

Solar-Powered Reverse Vending Machine for Aluminum Cans and Pet Bottles with Short Bond Paper Redemption System

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Abstract- This study focused on the development of a solar-powered reverse vending machine for PET bottles and aluminum cans with a short bond-paper redemption system. The project aimed to promote proper waste segregation, recycling awareness, and sustainable waste management within Laguna University through an automated and eco-friendly recycling system. Specifically, the study aimed to design and fabricate a machine capable of identifying and segregating PET bottles and aluminum cans while dispensing short bond paper as a reward system. The machine also integrated a liquid detection feature using a weighing scale sensor to reject containers containing excessive liquid. The prototype was evaluated in terms of functionality, segregation accuracy, liquid detection capability, sustainability, acceptability, and overall performance. The developed machine was tested using different types and sizes of PET bottles and aluminum cans. Results showed that the machine achieved an overall average accuracy of 84.67% in identifying and segregating recyclable materials. The system was also evaluated through a survey conducted among 100 respondents using Google Forms. The survey results revealed a high level of acceptability and positive evaluation regarding the machine's functionality, sustainability, usability, and contribution to proper waste disposal and recycling awareness. Furthermore, the study demonstrated that the developed solar-powered reverse vending machine can serve as an innovative and sustainable solution for waste management within educational institutions. The researchers concluded that the machine has the potential to encourage recycling participation, reduce improper waste disposal, and support environmental sustainability efforts in the university community.

I. INTRODUCTION

The global landscape of recycling and extended producer responsibility has increasingly integrated automated collection technologies, with reverse vending machines (RVMs) emerging as a scalable

solution to incentivize consumer returns of beverage containers and improve material recovery efficiency. Market analyses report growing deployment of RVMs across retail, transit, and institutional settings driven by deposit-return schemes, corporate sustainability programs, and the need to reduce contamination in recycling streams [1]. In parallel, research has highlighted the trade-offs between sensor-rich, high-accuracy systems and simpler mechanical approaches that prioritize cost, reliability, and low energy consumption for decentralized deployments [2].

In the Philippines, pilot programs and local government initiatives have begun adopting RVMs and related incentive schemes to tackle plastic and aluminum waste while encouraging circular behavior among citizens [3]. Municipal rollouts and municipal-private partnerships have showcased RVMs placed in public buildings and transit hubs, paired with point-based or rewards systems to increase user uptake and link recycling to digital loyalty programs [3]. Local engineering efforts have likewise explored solar-assisted prototypes to ensure off-grid operation in barangays and remote community settings, addressing frequent power constraints and maintenance limitations [4].

Existing studies both globally and in the Philippines examine technical designs, user incentives, and operational constraints of RVMs, with several technical reports and capstone projects documenting mechanical sorting alternatives to sensor-based architectures [2][4]. Internationally, design studies demonstrate how optimized mechanical pathways—including chutes, gates, and diverters—can reduce reliance on active sensing while maintaining acceptable sorting performance for common

recyclable types [2]. Nationally, engineering theses and pilot prototypes report practical adaptations such as single-slot inputs, gravity-fed chutes, and solar power integration to meet local cost and energy realities [4][5].

Despite these advances, gaps remain in rigorously validated, low-cost mechanical segregation systems that are optimized specifically for combined aluminum can and multi-size plastic bottle streams under real-world conditions in the Philippines [5]. Many existing prototypes and studies describe concepts or limited trials but do not provide comprehensive field evaluations of accuracy, throughput, maintenance burden, or compatibility with local recycling value chains. There is also limited documentation on integrating a simple, robust mechanical sorter with a secure rewards system suitable for offline or intermittent-connectivity environments [5].

This study designed, fabricated, and evaluated a solar-powered reverse vending machine (RVM) tailored to the needs of Laguna University. The machine was developed based on its power requirements, material selection, and structural geometry, integrating a single feeder, a belt conveyor, a diverter system, and a chute for handling polyethylene terephthalate (PET) bottles and aluminum cans. Sensor-assisted verification was implemented using ultrasonic, weighing scale, and infrared.

The RVM dispensed short bond paper as a tangible reward for each verified deposit, supporting offline use and low-connectivity environments. Performance testing included sorting accuracy, throughput, and solar energy efficiency, while user acceptance was assessed through a survey conducted among Laguna University students. The results were compared with existing benchmarks from previous mechanical and sensor-based prototypes to validate the system's practicality, reliability, and potential for scalable deployment in Philippine settings.

A. Objectives of the Study

To design and develop a solar-powered reverse vending machine for PET bottles and aluminum cans with a short bond-paper redemption system.

Specific objectives

1. To design a mechanism that segregates PET bottles and aluminum cans and dispenses short bond paper in exchange.
2. To integrate a system that automatically rejects PET bottles or aluminum cans when residual fluid is detected inside, ensuring only empty containers are accepted by the reverse vending machine.
3. To test and assess the acceptability of the solar-powered reverse vending machine through a survey conducted among 100 respondents from Laguna University.

B. Scope and Limitations of Research

This study designed, built, and field-tested a solar-powered reverse vending machine (RVM) for PET bottles and aluminum cans. The machine was sized for its power needs, constructed with appropriate materials, and optimized geometrically to run reliably on solar energy within a school campus environment. Mechanically, the RVM included a single feeder, a belt conveyor, a diverter, chutes/slides to move containers, and a cassette friction pick roller with a transport mechanism for bond-paper dispensing. Ultrasonic, weighing scale, and infrared sensors checked and classified items, while level sensors detected when collection bins reached capacity. The machine automatically dispensed short bond paper as the direct reward for each deposited item.

