

Design and Development of an IoT-Enabled Smart Energy Meter with Automatic Recharge for Prepaid Electricity Users in Rwanda

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Abstract—prepaid electricity metering in Rwanda is dominated by token-based systems that require manual entry on a keypad, which can be inconvenient and contributes to delay recharging and avoidable service interruptions. This paper presents the design and prototype implementation of an Internet-of-Things (IoT) smart energy meter that measures voltage, current, power, energy, and frequency in real time, logs consumption to a remote MySQL database, and supports automatic recharge notifications. The proposed architecture combines a PZEM-004T metering module with an ESP32 microcontroller for data acquisition and Wi-Fi connectivity, a local 16×2 LCD for in-situ visibility, a relay for load control, and an SMS gateway for low-balance alerts. A web dashboard and a Blynk-based mobile interface provide real-time visualization and access to historical records. Prototype verification using representative residential loads demonstrates end-to-end sensing, data transmission, and alerting, and a component-level cost analysis indicates that a functional prototype can be realized at approximately 75,000 RWF (≈USD 50-60, depending on exchange rates). The results suggest that locally-adapted smart metering with automated recharge support can improve user experience, reduce unplanned disconnections, and provide a practical pathway toward more data-driven energy management in Rwanda's grid-connected households.

Keywords—Smart energy meter, prepaid metering, IoT, ESP32, PZEM-004T, MySQL, SMS alerts, real-time monitoring, Rwanda..

I. INTRODUCTION

Electricity access in Sub-Saharan Africa has improved in recent years, yet utilities and consumers continue to face operational and customer-service challenges arising from billing inaccuracies, limited visibility of consumption, and the practical frictions of prepaid credit management [4]-[7]. In Rwanda, the predominant prepaid approach relies on purchasing a numeric token and manually entering it into the household meter. While prepaid metering supports budgeting and revenue assurance, manual entry can be inconvenient and error-prone, and it offers limited real-time feedback for managing consumption [14], [15]. This paper presents the design and evaluation of a low-cost IoT-enabled smart energy meter prototype that (i) measures key electrical parameters in real time, (ii) transmits readings to a database for visualization and auditability, and (iii) supports automated low-balance notifications and remote recharge workflows to reduce unexpected outages in residential environments.

This work addresses the gap between widely deployed prepaid meters and more advanced smart metering functions (real-time analytics, automated alerts, and simplified recharge workflows) by developing a locally implementable smart energy meter prototype. The main contributions are: (1) an end-to-end architecture for real-time electrical parameter sensing and networked logging using ESP32 and a commodity metering module; (2) a recharge support workflow based on

low-balance SMS notifications and database-backed account handling; and (3) an economic assessment of prototype bill of materials to inform feasibility in cost-constrained settings.

The remainder of the paper is organized as follows. Section II reviews related work on smart and prepaid metering and IoT-based monitoring. Section III describes the methodology and system requirements. Section IV details the hardware/software implementation. Section V presents prototype verification, economic findings, and discussion. Section VI concludes with recommendations for scaling and future

II. RELATED WORK

Smart metering has evolved from electromechanical and early digital meters toward systems that support remote data acquisition and richer power-quality and usage analytics [8]-[11]. The introduction of automated meter reading (AMR) and, later, advanced metering infrastructure (AMI) enabled more frequent measurement, improved billing accuracy, and operational capabilities such as outage detection and load profiling [10], [11].

In prepaid contexts, remote and mobile-assisted recharging has been explored to reduce service interruptions and streamline payment workflows [12]. In Rwanda, the Cash Power prepaid system has improved revenue collection and budgeting behavior, but it still depends on manual token entry at the meter for many customers [14], [15].

Recent research prototypes and deployments increasingly leverage IoT microcontrollers and low-cost metering sensors to provide real-time monitoring, local visualization, and cloud-connected dashboards for household energy management [19]-[21]. Such designs typically transmit voltage, current, power, and energy data over Wi-Fi or cellular networks to a backend for storage and visualization, allowing users to track consumption patterns and take corrective actions.

However, deployment in developing-country settings faces constraints including upfront costs, connectivity reliability, maintenance capacity, and user training needs [22], [23]. These constraints motivate locally adaptable designs that balance functionality, cost, and robustness in Rwanda's residential environment.

III. METHODOLOGY

A design-science methodology was adopted to translate user and utility challenges into system requirements and validate a working prototype. The process comprised: (A) requirement elicitation based on observed shortcomings of token-based prepaid meters; (B) system design (hardware, communications, data model, and user interfaces); (C) implementation of the prototype; and (D) verification through controlled testing and cost analysis.

A. Requirements and Functional Specification

The prototype targets residential prepaid electricity users and emphasizes: (1) real-time measurement of voltage, current, power, frequency, and accumulated energy; (2) local display of key parameters; (3) remote logging to enable dashboards and historical analysis; (4) low-balance detection and SMS alerts to prompt timely recharge; and (5) load disconnection logic when credit is depleted or critical thresholds are reached.

B. Data Collection Approach

Two complementary data streams are considered. Quantitative data consist of time-stamped electrical measurements acquired from the metering module and transmitted to the database. Qualitative data consist of user feedback on usability (visibility of consumption, convenience of alerts, and perceived reduction of recharge friction). In the prototype stage, emphasis was placed on technical verification of the measurement-to-dashboard pipeline and alerting behavior.

