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eVolta: A Cloud-Based and Real-Time Electricity Usage Monitoring System

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ABSTRACT

Electricity consumption in Oriental Mindoro remains inefficient, often leading to high costs. This study presents eVolta, a cloud-based, real-time electricity monitoring system for local adaptation. Unlike existing solutions, eVolta features direct integration with ORMECO to provide users timely maintenance and service interruption updates. It features live consumption tracking, estimated billing, and alerts when usage limits are exceeded. The system ensures secure access through OTP-based authentication. Developed using the Agile methodology, eVolta combines hardware and software for a user-focused experience. Its effectiveness was assessed by 100 respondents using the ISO/IEC 25010 quality model, yielding an overall mean score of 3.625—classified as "Very Effective" across all eight attributes: Functional Suitability, Performance Efficiency, Compatibility, Usability, Reliability, Security, Maintainability, and Portability. eVolta supports energy efficiency, cost reduction, and informed usage. Future improvements may include renewable energy integration, enhanced data visualization, and stronger security to promote energy conservation and engagement further.

INTRODUCTION

Electricity is essential to modern life, powering homes, industries, transportation, and communication systems that enable social and economic advancement. However, as global electricity demand increases, so does the necessity for effective utilization. Poor energy management leads to higher costs, environmental degradation, and the depletion of limited resources, which emphasizes the urgent need for collaborative efforts to promote energy efficiency and sustainability. In light of the 2024 power crisis in Luzon, the urgency to modernize electricity consumption systems has become even more critical (DOE, 2024).

The global call for energy conservation has intensified due to environmental concerns, energy waste, and resource shortages that threaten future generations. Current initiatives aim to promote energy-efficient practices and optimize electricity usage to minimize waste. However, the success of these initiatives largely depends on consumer behavior. Udoakah and Okure (2017) revealed a significant gap between awareness and implementation, with 78% of respondents recognizing energy-saving technologies but only 50.8% actively using them. This gap highlights the need for innovative solutions to encourage the adoption of energy-efficient behaviors. Similarly, Marquez and Pitarma (2019) emphasized the potential of cloud-based technologies to improve energy conservation by enabling real-time monitoring, remote access, and efficient data storage. These platforms empower users to make informed decisions, significantly reducing electricity waste. However, existing systems often lack local customization and direct utility-provider integration—gaps that eVolta aims to address.

The Philippine energy sector faces persistent challenges such as high electricity costs, inefficiencies, and reliance on imported fossil fuels. Electricity generation expenses constitute approximately 47% of household budgets, placing a heavy financial burden on families and underscoring the need for government intervention to lower energy costs (Ravago *et al.,* 2023). Rural electrification's outdated infrastructure and geographical challenges further exacerbate the problem, limiting access to affordable and reliable electricity (Cham, 2022; Marcelo-Galapon, 2023). In 2024, the Department of Energy launched initiatives to expand renewable energy and upgrade transmission infrastructure, yet technological solutions tailored to consumer engagement remain limited (DOE, 2024). These issues highlight the urgent need for sustainable solutions to address inefficiencies and promote energy conservation.

In Oriental Mindoro, the Oriental Mindoro Electric Cooperative (ORMECO) is the primary electricity provider, working to meet the region's growing energy demands. However, ORMECO faces several challenges, including difficulties in accurately predicting electricity consumption, inconsistent billing systems, and a lack of real-time data. Predicting electricity usage remains challenging due to the high granularity of data, vast service areas, and the absence of integrated forecasting methods (Hong *et al.,* 2022). Furthermore, the complexity of tariff structures and diverse consumption patterns make billing more difficult, emphasizing the need for improved methodologies (Vinyals *et al.,* 2022). A lack of consumer awareness regarding energy-saving practices further compounds these challenges. Studies indicate that consumers with higher educational attainment and

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awareness about electricity costs are more likely to adopt sustainable practices (Aquino & Bernal, 2024; Gajdzik *et al.,* 2024). eVolta directly addresses these local gaps by integrating real-time monitoring, localized alerts, and tailored visualizations to promote informed energy usage in ORMECO's service area.

Cloud-based platforms have gained prominence in energy management for their ability to process and deliver large volumes of consumption data. For example, Azure IoT and Smart Energy Management Systems (SEMS) allow for real-time insights and system-wide visibility (Marquez & Pitarma, 2019). These systems, however, are often enterprise-focused and lack modularity for community-level applications. eVolta distinguishes itself with a dual-server architecture—one server for administrative monitoring (ORMECO) and another for consumer usage—ensuring real-time access, role-based functionalities, and adaptability to local infrastructure.

IoT devices like smart meters and sensors have transformed electricity tracking by enabling real-time data collection. Choudhari *et al.* (2022) demonstrated that text message alerts from advanced metering systems reduce excessive energy use. However, many low-cost IoT models face scalability, latency, and security challenges. eVolta balances affordability and functionality by combining lightweight IoT hardware with secure cloud storage and OTP (One-Time Password) verification to ensure seamless and protected user interactions. Kang *et al.* (2022) affirmed that OTP integration enhances system trustworthiness by reducing the risk of data breaches.

While many innovative grid systems are designed for urban contexts, hyperlocal energy monitoring remains underexplored in provinces like Oriental Mindoro. Existing models often neglect rural infrastructure constraints, such as limited bandwidth and inconsistent power supply. eVolta addresses these limitations by operating effectively even with basic internet connectivity and providing community-relevant insights like barangay-level usage trends, outage alerts, and personalized consumption feedback. These features make the system highly practical and impactful for local users (Aquino & Bernal, 2024).