Table 1 PET Bottles and Aluminum Cans Equivalent to Short Bond-Paper

ACCEPTED ITEM TYPE	CONTAINER SIZE	REWARD RULE	EQUIVALENT BOND PAPER
Small PET Bottles	250–500 ml	4 pieces	1 sheet
PET Bottles	1 L	1 piece	1 sheet
PET Bottles	1.5 L	1 piece	1.5 sheets
PET Bottles	1.5 L	2 pieces	3 sheets
PET	2 L	1 piece	2 sheets (or 1.5

Bottles			sheets during low-price periods)
Aluminum Cans	250–355 ml	1–2 pieces	2 sheets

Table 1 presents the reward equivalent system of the developed reverse vending machine, showing the corresponding bond paper incentive for accepted PET bottles and aluminum cans based on their container size and quantity. This system was designed to encourage proper recycling practices and promote sustainable waste management within the university. For the detailed computation process and step-by-step derivation.

Design work produced clear engineering drawings and documentation outlining power calculations, material choices, and machine geometry. Fabrication yielded a working prototype of the mechanical subsystems and the bond-paper dispenser. Bench tests measured sorting accuracy, throughput, and operational reliability. The solar power system was sized and monitored to record energy generation and consumption during normal campus hours.

Field testing was carried out at Laguna University during the 2025–2026 academic year. Site placement was coordinated with school administrators to ensure safety, visibility, and access for servicing and data collection. Pre- and post-implementation surveys and activity logs captured user acceptance and changes in student recycling participation due to the visible, on-site reward system.

Deliverables included engineering drawings, sensor integration plans, controller logic, prototype test reports, and operation and maintenance instructions for school staff.

This study did not include large-scale commercial deployment or long-term operation beyond the pilot period. It did not develop cloud-based reward platforms, nor did it require continuous internet access. The scope excluded container compaction or crushing, detailed downstream processing or transport logistics beyond handing materials to local recyclers, and full lifecycle environmental or economic impact studies.

The study was strictly limited to PET bottles ranging from 250 mL to 1 L and aluminum cans within the specified size range. The machine operated using a maximum weight threshold to determine if a container contained excessive liquid. Due to this limitation, larger PET bottles, such as empty 1.5 L bottles, were rejected because their tare weight exceeded the preset acceptable range of the sensor even without liquid content. For this reason, 1.5 L and 2 L PET bottles were excluded from the final testing and evaluation phases of the study, though they remain listed in the preliminary baseline system matrix.

Only the short bond-paper dispensed by the machine was used as the reward; no other reward types, credits, or conversion systems were included in this study.

The project demonstrated a simple, low-maintenance, off-grid RVM that schools can use to increase container returns, reduce waste-management costs, and encourage recycling by giving students short bond-paper directly from the machine as the sole reward.

II. LITERATURE REVIEW

Foreign Literature and Studies

Foreign literature emphasizes the effectiveness of Reverse Vending Machines (RVMs) in promoting recycling, reducing litter, and supporting circular economy initiatives through incentive-based waste collection systems. Modern RVMs commonly integrate sensors, cameras, conveyors, sorting mechanisms, and reward systems to improve user participation and material recovery. Studies also highlight the importance of modular designs, sensor fusion, solar power integration, and transaction logging to improve machine reliability, sorting accuracy, and off-grid operation. Additionally, research indicates that compact machine footprints, efficient paper dispensing mechanisms, reliable diverters, and properly sized solar energy systems are essential for campus and community-based deployments [13]–[21].

Several foreign studies demonstrated the practical implementation of advanced RVM technologies. The Kazakhstan Systems Engineering Study examined the integration of RVMs into municipal waste management and found that machine capacity, collection logistics, and stakeholder cooperation significantly influence successful deployment. Another study developed a low-cost deep learning-based RVM that achieved 99.2% classification accuracy using MobileNet and collected over 650 kg of plastic waste during a six-month university deployment. Similarly, a convenience-store RVM study improved sorting efficiency through sensor fusion, barcode scanning, vision systems, and near-infrared sensors, resulting in higher classification accuracy and reduced sorting errors. These studies demonstrate the effectiveness of combining intelligent sensing, automated sorting, and incentive mechanisms to improve recycling participation and waste management efficiency [22]– [24].

Local Literature and Studies

Local studies have explored the development of community-scale reverse vending machines using affordable and locally available technologies. The Plastic2Fantastic project utilized a Raspberry Pi, RFID system, proximity sensors, load cells, and coin dispensing mechanisms to encourage plastic bottle recycling. User evaluation results showed high perceived usefulness and ease of use, indicating strong acceptance among participants. The study also recommended future improvements such as larger storage capacity, multi-denomination rewards, and solar power integration [25].

Another local study, Reverse Vending Machines: A Potential Solution for the Plastic Waste Management of Ibaan, developed an Arduino-based RVM equipped with RFID identification, weighing modules, ultrasonic sensors, and reward dispensing mechanisms. The system was designed for municipal and barangay-level waste management applications and emphasized low-cost implementation, maintainability, and user incentivization. The researchers recommended incorporating solar power systems, enhanced sorting capabilities, and larger storage capacities to improve long-term performance and scalability. These local studies demonstrate the

feasibility of implementing reverse vending machines in Philippine communities and provide valuable design concepts that support the development of the proposed Solar-Powered Reverse Vending Machine [26].

III. RESEARCH METHODOLOGY

A. General Method Use

The researchers utilized the developmental method as the primary approach to gather data and derive insights for the design and enhancement of the solar-powered reverse vending machine (RVM). This method allowed a step-by-step assessment and iterative innovation process, which was essential in identifying gaps and areas for improvement in existing waste-collection and small-scale recycling practices. The central objective of the study was to develop a compact, low-cost RVM that reliably identified, sorted, stored, and rewarded users for plastic bottle and aluminum can deposits in campus settings where conventional collection systems are limited or inefficient.

In the initial stages, the researchers conducted an extensive review of existing RVM technologies, analyzed local waste streams at target sites, and evaluated key technical elements to be incorporated into the system—such as sensor fusion for material classification using ultrasonic, weight, and infrared (IR) detectors, mechanical routing and diverters to reduce jams, load-cell weighing for reward calculation, and bin-level sensing to optimize collection cycles. Site surveys and stakeholder consultations defined constraints for the installation footprint, expected daily deposit volumes, user interaction flows, and maintenance capacities.