C. Evaluation Criteria

Prototype performance was evaluated against: (i) end-to-end functionality (sensing → processing → transmission → storage → visualization); (ii) responsiveness of real-time updates and alerts under typical Wi-Fi connectivity; and (iii) economic feasibility via a bill-of-materials cost estimate using locally referenced component prices.

IV. SYSTEM DESIGN AND IMPLEMENTATION

This chapter documents the practical design and implementation of the proposed smart energy meter prototype, with emphasis on how the selected hardware and software components were integrated to deliver real-time metering,

remote monitoring, automated alerts, and load control. The prototype was conceptualized as an IoT-enabled prepaid-style energy management system capable of measuring key electrical parameters, presenting them locally to the user, transmitting readings to a backend database for storage and analysis, and enforcing control actions (warning alerts and disconnection) when energy balance becomes low or reaches zero. The overall design goal was to ensure accurate measurement, reliable communication, responsive control, and user-friendly interaction in realistic household operating conditions.

At the heart of the prototype is the ESP32 microcontroller, selected for its strong processing capability, low power consumption, and built-in Wi-Fi/Bluetooth features that support Internet of Things deployments. In the implemented system, the ESP32 serves as the main controller responsible for continuous acquisition of energy measurements from the sensor module, real-time processing and formatting of readings, updating the LCD interface, and transmitting data to the server/database through a wireless connection. In addition, the ESP32 executes the system decision logic, including threshold checks for low-balance conditions, triggering SMS notifications, and controlling the relay to disconnect or reconnect the load based on balance status. The central role of the ESP32 as the orchestrating unit is illustrated in the system block representation.

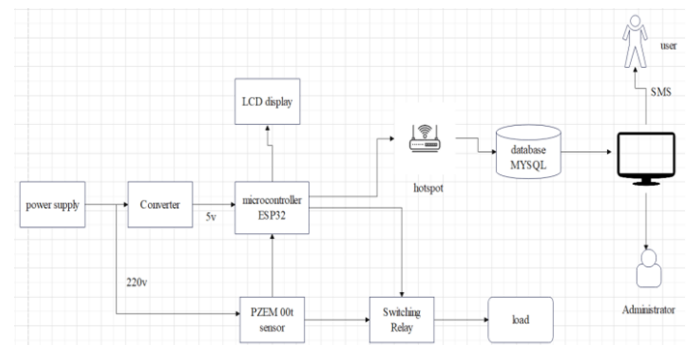


Figure 1. Block Diagram

Energy metering is implemented using the PZEM-004T energy metering module, which measures critical electrical parameters including voltage, current, power, frequency, and cumulative energy (kWh). The module communicates with the ESP32 over a serial interface, enabling continuous and structured data acquisition. The PZEM-004T was selected because it provides stable real-time parameter measurement suitable for validating the prototype's monitoring and reporting functions. The measured parameters form the basis for local user feedback (LCD) and backend storage (MySQL), enabling real-time monitoring and historical analytics.

To ensure that users can access consumption data even without a mobile phone or persistent connectivity, the prototype integrates a 16×2 LCD, which functions as the local user interface. The LCD displays real-time values of the monitored parameters, allowing instant confirmation of current usage and system status. This local visualization is especially relevant in environments where connectivity may

be intermittent, because it ensures that basic monitoring remains available offline and improves transparency for the user.

Automated control is supported through a relay module, which provides safe electrical switching between the monitoring/control electronics and the appliance load. The relay enables the system to enforce operational rules typical of prepaid metering by disconnecting the load when balance conditions become critical. Specifically, when energy balance reaches a defined minimum threshold, the system can issue warnings; when the balance reaches zero, the relay is actuated to disconnect supply, preventing further consumption until recharged. This load-control function improves user experience by reducing unexpected outages and supports prepaid compliance by enforcing balance-based usage limitations. The integration logic behind this behavior is explicitly captured in the prototype's operational algorithm.

