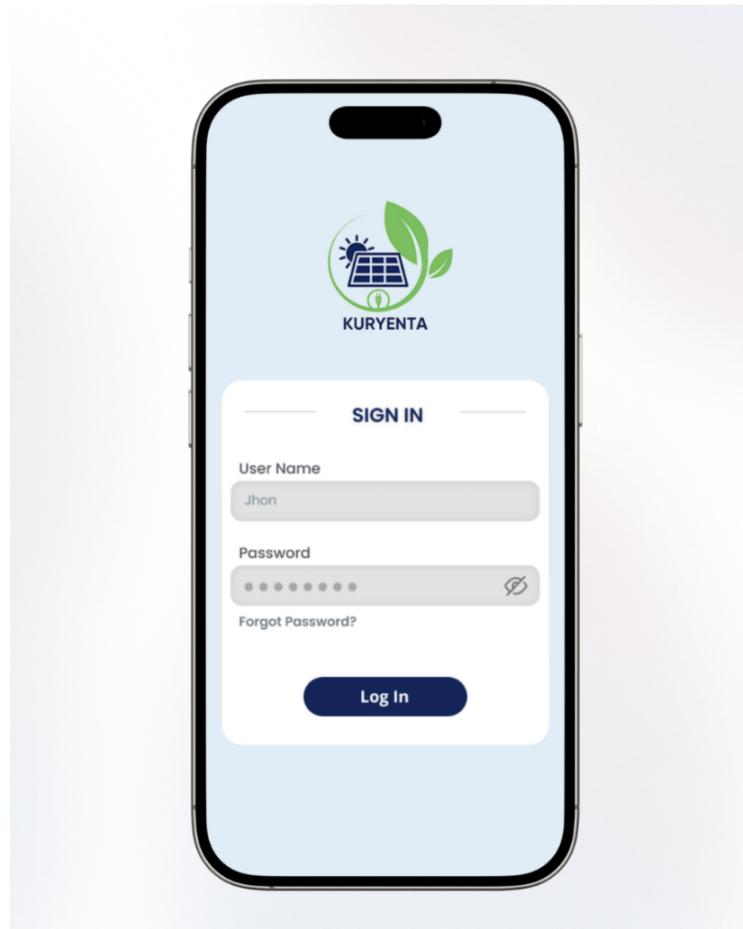
3.2.12 Mobile App

Figure 3.14

Welcome Page

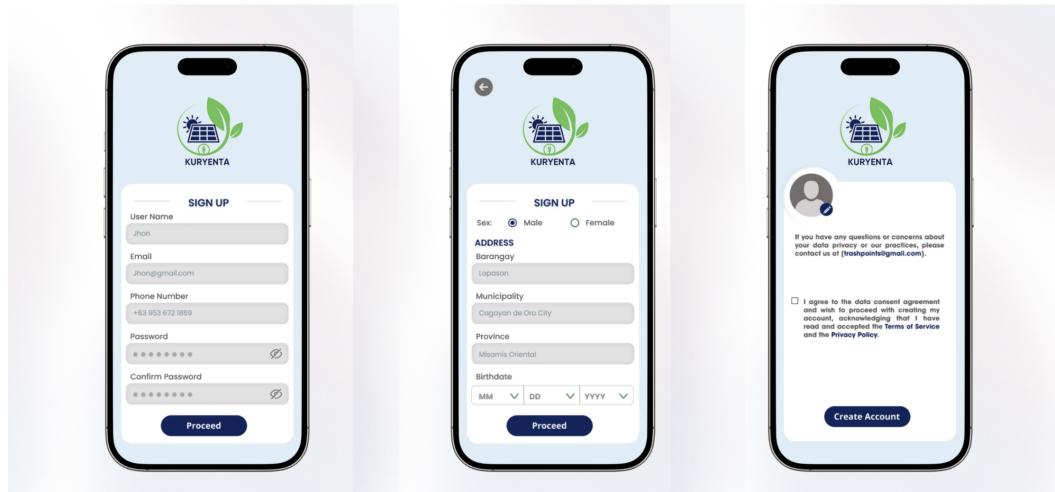


The welcome interface presents the system logo and entry actions. The left panel shows a splash screen with a “Get Started” control; the right panel shows a gateway card offering Log In and Sign Up. This screen functions as the access point to the authentication flow.