Subsequent phases of the research involved iterative prototyping, component selection, and experimental evaluation focusing on classification accuracy, throughput (items per hour and per day), storage capacity, and energy consumption. The researchers-built bench prototypes to validate sensor and control logic, then integrated mechanical subsystems into full prototypes for stress testing. They also implemented solar power configurations to eliminate reliance on

grid power and improve resilience for off-grid or intermittently powered locations.

Furthermore, the system’s performance was assessed not only in technical terms but also for economic viability, environmental benefits (reduced transport and increased local recycling), and potential for community adoption. Evaluation combined automated logs (including acceptance and rejection rates, weight per deposit, and fault events), observational notes, and short user surveys to triangulate findings. The developmental cycles produced a validated, context-appropriate RVM prototype, prioritized design improvements for reliability and maintainability, and demonstrated a practical pathway for scaling deployments that can increase recycling rates, reduce contamination in collection streams, and support campus-level circularity.

B. Conceptual Framework

To successfully achieve the desired outcome of this study, specific procedures, requirements, and ideas were discussed to conceptualize the project’s design and development. After a period of deliberation and brainstorming, a unified structural approach was established.

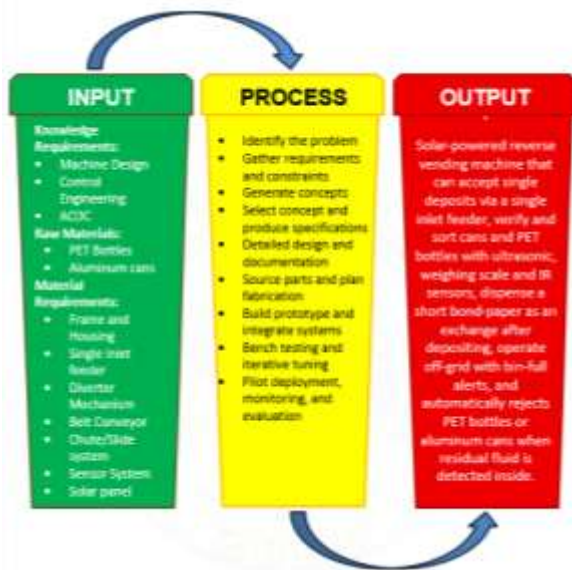


Figure 1. Conceptual framework of the study

Figure 1 shows the conceptual framework of the solar-powered reverse vending machine, composed of three interconnected phases: input, process, and output. The diagram frames how technical knowledge, recyclable feedstock, and physical components fed a structured engineering workflow that culminated in an off-grid, automated deposit, verification, sorting, and reward system. Understanding the relationships between these phases is essential for designing a reliable, user-friendly, and energy-autonomous prototype.

The input phase lists the knowledge domains, raw materials, and material components required to realize the machine. Knowledge requirements include machine design, control engineering, and AC/DC power expertise needed for mechanical systems, sensing, embedded control, and solar/battery power management. The raw material stream focuses on PET bottles and aluminum cans, whose geometries and material properties shape feeder, sensing, and sorting designs. Material requirements define the primary subsystems: a structural frame and housing, a single inlet feeder to accept items, a diverter mechanism to route items, a belt conveyor and chute/slide for controlled transport, a sensor system (ultrasonic, weight, and IR) for verification, and a solar panel to enable off-grid operation.

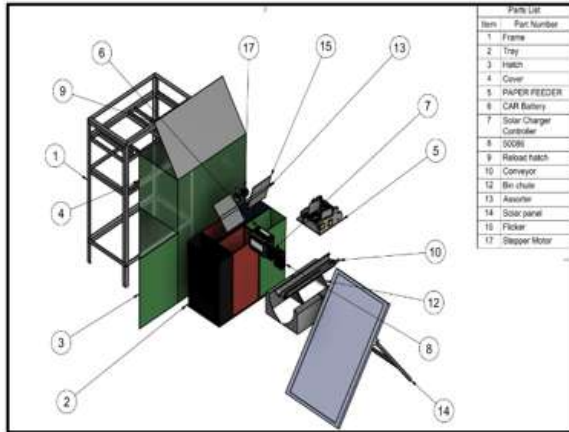
The process phase describes the engineering lifecycle used to convert inputs into a working system. Work began with problem identification and the gathering of functional and nonfunctional requirements and constraints. Concept generation produced multiple handling, sensing, and reward delivery approaches; selected concepts were refined into specifications and detailed designs. The team then sourced parts, planned fabrication, and built an integrated prototype. Bench testing and iterative tuning of mechanical, sensing, and control subsystems followed, and a pilot deployment evaluated real-world performance, user flow, reliability, and maintenance needs.

The output phase defines the completed system capabilities and user services. The delivered product is a solar-powered reverse vending machine that accepts single deposits via a single inlet feeder, verifies and sorts of PET bottles and aluminum cans

using ultrasonic, weighing scale, and IR sensors, and dispenses short bond-paper after a successful deposit. The system operates off-grid, issues bin-full alerts and supports reliable sorting and user feedback to promote recycling, reduce manual handling, and automatically rejects PET bottles or aluminum cans when residual fluid is detected inside.