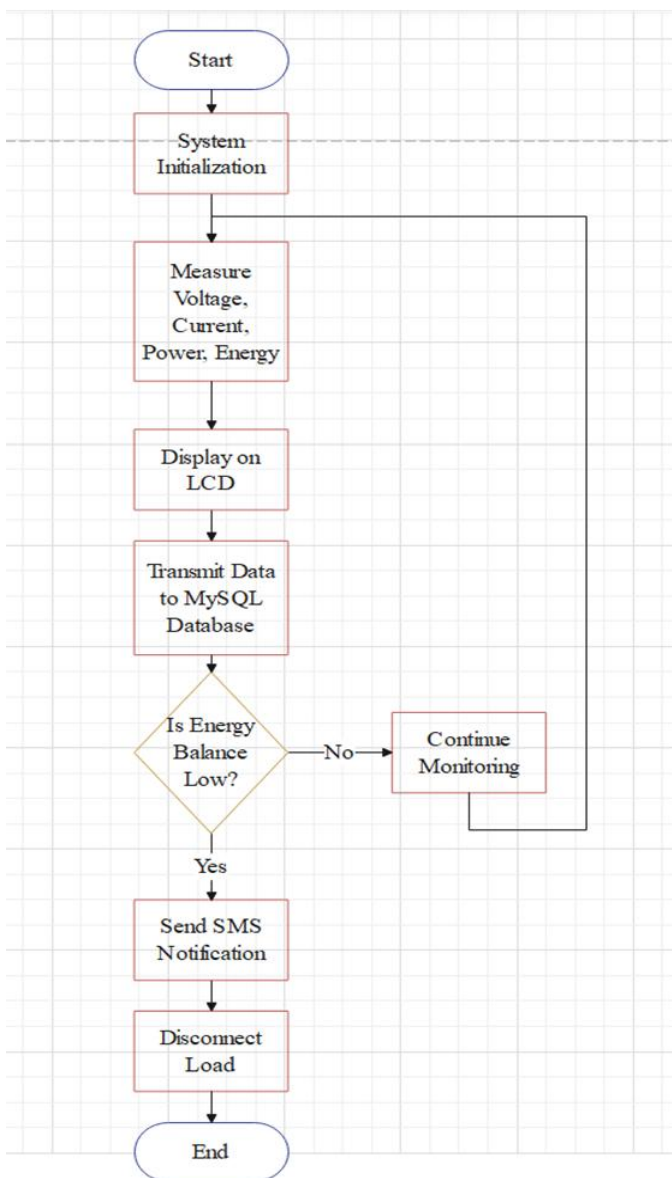


Figure 2. Algorithm design

To enhance reliability, the prototype uses a 5V power arrangement (including battery support), allowing the system controller and monitoring functions to remain active during brief interruptions. Maintaining uptime supports continuity of measurement, timely alerting, and improved robustness in real-world deployment contexts. A representative appliance load is also incorporated to validate the prototype under realistic consumption conditions and to demonstrate correct operation of sensing, monitoring, and load switching functions.

System operation follows a structured algorithm that links sensing, processing, decision-making, and user notification into a continuous loop. After initialization, the ESP32 reads the electrical parameters from the PZEM-004T sensor, updates the LCD with the most recent values, and transmits the same data to the remote MySQL database through Wi-Fi. The system then evaluates the remaining balance against predefined thresholds. If balance is above the warning threshold, monitoring continues uninterrupted; if balance falls below the warning threshold, an SMS alert is issued to prompt timely recharge; and if balance reaches zero, the relay disconnects the load to halt consumption. This closed-loop operational workflow is central to the proposed contribution because it transforms monitoring into an actionable management system rather than a passive measurement device.

To communicate the prototype clearly and support reproducibility, the design is documented using three complementary diagram layers: a block diagram, an architecture diagram, and a circuit diagram. The block diagram summarizes functional modules and system flow, showing how the AC supply is measured by the PZEM-004T, processed by the ESP32, displayed locally on the LCD, and transmitted via Wi-Fi to a MySQL database where user dashboards can visualize consumption and trigger associated services such as SMS alerts.

The architecture diagram extends this functional view by explicitly mapping stakeholder interactions. It illustrates how the user interfaces (local LCD, web dashboard, and mobile monitoring) connect through the server/database layer, while the administrator supports essential operations such as user enrollment, system updates, and balance management. This representation is important in a publishable paper because it clarifies component boundaries, communication paths, and functional roles across hardware and server-side services.

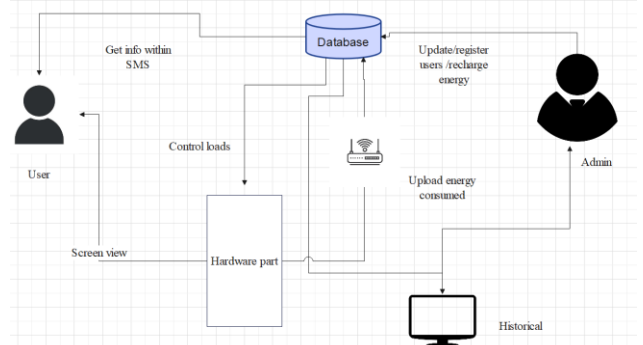


Figure 3. Architecture diagram

At implementation level, the circuit diagram documents how the controller interfaces with the metering sensor, the LCD display, and relay channels used to control loads. While detailed schematics may sometimes be moved to appendices in journal articles, including the circuit view strengthens technical clarity by demonstrating how sensing and switching were physically realized in the prototype.

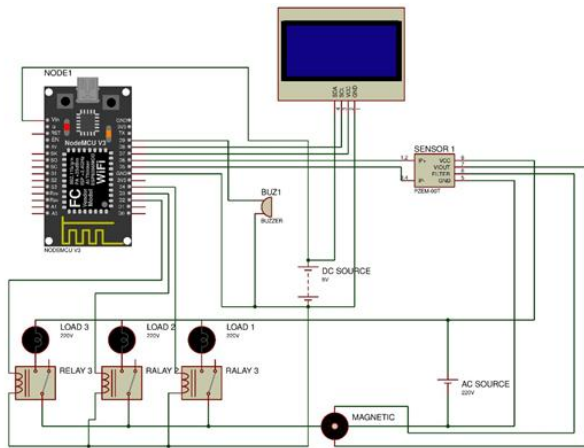


Figure 4. Circuit diagram

Beyond the embedded layer, the prototype includes a PHP-based web interface connected to a MySQL database for storing and visualizing consumption records. The system dashboard presents key indicators such as total energy consumption, estimated cost, unit pricing, and meter connection status, while providing navigation to detailed consumption views and historical records. For publication, it is usually sufficient to include only the most informative UI screenshots typically the login view, the main dashboard, and one historical/usage page so as to avoid overloading the paper with interface figures.