Figure 3.15*Sign n Screen*

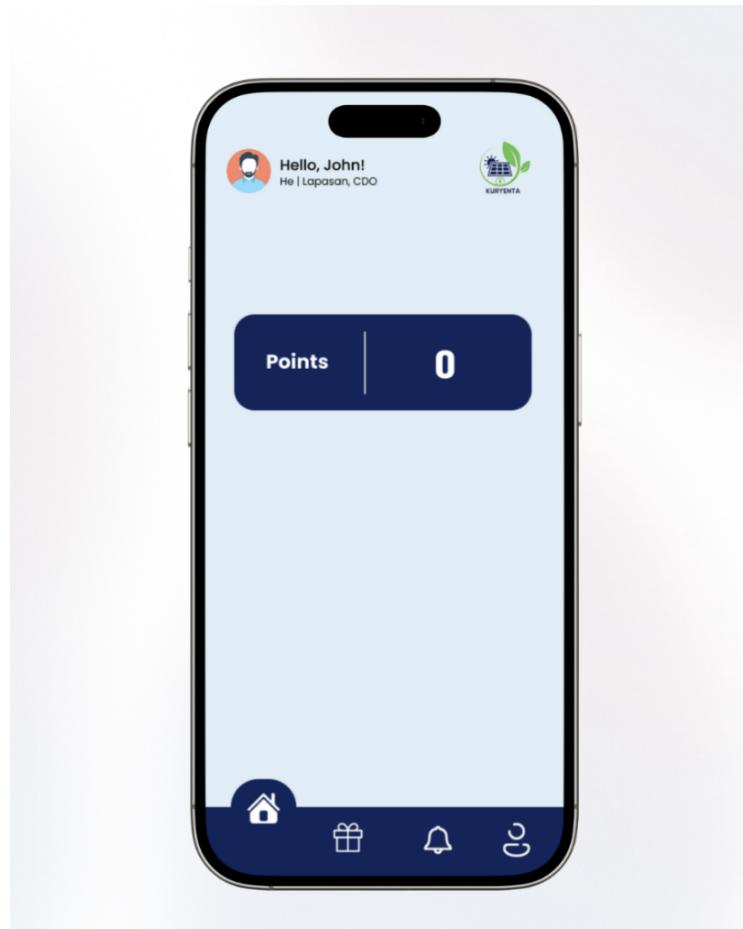
The sign-in interface collects the username and password with options to reveal the password and recover forgotten credentials. A primary Log In control initiates authentication for registered users. The design supports secure access to user functions.

Figure 3.16
Sign Up Screen



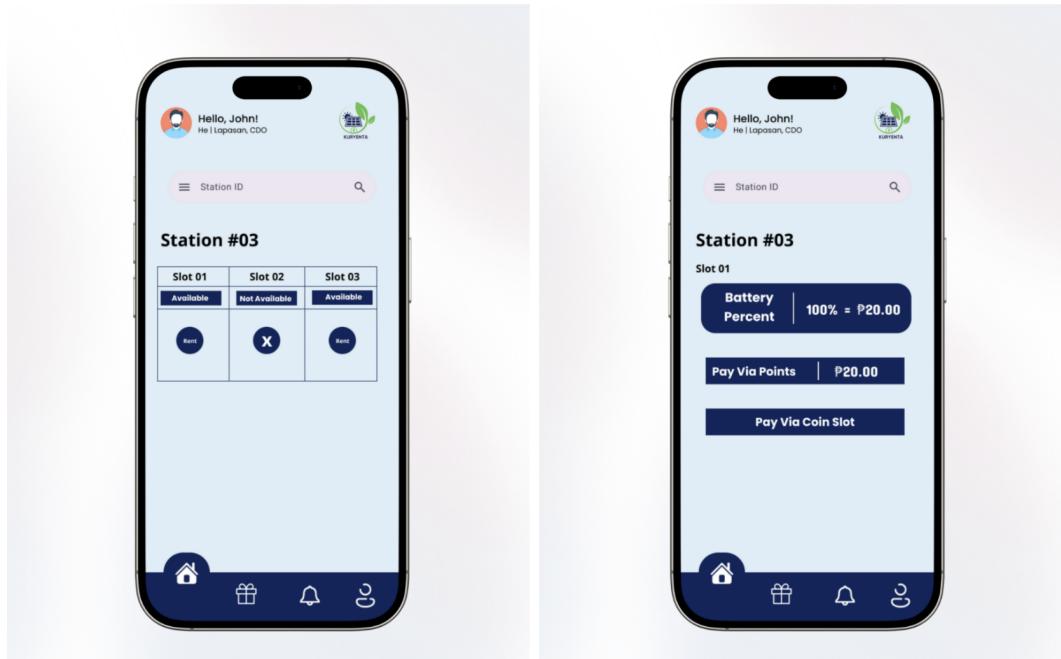
Registration is implemented as a three-step process. Step 1 captures account credentials (username, email, phone number, password, and confirmation). Step 2 records profile and address data (sex, barangay, municipality, province, and birthdate). Step 3 presents a data-privacy notice and obtains consent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