C. Machine Design

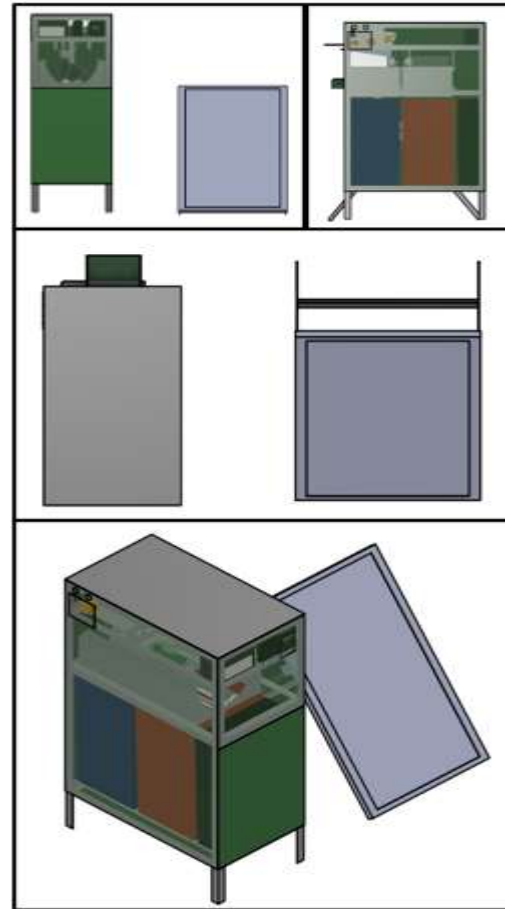
Figure 2. Exploded view of the machine



The Solar-Powered Reverse Vending Machine consists of a conveyor-based sorting mechanism, sensors for identifying PET bottles and aluminum cans, a weighing scale sensor for liquid detection, a Raspberry Pi control system, and a short bond-paper dispensing mechanism. The system uses a conveyor and servo-operated segregation mechanism to automatically classify recyclable containers and direct them to their designated bins. The machine is powered by a solar panel and deep-cycle battery system, providing a sustainable and energy-efficient solution for waste segregation and recycling.

Figure 3. Technical Design of Solar-Powered Reverse Vending Machine

Figure 3 shows the front view, side view, top view, and isometric view, of the Solar-Powered Reverse Vending Machine.



C. Data Flow Diagram

Figure 4. Use Case for Solar-Powered Reverse Vending Machine

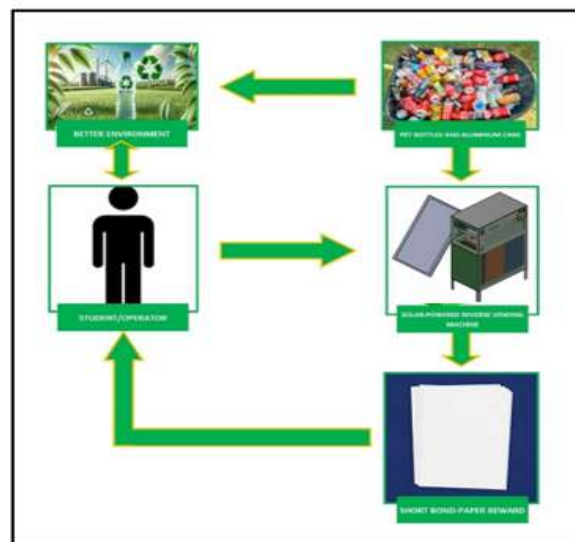


Figure 4 shows the use case established in this requirement specification. The student, acting as the

depositor, inserts PET bottles or aluminum cans into the solar-powered reverse vending machine installed at Laguna University. Upon successful validation, the machine dispenses a short bond-paper reward, encouraging the student to participate in proper waste disposal. This process not only promotes environmental awareness and cleanliness on campus but also empowers students to take an active role in sustainability efforts. By using the machine, students contribute to a greener university environment while benefiting from a simple, rewarding recycling experience.

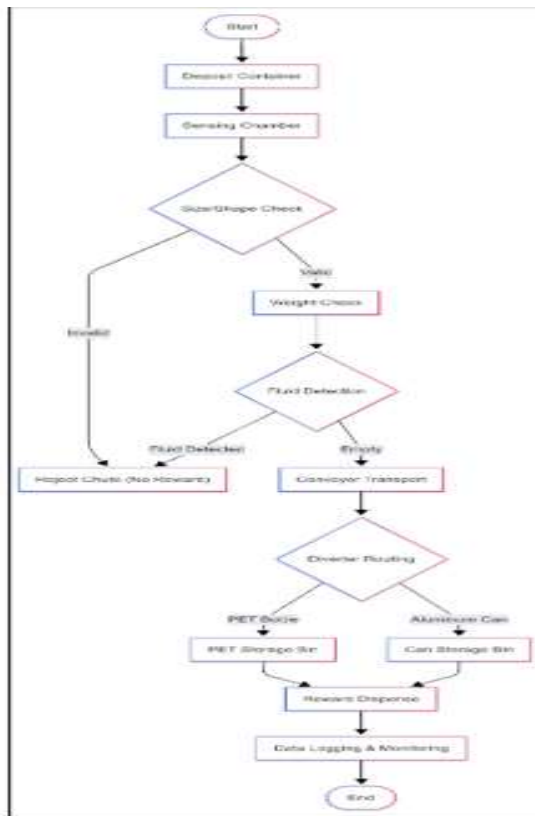


Figure 5. Process Flowchart of the Solar-Powered Reverse Vending Machine

Figure 5 illustrates the process flow of the solar-powered reverse vending machine (RVM) starting from the local display control interface. The user initiates the transaction by selecting the option to deposit a container. Once a PET bottle or aluminum can is inserted, the item passes through the sensing chamber where it undergoes a series of verification checks. First, the system validates the size and shape of the container, followed by a weight check to

ensure it falls within the expected range. A fluid-detection mechanism is then applied; if residual liquid is detected, the container is automatically rejected through a designated chute, and no reward is dispensed.

For empty and valid containers, the conveyor transports the item to the diverter, which routes PET bottles and aluminum cans into separate storage bins. Upon successful acceptance, the reward dispenser issues the corresponding bond-paper sheet equivalence, while the control panel provides feedback to the user. Finally, the system logs all accepted and rejected transactions, including reward dispenses and operational data, before returning to standby mode.