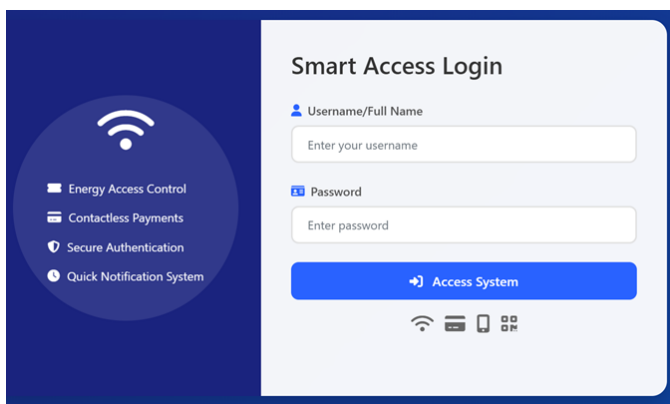


Figure 5. Login Page

Finally, the prototype supports real-time remote monitoring via the Blynk mobile platform, where the ESP32 publishes sensor-derived values to a mobile dashboard. Widgets display key parameters such as voltage, current, power, and energy consumption, enabling users to track consumption conveniently and respond quickly to alerts even

when away from the meter location. In system terms, Blynk complements the local LCD interface: the LCD provides immediate local visibility, while Blynk provides remote access and live monitoring over the internet.

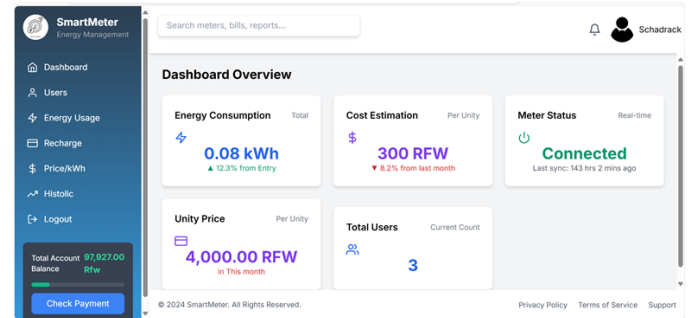


Figure 6. Dashboard

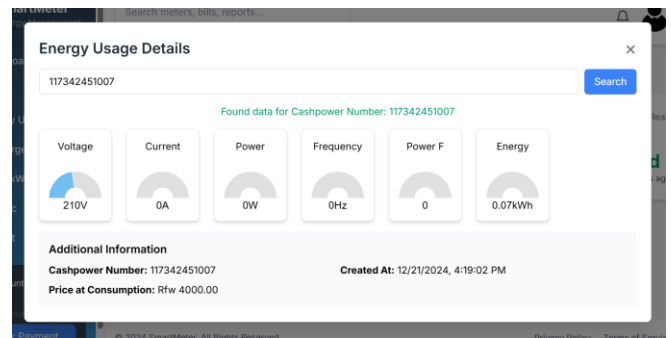


Figure 7. Energy Usage

Full Name	Sex	Age	Address	Phone	Cashpower Number	Amount	Unity	Date
Schadrack	male	26	Kigali	0788225125	117342451007	10000.00	45.45	2024-12-06 17:44:39
Schadrack	male	26	Kigali	0788225125	117342451007	30000.00	136.36	2024-12-06 17:47:26
Schadrack	male	26	Kigali	0788225125	117342451007	7.00	0.03	2024-12-06 18:01:12
Schadrack	male	26	Kigali	0788225125	117342451007	20000.00	90.91	2024-12-06 22:16:58
Schadrack	male	26	Kigali	0788225125	117342451007	50000.00	227.27	2024-12-20 14:21:17
Schadrack	male	26	Kigali	0788225125	117342451007	66.00	0.30	2024-12-20 14:33:15
Schadrack	male	26	Kigali	0788225125	117342451007	77.00	0.15	2024-12-20 14:47:08
Schadrack	male	26	Kigali	0788225125	117342451007	1000.00	1.00	2024-12-20 15:15:03
Schadrack	male	26	Kigali	0788225125	117342451007	5000.00	5.00	2024-12-20 18:41:56
Schadrack	male	26	Kigali	0788225125	117342451007	4000.00	1000.00	2024-12-21 13:33:05
Schadrack	male	26	Kigali	0788225125	117342451007	4000.00	20.00	2024-12-21 15:35:46
Schadrack	male	26	Kigali	0788225125	117342451007	60000.00	15.00	2024-12-27 15:25:14

Figure 8. Historical

In summary, the design and development of the prototype demonstrate an end-to-end smart metering solution integrating accurate sensing (PZEM-004T), IoT processing and connectivity (ESP32 + Wi-Fi), local visibility (LCD), automated enforcement (relay-based load control), persistent storage and analytics (MySQL + PHP), remote visualization (Blynk/web dashboard), and proactive notification (SMS gateway). Collectively, these integrated functions address key limitations of conventional prepaid meters especially limited visibility, user inconvenience, and delayed recharge actions while providing a scalable foundation for smart energy management in Rwanda.