Figure 3.17
User Home Screen



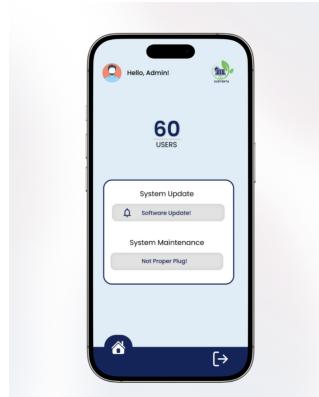
The user dashboard displays a greeting header with location metadata and a card showing the current points balance. A bottom navigation bar provides access to core modules (home, rewards, notifications, and account/tools). This screen serves as the primary hub for user activities.

Figure 3.18
Renting Screen



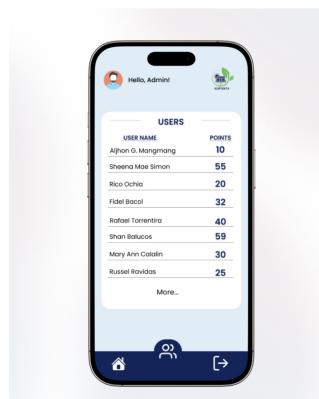
The renting module allows search by Station ID and shows slot availability per station. Users select a slot and view its battery percentage with the corresponding price. Payment options include Pay via Points and Pay via Coin Slot, enabling transaction initiation.

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 bal-

ances. 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.

3.2.14 Performance Testing

The primary objective of performance testing is to evaluate the system’s ability to handle user interactions and data processing without significant de-

lay. Key performance indicators (KPIs) such as response time, processing speed, and system throughput will be assessed during peak and off-peak usage hours. The system will undergo stress testing to determine its capacity for managing multiple simultaneous user requests, ensuring reliability under high demand conditions.

Testing will include the measurement of real-time monitoring capabilities, particularly the speed at which data is transmitted from the power stations to the mobile app. Performance testing will also assess the efficiency of the GPS and GSM modules, evaluating their responsiveness to ensure timely updates for location tracking and system alerts. This phase will confirm that the system remains stable, efficient, and user-friendly during various operational loads.

3.2.15 Usability Testing

Usability testing will focus on evaluating the user experience for both community residents and administrators. This will involve assessing the clarity, intuitiveness, and ease of navigation of the mobile app interface. A group of representative users will be selected from the target community to perform typical tasks such as account registration, power source rental, and payment processing.

The System Usability Scale (SUS) will be used to quantitatively measure the users' perception of the app's usability. Users will provide feedback on key aspects such as the accessibility of the mobile interface, ease of system navigation, and satisfaction with the power source rental process. In addition to SUS, qualitative data will be gathered through observational analysis and user interviews, allowing for in-depth insights into any usability concerns. This testing phase will help identify potential friction points in the user interface and guide refinements to improve overall user satisfaction.

APPENDICES