IV. RESULTS AND DISCUSSION

A.) Design computation

TABLE 2 Summary of Computations

Parameters		Formula	Values
Determination of Belt Conveyor Velocity	Low throughput	$v = \text{pitch} \times \frac{\text{items/min}}{s}$	$v = 0.04 \frac{m}{s}$
	High throughput	$v = \text{pitch} \times \frac{\text{items/min}}{s}$	$v = 0.06 \frac{m}{s}$
Determination of drive sizing	Normal Load	$N = m_{max} \cdot g$	$N = 0.589N$
	Traction force	$F_{tr} = \mu \cdot N$	$F_{tr} = 0.353N$
Determination of Power Requirement	Torque at roller	$\tau = F_{req} \cdot r$	$\tau = 0.0125 N \cdot m$
	Angular Speed	$\omega = \frac{v}{r}$	$\omega = 2 \frac{rad}{s}$
		$RPM = \frac{\omega 60}{2\pi}$	$RPM = 19.1$
	Power	$P = \frac{2\pi TN}{60}$	$P = 0.030 W$
Design Power	$P_{design} = P \cdot S \cdot F_{cont}$	$P_{design} = 0.12W$	
Determination of Battery Sizing	Energy requirement	$E_{daily} = P_{load} \cdot t_{op}$	$E_{daily} = 120 Wh$
	Energy for autonomy	$E_{aut} = E_{daily} \cdot 2$	$E_{aut} = 240 Wh$
	Usable energy	$E_{bat, nom} = \frac{E_{aut}}{DoD}$	$E_{bat, nom} = 480 Wh$

	with DoD 50%		
	Capacity at 12V	$C_{Ah} = \frac{E_{bnt,nom}}{V_{sys}}$	$C_{Ah} = 40 Ah$
Determinati on of Solar Panel Sizing	PV Energy	$E_{PV} = \frac{E_{daily}}{\eta_{sys}}$	$E_{PV} = 150 Wh$
	Required PV Power	$P_{PV} = \frac{E_{PV}}{PSH \cdot \eta_{PV}}$	$P_{PV} = 44 W$
Charge controller and wiring		$I_{ctrl} \geq \frac{P_{PV}}{V_{sys}}$	$I_{ctrl} = 8.3 A$
Determinati on of Bond paper equivalence	PET Bottles 250 mL	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.144$ $V_{high} = \text{₱}0.192$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 0.277$ $S_{high} = 0.400$
	PET Bottles 290 mL	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.192$ $V_{high} = \text{₱}0.256$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 0.369$ $S_{high} = 0.533$
	PET Bottles 500 mL	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.246$ $V_{high} = \text{₱}0.326$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 0.462$ $S_{high} = 0.667$
	PET Bottles 1 Liter	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.426$ $V_{high} = \text{₱}0.566$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 0.808$ $S_{high} = 1.167$
	PET Bottles 1.5 Liters	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.606$ $V_{high} = \text{₱}0.806$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 1.154$ $S_{high} = 1.667$
	PET Bottles 2 Liters	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.726$ $V_{high} = \text{₱}0.966$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 1.385$ $S_{high} = 2.00$
	Aluminu m can 250 mL	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.636$ $V_{high} = \text{₱}0.986$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 1.212$ $S_{high} = 2.042$
	Aluminu m can	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.636$ $V_{high} = \text{₱}0.986$

	330 mL	$S = \frac{V}{P_{sheet}}$	$S_{low} = 1.212$ $S_{high} = 2.042$
	Aluminu m can 355 mL	$V = m_{piece} \cdot P_{PET}$	$V_{low} = \text{₱}0.673$ $V_{high} = \text{₱}1.056$
		$S = \frac{V}{P_{sheet}}$	$S_{low} = 1.298$ $S_{high} = 2.187$

The table 2 presents the calculated baseline values necessary to design the solar-powered reverse vending machine for aluminum cans and PET bottles with a short bond-paper redemption system.

TABLE 3 Functional Testing of Segregation & Acceptance for 250 mL to 500 mL

TRIAL NO.	INPUT TYPE (PET/CANS)	ACCEPT ANCE RESULT (EMPTY / WITH LIQUID)	SEGREGATIO N RESULT (CORRECT/IN CORRECT)	REMAR KS
1	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
2	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
3	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
4	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
5	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
6	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
7	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
8	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
9	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
10	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL

11	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
12	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
13	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
14	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
15	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
16	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
17	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
18	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
19	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
20	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
21	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
22	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
23	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
24	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
25	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
26	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
27	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
28	PET	EMPTY	INCORRECT	NO

	SMAL L			DETEC TION
29	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
30	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
31	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
32	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
33	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
34	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
35	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
36	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
37	PET SMAL L	EMPTY	INCORRECT	WRON G BIN
38	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
39	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
40	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
41	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
42	PET SMAL L	EMPTY	INCORRECT	NO DETEC TION
43	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
44	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
45	PET SMAL	EMPTY	CORRECT	SUCCE SSFUL

	L			
46	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
47	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
48	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
49	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL
50	PET SMAL L	EMPTY	CORRECT	SUCCE SSFUL

In Table 3, the input type refers to the material inserted into the machine, either a PET bottle or an aluminum can. The acceptance result indicates whether the inserted container is empty or contains liquid during the testing process. The segregation result determines whether the material was properly sorted into its designated bin, classified as correct or incorrect. Lastly, the remarks provide additional observations regarding the machine's performance, such as accepted or rejected inputs, detection issues, or other system-related conditions encountered during testing.