Figure 9. Blynk widget monitoring of energy usage on smart phone

V. RESULTS, KEY FINDINGS, AND DISCUSSION

This chapter presents and interprets the results obtained from implementing and testing the smart energy meter prototype with automatic recharge support. The discussion focuses on three major outcome areas: (i) system performance and operational behavior, (ii) economic implications for users and utility providers, and (iii) cost evaluation and sources of technical losses. Collectively, the results demonstrate that the proposed solution improves transparency in energy consumption, supports proactive recharge decision-making through alerts, and reduces the operational burden associated with manual monitoring and metering.

5.1 System performance outcomes and operational behavior

The implemented prototype successfully delivered continuous monitoring of key electrical parameters (voltage, current, power, frequency and cumulative energy). These

measurements were processed in real time by the controller and made available through local and remote interfaces, enabling users to observe energy consumption as it occurs rather than relying on delayed or indirect estimates. The design objective of linking monitoring to action was also achieved: the system's logic supports threshold-based decision making, where warnings are generated when the balance becomes low and service interruption is enforced only when the balance reaches zero. This functionality reduces the likelihood of unexpected disconnection events because users are informed early enough to respond.

From a usability and practical deployment perspective, the results indicate that presenting consumption trends in a visual form improves user understanding of energy behavior and encourages load management decisions (e.g., shifting usage or reducing unnecessary consumption). The prototype therefore moves beyond "metering as measurement" to "metering as management" by translating raw electrical values into user-facing insights and actionable alerts.

5.2 Economic evaluation results

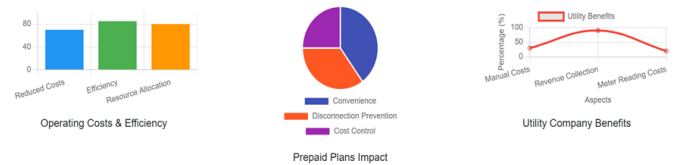


Figure 10. Economic aspect

The economic results are discussed across three levels: the user, the utility provider, and the broader economy. Overall, the results suggest that the system can generate value by reducing avoidable costs linked to outages, inefficiencies, manual processes, and low observability of consumption.

5.2.1 Effect on users

For users, the main impact arises from improved visibility and proactive control. In conventional prepaid arrangements, customers may experience inconvenience and indirect costs when credit is depleted unexpectedly, including disruption of household activities and time spent managing recharges.

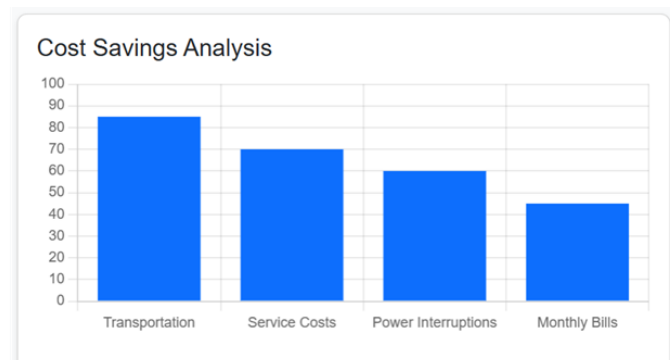


Figure 10. Cost saving for users

The proposed system reduces these outcomes through real-time tracking and low-balance notifications. In addition, by making consumption visible on a continuous basis, the meter supports behavior change: users can identify high-use periods

and adjust appliance usage accordingly, leading to potential reductions in monthly expenditure. These results are consistent with the general expectation that feedback and visibility improve energy efficiency and reduce wastage when users can respond in real time rather than retrospectively.

5.2.2 Effect on utility providers

For utility providers, the results indicate improvements in operational efficiency and billing reliability. Automated and continuous reporting (via database integration) reduces reliance on manual collection processes and minimizes human error. This can translate into lower operational costs and improved consistency of revenue collection. In addition, early alerts reduce customer service pressure because fewer customers reach “zero balance” without prior awareness. The system therefore supports a more predictable revenue cycle and a more efficient service model, particularly when scaled to large numbers of customers.