TABLE 4 Bond Paper Dispensing System Testing for 250 mL to 500 mL

TRIAL NO.	INPUT ACCE PTED (YES/ NO)	EXPE CTED NO. OF OUTP UTS	ACT UAL NO. OF PAPE RS	DISPEN SING TIME (SEC)	REMAR KS
1	YES	0	0		NO REWAR D
2	YES	0	0		NO REWAR D
3	YES	0	0		NO REWAR D
4	YES	1	1	2 secs.	SUCCES SFUL
5	NO	0	0		NO REWAR

					D
6	YES	0	0		NO REWAR D
7	NO	0	0		NO REWAR D
8	YES	0	0		NO REWAR D
9	YES	0	0		NO REWAR D
10	YES	1	1	2 secs.	SUCCES SFUL
11	YES	0	0		NO REWAR D
12	YES	0	0		NO REWAR D
13	YES	0	0		NO REWAR D
14	YES	1	1	2 secs.	SUCCES SFUL
15	YES	0	0		NO REWAR D
16	NO	0	0		NO REWAR D
17	YES	0	0		NO REWAR D
18	YES	0	0		NO REWAR D
19	YES	1	1	2 secs.	SUCCES SFUL
20	YES	0	0		NO REWAR D
21	YES	0	0		NO REWAR D
22	YES	0	0		NO REWAR D
23	YES	1	1	2 secs.	SUCCES SFUL
24	YES	0	0		NO

					REWARD
25	YES	0	0		NO REWARD
26	YES	0	0		NO REWARD
27	NO	0	0		NO REWARD
28	NO	0	0		NO REWARD
29	YES	1	1	2 secs.	SUCCESSFUL
30	YES	0	0		NO REWARD
31	YES	0	0		NO REWARD
32	YES	0	0		NO REWARD
33	YES	1	1	2 secs.	SUCCESSFUL
34	NO	0	0		NO REWARD
35	NO	0	0		NO REWARD
36	NO	0	0		NO REWARD
37	YES	0	0		NO REWARD
38	YES	0	0		NO REWARD
39	YES	0	0		NO REWARD
40	YES	1	1	2 secs.	SUCCESSFUL
41	YES	0	0		NO REWARD
42	YES	0	0		NO REWARD

					D
43	YES	0	0		NO REWARD
44	YES	1	1	2 secs.	SUCCESSFUL
45	YES	0	0		NO REWARD
46	YES	0	0		NO REWARD
47	YES	0	0		NO REWARD
48	YES	1	1	2 secs.	SUCCESSFUL
49	YES	0	0		NO REWARD
50	YES	0	0		NO REWARD

Table 4 shows the input accepted, indicating whether the machine successfully accepted the inserted material during the testing process. The expected number of outputs refers to the intended number of paper rewards based on the accepted container type and size. The actual number of papers represents the actual quantity of paper dispensed by the machine. The Dispensing Time (sec) measures the time required for the machine to release the paper reward after processing the input. Lastly, the remarks provide additional observations such as successful dispensing, delayed output, paper jam, or incorrect paper quantity during testing.

TABLE 5 Overall System Performance Summary for 250 mL to 500 mL

PARAMETER	TOTAL TRIALS	SUCCESSFUL TRIALS	FAILURE TRIALS	ACCURACY (%)
Segregation System	50	42	8	84%
Dispensing System	50	42	8	84%
Overall System	50	42	8	84%

The total trials represent the overall number of test runs conducted during the evaluation of the machine. The Successful Trials refer to the number of trials in which the machine operated correctly according to the defined criteria, while the Failure Trials indicate the number of trials that resulted in errors or malfunctions. The accuracy expresses the percentage of successful trials relative to the total number of trials, providing a quantitative measure of the machine's overall performance.

TABLE 6 Functional Testing of Segregation & Acceptance for 1 Liter

TRIAL NO.	INPUT TYPE (PET/CAN)	ACCEPTANCE RESULT (EMPTY /WITH LIQUID)	SEGREGATION RESULT (CORRECT/INCORRECT)	REMARKS
1	YES	EMPTY	CORRECT	SUCCESSFUL
2	YES	EMPTY	CORRECT	SUCCESSFUL
3	YES	EMPTY	CORRECT	SUCCESSFUL
4	YES	EMPTY	CORRECT	SUCCESSFUL
5	NO	EMPTY	INCORRECT	WRONG DETECTION
6	YES	EMPTY	CORRECT	SUCCESSFUL
7	NO	EMPTY	INCORRECT	WRONG DETECTION
8	YES	EMPTY	CORRECT	SUCCESSFUL
9	YES	EMPTY	CORRECT	SUCCESSFUL
10	YES	EMPTY	CORRECT	SUCCESSFUL
11	NO	EMPTY	INCORRECT	WRONG DETECTION
12	YES	EMPTY	CORRECT	SUCCESSFUL
13	NO	EMPTY	INCORRECT	WRONG

14	YES	EMPTY	CORRECT	SUCCESSFUL
15	YES	EMPTY	CORRECT	SUCCESSFUL
16	NO	EMPTY	INCORRECT	WRONG DETECTION
17	YES	EMPTY	CORRECT	SUCCESSFUL
18	YES	EMPTY	CORRECT	SUCCESSFUL
19	NO	EMPTY	INCORRECT	WRONG DETECTION
20	YES	EMPTY	CORRECT	SUCCESSFUL
21	YES	EMPTY	CORRECT	SUCCESSFUL
22	YES	EMPTY	CORRECT	SUCCESSFUL
23	YES	EMPTY	CORRECT	SUCCESSFUL
24	YES	EMPTY	CORRECT	SUCCESSFUL
25	YES	EMPTY	CORRECT	SUCCESSFUL
26	YES	EMPTY	CORRECT	SUCCESSFUL
27	YES	EMPTY	CORRECT	SUCCESSFUL
28	YES	EMPTY	CORRECT	SUCCESSFUL
29	YES	EMPTY	CORRECT	SUCCESSFUL
30	YES	EMPTY	CORRECT	SUCCESSFUL
31	YES	EMPTY	CORRECT	SUCCESSFUL
32	YES	EMPTY	CORRECT	SUCCESSFUL
33	YES	EMPTY	CORRECT	SUCCESSFUL
34	YES	EMPTY	CORRECT	SUCCESSFUL
35	YES	EMPTY	CORRECT	SUCCESSFUL
36	YES	EMPTY	CORRECT	SUCCESSFUL

37	YES	EMPTY	CORRECT	SUCCESSFUL
38	YES	EMPTY	CORRECT	SUCCESSFUL
39	YES	EMPTY	CORRECT	SUCCESSFUL
40	YES	EMPTY	CORRECT	SUCCESSFUL
41	YES	EMPTY	CORRECT	SUCCESSFUL
42	YES	EMPTY	CORRECT	SUCCESSFUL
43	YES	EMPTY	CORRECT	SUCCESSFUL
44	NO	EMPTY	INCORRECT	WRONG DETECTION
45	YES	EMPTY	CORRECT	SUCCESSFUL
46	YES	EMPTY	CORRECT	SUCCESSFUL
47	YES	EMPTY	CORRECT	SUCCESSFUL
48	YES	EMPTY	CORRECT	SUCCESSFUL
49	YES	EMPTY	CORRECT	SUCCESSFUL
50	YES	EMPTY	CORRECT	SUCCESSFUL

7	NO	0	0		No reward
8	YES	1	1	2 secs.	Successful
9	YES	0	0		No reward
10	YES	1	1	2 secs.	Successful
11	NO	0	0		No reward
12	YES	1	1	2 secs.	Successful
13	NO	0	0		No reward
14	YES	1	1	2 secs.	Successful
15	YES	0	0		No reward
16	NO	0	0		No reward
17	YES	0	0		No reward
18	YES	1	1	2 secs.	Successful
19	NO	0	0		No reward
20	YES	1	1	2 secs.	Successful
21	YES	0	0		No reward
22	YES	1	1	2 secs.	Successful
23	YES	0	0		No reward
24	YES	1	1	2 secs.	Successful
25	YES	0	0		No reward
26	YES	1	1	2 secs.	Successful
27	YES	0	0		No reward
28	YES	1	1	2 secs.	Successful
29	YES	0	0		No reward
30	YES	1	1	2 secs.	Successful
31	YES	0	0		No reward
32	YES	1	1	2 secs.	Successful

TABLE 7 Bond Paper Dispensing System Testing for 1 Liter

TRIAL NO.	INPUT ACCEPTED (YES/NO)	EXPECTED NO. OF OUTPUT	ACTUAL NUMBER OF PAPER	DISPENSING TIME (SEC)	REMARKS
1	YES	0	0		No reward
2	YES	1	1	2 secs.	Successful
3	YES	0	0		No reward
4	YES	1	1	2 secs.	Successful
5	NO	0	0		No reward
6	YES	1	1	2 secs.	Successful

33	YES	0	0		No reward
34	YES	1	1	2 secs.	Successful
35	YES	0	0		No reward
36	YES	1	1	2 secs.	Successful
37	YES	0	0		No reward
38	YES	1	1	2 secs.	Successful
39	YES	0	0		No reward
40	YES	1	1	2 secs.	Successful
41	YES	0	0		No reward
42	YES	1	1	2 secs.	Successful
43	YES	0	0		No reward
44	NO	0	0		No reward
45	YES	1	1	2 secs.	Successful
46	YES	0	0		No reward
47	YES	1	1	2 secs.	Successful
48	YES	0	0		No reward
49	YES	1	1	2 secs.	Successful
50	YES	0	0		No reward

TABLE 8 Overall System Performance Summary for 1 Liter

PARAMETER	TOTAL TRIALS	SUCCESSFUL TRIALS	FAILURE TRIALS	ACCURACY (%)
Segregation System	50	43	7	86%
Dispensing System	50	43	7	86%
Overall System	50	43	7	86%

TABLE 9 Functional Testing of Segregation & Acceptance for Aluminum Cans

TRIAL NO.	INPUT TYPE (PET/CAN)	ACCEPTANCE RESULT (EMPTY /WITH LIQUID)	SEGREGATION RESULT (CORRECT/INCORRECT)	REMARKS
1	CAN	EMPTY	CORRECT	SUCCESSFUL
2	CAN	EMPTY	CORRECT	SUCCESSFUL
3	CAN	EMPTY	INCORRECT	DELAY DETECTION
4	CAN	EMPTY	CORRECT	SUCCESSFUL
5	CAN	EMPTY	CORRECT	SUCCESSFUL
6	CAN	EMPTY	CORRECT	SUCCESSFUL
7	CAN	EMPTY	INCORRECT	DELAY DETECTION
8	CAN	EMPTY	CORRECT	SUCCESSFUL
9	CAN	EMPTY	CORRECT	SUCCESSFUL
10	CAN	EMPTY	CORRECT	SUCCESSFUL
11	CAN	EMPTY	CORRECT	SUCCESSFUL
12	CAN	EMPTY	CORRECT	SUCCESSFUL
13	CAN	EMPTY	CORRECT	SUCCESSFUL
14	CAN	EMPTY	CORRECT	SUCCESSFUL
15	CAN	EMPTY	INCORRECT	DELAY DETECTION
16	CAN	EMPTY	CORRECT	SUCCESSFUL
17	CAN	EMPTY	CORRECT	SUCCESSFUL
18	CAN	EMPTY	CORRECT	SUCCESSFUL
19	CAN	EMPTY	INCORRECT	DELAY DETECTION
20	CAN	EMPTY	CORRECT	SUCCESSFUL