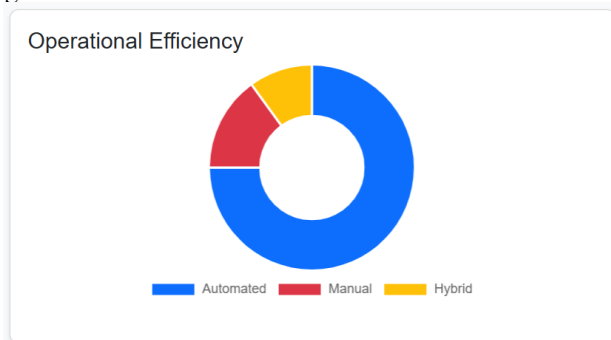


Figure 11. Operation Efficiency

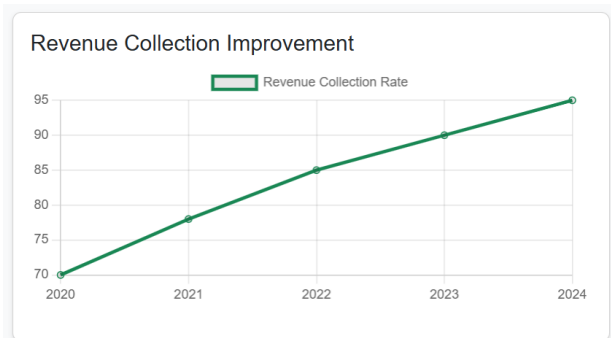


Figure 12. Revenue Collection

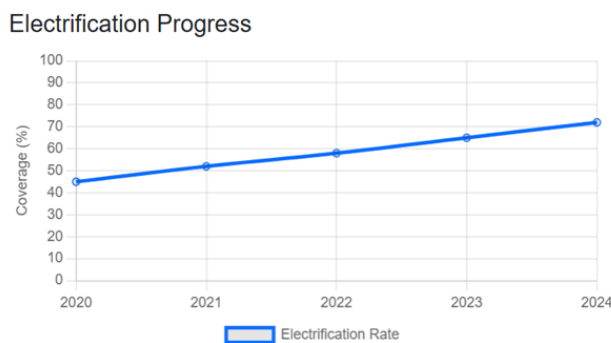


Figure 13. electrification progress

5.2.3 Effect on Rwanda's economy

At the macro level, the results support the argument that smart metering strengthens national energy-sector performance by improving monitoring and reducing losses. Better observability of consumption and improved billing accuracy can contribute to reduced non-technical losses, improved utility sustainability, and better planning for supply and distribution. Furthermore, the digitization element aligns with national ambitions for smart services and modern infrastructure. While the prototype is not yet a national-scale deployment, the demonstrated impacts suggest that scaling could contribute to improved electrification outcomes and efficiency gains across the energy ecosystem.

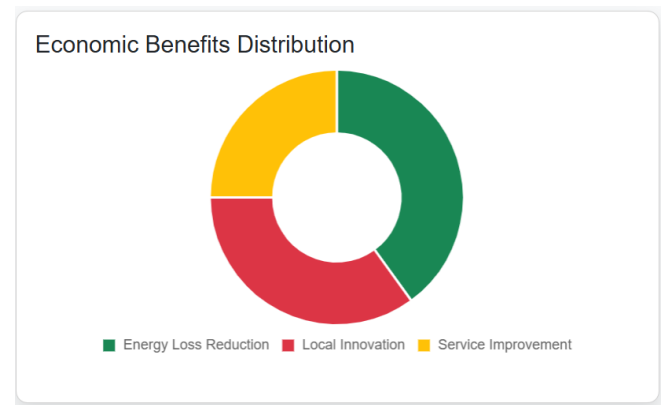


Figure 14. Economic benefits distribution

5.3 Cost analysis results

A practical cost estimate was developed using the prototype bill of materials. The total prototype hardware cost is reported as 75,000 RWF, covering the controller (ESP32), metering module (PZEM-004T), LCD, relay, wiring/connectors, power supply components, battery, and housing. This cost evaluation is important because affordability is a key barrier to adoption in many developing contexts. The results indicate that the prototype can be constructed using widely available components at a relatively low cost, which improves feasibility for pilots and iterative scaling.

TABLE 1: Cost estimation

S/N	Component	Quantity	Unit Price RFW	Total Price RFW
1	ESP32 Microcontroller	1	15000	15000
2	PZEM-004T Energy Meter	1	30000	30000
3	16x2 LCD Screen	1	8000	8000
4	Relay	1	3000	3000
5	Miscellaneous jumper wires	1 Set	2000	2000
6	Power Supply (Adapter)	1	4000	1000
7	Cables and Connectors	1 meter	500	500
8	Battery	2	3000	6000
9	Cover			2500
	Total			75000

In a publication context, this table is useful because it demonstrates replicability and supports cost benefit

discussion. If the paper requires deeper cost justification, the table can be expanded to include installation labor and connectivity costs; however, for a prototype and proof-of-concept paper, the materials-based estimate is typically acceptable.

5.4 System losses and implementation limitations

The results also identify important loss categories that can affect performance when the system is deployed in real conditions. First, data transmission losses can occur due to network latency, intermittent Wi-Fi coverage, or server unavailability, which may delay updates to the database or dashboard even when local measurements remain correct. Second, small energy losses are expected due to heat dissipation and conversion inefficiencies across electronic components (relay, power conversion, and continuous device operation). Third, system effectiveness can be influenced by human factors (e.g., delayed response to alerts, recharge timing, or incorrect inputs in payment steps where applicable). Recognizing these losses is important because it clarifies the boundary between prototype capability and deployment realities and guides improvement priorities for future iterations.

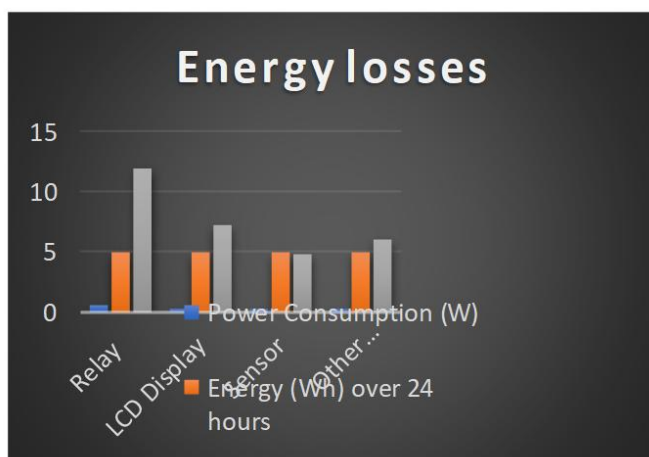


Figure 16. Energy losses graph

5.5 Demonstration calculations and validation examples

User errors can impact overall efficiency by causing users to enter inaccurate recharge amounts or encounter delays in receiving SMS messages.