21	CAN	EMPTY	INCORRECT	DELAY DETECTION
22	CAN	EMPTY	INCORRECT	DELAY DETECTION
23	CAN	EMPTY	CORRECT	SUCCESSFUL
24	CAN	EMPTY	CORRECT	SUCCESSFUL
25	CAN	EMPTY	CORRECT	SUCCESSFUL
26	CAN	EMPTY	CORRECT	SUCCESSFUL
27	CAN	EMPTY	CORRECT	SUCCESSFUL
28	CAN	EMPTY	CORRECT	SUCCESSFUL
29	CAN	EMPTY	CORRECT	SUCCESSFUL
30	CAN	EMPTY	CORRECT	SUCCESSFUL
31	CAN	EMPTY	CORRECT	SUCCESSFUL
32	CAN	EMPTY	CORRECT	SUCCESSFUL
33	CAN	EMPTY	CORRECT	SUCCESSFUL
34	CAN	EMPTY	CORRECT	SUCCESSFUL
35	CAN	EMPTY	CORRECT	SUCCESSFUL
36	CAN	EMPTY	CORRECT	SUCCESSFUL
37	CAN	EMPTY	CORRECT	SUCCESSFUL
38	CAN	EMPTY	CORRECT	SUCCESSFUL
39	CAN	EMPTY	CORRECT	SUCCESSFUL
40	CAN	EMPTY	INCORRECT	DELAY DETECTION
41	CAN	EMPTY	CORRECT	SUCCESSFUL
42	CAN	EMPTY	CORRECT	SUCCESSFUL
43	CAN	EMPTY	CORRECT	SUCCESSFUL
44	CAN	EMPTY	INCORRECT	DELAY DETECTION

45	CAN	EMPTY	CORRECT	SUCCESSFUL
46	CAN	EMPTY	CORRECT	SUCCESSFUL
47	CAN	EMPTY	CORRECT	SUCCESSFUL
48	CAN	EMPTY	CORRECT	SUCCESSFUL
49	CAN	EMPTY	CORRECT	SUCCESSFUL
50	CAN	EMPTY	CORRECT	SUCCESSFUL

TABLE 10 Bond Paper Dispensing System Testing for Aluminum Cans

TRIAL NO.	INPUT ACCEPTED (YES/NO)	EXPECTED NO. OF OUTPUT	ACTUAL NUMBER OF PAPER	DISPENSING TIME (SEC)	REMARKS
1	YES	1	1	2 secs.	Successful
2	YES	1	1	2 secs.	Successful
3	NO	0	0		No reward
4	YES	1	1	2 secs.	Successful
5	YES	1	1	2 secs.	Successful
6	YES	1	1	2 secs.	Successful
7	NO	0	0		No reward
8	YES	1	1	2 secs.	Successful
9	YES	1	1	2 secs.	Successful
10	YES	1	1	2 secs.	Successful
11	YES	1	1	2 secs.	Successful
12	YES	1	1	2 secs.	Successful
13	YES	1	1	2 secs.	Successful
14	YES	1	1	2 secs.	Successful
15	NO	0	0		No reward

16	YES	1	1	2 secs.	Successful
17	YES	1	1	2 secs.	Successful
18	YES	1	1	2 secs.	Successful
19	NO	0	0		No reward
20	YES	1	1	2 secs.	Successful
21	NO	0	0		No reward
22	NO	0	0		No reward
23	YES	1	1	2 secs.	Successful
24	YES	1	1	2 secs.	Successful
25	YES	1	1	2 secs.	Successful
26	YES	1	1	2 secs.	Successful
27	YES	1	1	2 secs.	Successful
28	YES	1	1	2 secs.	Successful
29	YES	1	1	2 secs.	Successful
30	YES	1	1	2 secs.	Successful
31	YES	1	1	2 secs.	Successful
32	YES	1	1	2 secs.	Successful
33	YES	1	1	2 secs.	Successful
34	YES	1	1	2 secs.	Successful
35	YES	1	1	2 secs.	Successful
36	YES	1	1	2 secs.	Successful
37	YES	1	1	2 secs.	Successful
38	YES	1	1	2 secs.	Successful
39	YES	1	1	2 secs.	Successful
40	NO	0	0		No reward
41	YES	1	1	2 secs.	Successful

42	YES	1	1	2 secs.	Successful
43	YES	1	1	2 secs.	Successful
44	NO	0	0		No reward
45	YES	1	1	2 secs.	Successful
46	YES	1	1	2 secs.	Successful
47	YES	1	1	2 secs.	Successful
48	YES	1	1	2 secs.	Successful
49	YES	1	1	2 secs.	Successful
50	YES	1	1	2 secs.	Successful

TABLE 11 Overall System Performance Summary for Aluminum Cans

PARAMETER	TOTAL TRIALS	SUCCESSFUL TRIALS	FAILURE TRIALS	ACCURACY (%)
Segregation System	50	42	8	84%
Dispensing System	50	42	8	84%
Overall System	50	42	8	84%

TABLE 12 Overall System Performance

PARAMETER	250 TO 500 mL PET BOTTLES	1 LITER PET BOTTLES	ALUMINUM CANS	MACHINE AVERAGE ACCURACY (%)
Accuracy (%)	84%	86%	84%	84.67%

Table 12 presents the overall system performance of the developed solar-powered reverse vending machine in terms of accuracy for different recyclable materials. The results indicate that the machine achieved an accuracy of 84% for 250 to 500 mL PET bottles, 86% for 1 Liter PET bottles, and 84% for aluminum cans. Based on the conducted prototype testing, the machine obtained an overall average accuracy of 84.67%, indicating that the system was

generally functional and capable of properly identifying, segregating, and processing recyclable materials during operation.

V. CONCLUSION

The study concludes that the developed Solar-Powered Reverse Vending Machine can identify, segregating, and processing PET bottles and aluminum cans while automatically dispensing short bond paper as a reward to users. The integrated weight-based liquid detection system was found to be functional in rejecting containers with excessive liquid content, although some limitations in detection accuracy were observed during testing. Despite these limitations, the machine demonstrated satisfactory performance in promoting proper waste segregation and recycling practices.

Furthermore, the developed machine successfully encouraged recycling awareness and environmental sustainability within Laguna University by providing an accessible and incentive-based waste management solution. The survey results revealed a high level of user acceptance and satisfaction regarding the machine's functionality, usability, and sustainability features. Overall, the findings indicate that the developed Solar-Powered Reverse Vending Machine is a functional, innovative, and sustainable technology that can contribute significantly to improving waste management practices and supporting environmental conservation efforts within the university community.

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M.A.E.P.
L.D.V.
T.D.L.

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