1. Power Calculation

$P = V \times I$ Where: P: Power (in watts, W), V: Voltage (in volts, V), I: Current (in amperes, A)

Given: Voltage (V) = 220V, Current (I) = 2A

Therefore: $P = 220 \times 2 = 440 \text{ W}$

2. Energy Consumption

$E = P \times t$ Where:

E: Energy (in watt-hours, Wh)

P: Power (in watts, W)

t: Time (in hours, h)

Given:

Power (P) = 440W

Time (t) = 3 hours

Therefore: $E = 440 \times 3 = 1,320 \text{ Wh}$ or 1.32 kWh

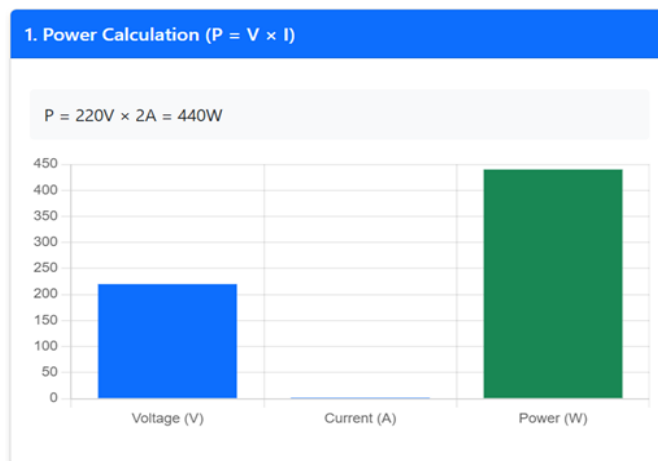


Figure 17. Power calculations

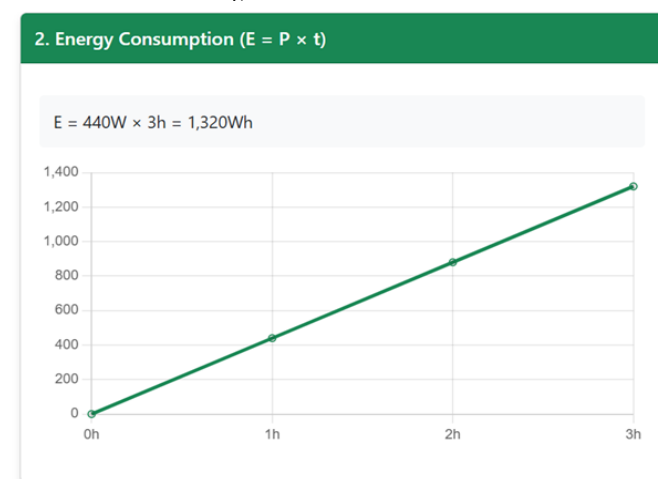


Figure 18. Energy consumption

Source: graphs Created independently using CSS, HTML, JavaScript, Bootstrap, and PHP programming languages. Code references (own screenshots)

3. Cost of Energy Consumption

$\text{Cost} = E \times \text{Rate}$ Where: E: Energy (in kWh), Rate: Cost per kWh (in RWF or currency unit)

Given: Energy (E) = 1.32 kWh, Rate = 300 RWF per kWh

Therefore: $\text{Cost} = 1.32 \times 300 = 396 \text{ RWF}$

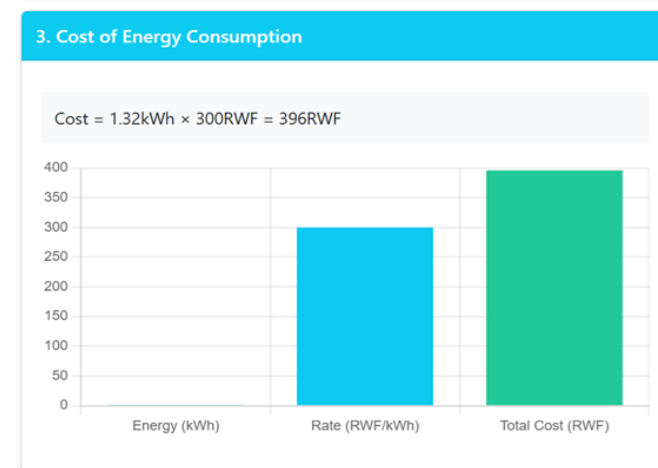


Figure 19. Cost calculation

4. Power Factor (PF)

$$PF = P / (V \times I)$$

Where: P: Real power (in watts, W) and $V \times I$: Apparent power (in volt-amperes, VA)

Given:

- Power (P) = 440W
- Voltage (V) = 220V
- Current (I) = 2A

$$\text{Therefore: } PF = 440 / (220 \times 2) = 440/440 = 1.0$$

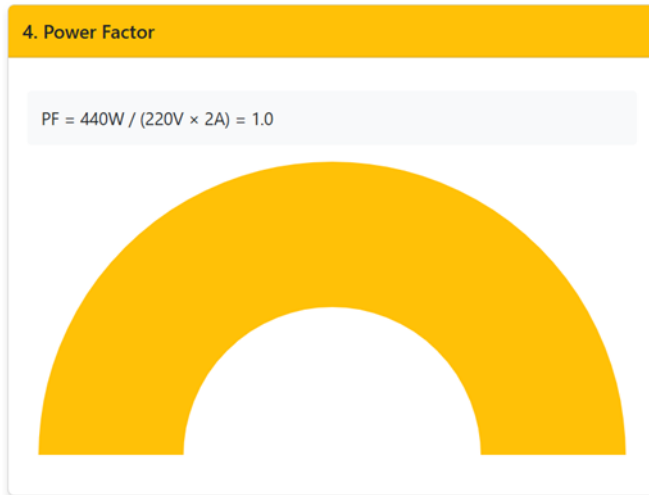


Figure 20. Power factor

5. Recharge Energy Estimate

$$\text{Recharge Time} = \text{Remaining Balance} / \text{Cost per Hour}$$

Where:

Remaining balance = Amount in RWF

Cost per hour = Power Consumption (kW) $\times$ Rate per kWh

Given:

Remaining Balance = 2,000 RWF

Power Consumption = 1.32 kW

Rate = 300 RWF per kWh

Therefore:

Cost per Hour = $1.32 \times 300 = 396$ RWF

Recharge Time = $2,000/396 \approx 5.05$ hours

6. Energy Efficiency of a Device

$$\text{Efficiency (\%)} = (\text{Output Power} / \text{Input Power}) \times 100$$

Where:

Output Power = Useful power delivered by the device (in W)

Input Power = Total power consumed by the device (in W)

Example

Given:

Output Power = 400W

Input Power = 500W

$$\text{Therefore: Efficiency} = (400/500) \times 100 = 80\%$$

5. Energy Efficiency

$$\text{Efficiency} = (400W / 500W) \times 100 = 80\%$$

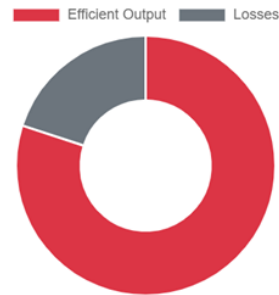


Figure 21. Energy Efficiency

7. Energy Losses

$$\text{Losses} = P_{\text{output}} - P_{\text{input}}$$

Where:

P_{input} : Input power (in W)

P_{output} : Output power (in W)

Given:

Input Power = 500W

Output Power = 400W

$$\text{Therefore: Losses} = 500 - 400 = 100 \text{ W}$$

8. Battery Recharge Time

$$\text{Time} = \text{Battery Capacity (Ah)} / \text{Charging Current (A)}$$

Where:

Battery Capacity (in ampere-hours, Ah)

Charging Current (in amperes, A)

Given:

Battery Capacity = 50Ah

Charging Current = 5A

$$\text{Therefore: Time} = 50/5 = 10 \text{ hours}$$

9. Load Consumption

$$\text{Load Consumption} = \text{Sum of All Devices' Power Consumption}$$

Given:

Device 1 = 100W

Device 2 = 200W

Device 3 = 150W

$$\text{Therefore: Total Load} = 100 + 200 + 150 = 450 \text{ W}$$

5.6 Key interpretation

Overall, the results demonstrate that the prototype achieves its core purpose: it measures electricity parameters reliably, translates consumption into understandable user information, and supports proactive actions through alerts and load control. Economically, the system provides value by reducing avoidable outage-related inconvenience for users and reducing administrative burden for utility providers. The cost analysis suggests that the design is feasible for pilot deployment using commercially available components, while the losses discussion highlights practical constraints (connectivity and device-level inefficiencies) that should be addressed in future iterations.

VI. RECOMMENDATIONS AND CONCLUSION

This paper presented an IoT-enabled smart energy meter prototype with automatic recharge support, combining real-time electrical parameter measurement, database-backed monitoring, and SMS-based low-balance alerts. The design targets practical challenges observed in token-based prepaid metering and demonstrates an implementable pathway toward improved customer experience and more data-driven energy management in Rwanda.

Recommendations for stakeholders include

- 1) Utilities (e.g., REG): conduct controlled pilots in urban and peri-urban settings, integrate with secure mobile payment/recharge channels, and define interoperability and cybersecurity requirements.
- 2) Regulators: develop guidelines for accuracy, safety, and data privacy for IoT-assisted metering, including approval pathways for locally developed devices.
- 3) Academia and innovators: extend the prototype toward metrological validation, robust offline/low-connectivity modes, and scalable cloud-native analytics.
- 4) Policy makers: support public awareness and capacity building to maximize user benefit and adoption of smart energy technologies.

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AUTHOR CONTRIBUTIONS

Nshimiyumuremyi Schadrack: Conceptualization; Methodology; System design; Hardware/prototype development; Firmware/software implementation; Testing and data collection; Data curation; Formal analysis; Writing original draft.

Nkurikiyeyezu Kizito: Supervision; Methodology guidance; Technical validation; Review of results and interpretation; Writing review & editing; Project administration.

Mbonimpa Jean de la Paix: Manuscript development from thesis; Paper structuring and organization; Writing, review & editing (language, coherence, academic style); Formatting to IJSES template and submission readiness; Reference and figure/table harmonization.

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