Smart metering and notification systems offer practical solutions to address these challenges. Choudhari *et al.* (2022) demonstrated that text message notifications in an advanced metering system successfully encouraged users to reduce excessive energy consumption. eVolta integrates this proactive approach by providing notification systems that alert users when their electricity usage nears predefined limits, fostering energy efficiency and cost reduction. Its integration with ORMECO allows users to receive live maintenance and service updates—a feature rarely found in consumer-focused energy apps.

Cloud-based technologies also play a crucial role in electricity management. These technologies facilitate real-time data monitoring, improve efficiency, and enhance communication between providers and consumers. Kang *et al.* (2022) emphasized the importance of security in such systems, highlighting how one-time passwords (OTPs) strengthen authentication processes and protect sensitive user data. eVolta incorporates OTP verification to ensure secure user authentication, addressing data breaches and unauthorized access concerns. This focus on security underscores the system's commitment to safeguarding consumer information. By applying OTP within a lightweight front-end system, eVolta provides robust security without compromising accessibility.

eVolta is a cloud-based, real-time electricity monitoring system designed to address ORMECO's specific needs and challenges. Its features include real-time usage monitoring, dual-server architecture for administrative and consumer applications, and advanced data visualization tools. Dominitz *et al.* (2023) stressed the importance of visual aids such as charts and graphs in helping users understand consumption patterns and make informed decisions to reduce energy waste. By implementing these tools, eVolta empowers users to track their electricity usage over time and adopt energy-saving measures. Its context-specific innovations, such as real-time ORMECO notifications, hyperlocal visualization, and locally deployable architecture, make it a scalable and sustainable energy solution for Oriental Mindoro and similarly underserved areas.

MATERIALS AND METHODS

Development Method

The development team adopted a dynamic and collaborative strategy through the Agile methodology (Iddo, 2019), facilitating the system's flexibility to user feedback and changing needs. This approach enabled the team to deliver a resilient, effective, and user-focused solution tailored to address the specific challenges faced by ORMECO and its consumers. Through iterative development cycles and continuous stakeholder involvement, the system was designed to evolve with user expectations and operational demands.

As an essential first step in the Agile process, the team conducted stakeholder interviews to ensure the system would directly address the real needs of both ORMECO and electricity consumers. These interviews provided critical insights into existing problems. Consumers expressed difficulty in estimating their electricity consumption, often resulting in unexpectedly high bills due to a lack of real-time monitoring and personalized notifications. On the other hand, ORMECO cited issues with delayed communication regarding maintenance and outages, which undermined consumer trust. These findings became the foundation for the system's design, ensuring targeted and efficient solutions.

During the design phase, the team focused on designing a prototype that met the collected requirements and addressed stakeholder issues. The prototype featured an intuitive online interface and a device capable of real-time electricity monitoring. The purpose was to ensure that both components functioned effectively to satisfy client requirements, encompassing the dissemination of timely

and precise information regarding energy usage and cost estimation.

In the development process, the system's website was developed with React JS, a framework selected for its responsiveness and interaction (React JS Documentation, 2023). The hardware device, developed for continuous monitoring of electricity consumption, was developed using Arduino components (Arduino, 2023). The team employed APIs and libraries to improve capabilities for efficient data management and smooth integration between the system's software and hardware components. During the testing phase, numerous tests were performed, encompassing Alpha, Beta, and System Testing. Each phase focused on identifying problems, including initial functionality tests in monitored environments and practical evaluations with ORMECO consumers. The feedback from these tests enabled the team to fix errors, enhance usability, and guarantee the system functioned effectively and dependably under different circumstances. In the release phase, the system was deployed to a select group of ORMECO consumers for practical application. Data was collected through observations and feedback to assess the system's effectiveness in delivering real-time usage measurements, personalized notifications, and detailed cost estimates. This phase also confirmed the system's readiness for deployment.

The feedback phase focused on gathering user evaluations to identify additional enhancements and guarantee ongoing optimization. Feedback was assessed utilizing the ISO/IEC 25010 framework (International Organization for Standardization, 2023). This iterative feedback mechanism enhanced the system's ability to better satisfy consumer requirements while promoting energy efficiency and cost reduction.

Development Tools

The development of the eVolta system integrated both hardware and software components to enable real-time electricity monitoring and user-friendly interaction. The hardware relied on the NodeMCU ESP8266 microcontroller and the PZEM-004T energy monitoring module, complemented by components like the DS3231 Real-Time Clock, LCD, voltage regulators, circuit breakers, and LED bulbs for enhanced reliability and data accuracy. ReactJS was used to build a responsive interface on the software side, while MySQL handled data storage and management. Development tools like Visual Studio Code and SQLyog supported efficient coding and debugging processes. The system was optimized for seamless operation on Google Chrome and Mozilla Firefox, ensuring a smooth and scalable user experience.

Testing and Evaluation

The system was presented, demonstrated, and used by the participants to assess its functionality. The system was evaluated according to ISO/IEC 25010 standards to assess its quality attributes. A total of 100 respondents participated in the survey, selected through a cluster sampling procedure. The survey questions were self-administered, closed-ended, and provided in both English and Filipino to be accessible to the various participants. Google Forms gathered responses from remote IT experts, and in-person participants completed paper questionnaires. Responses were analyzed using a 4-point Likert scale, where a score of 4.00–3.50 indicated "Strongly Agree," 3.49–2.50 "Agree," 2.49–1.50 "Disagree," and 1.49–1.00 "Strongly Disagree," ensuring structured and quantifiable data for system evaluation. The identity of the participants was kept hidden to preserve anonymity throughout the study.

ISO/IEC 25010

The system evaluated using ISO/IEC 25010 follows a quality model specifying eight essential features for a complete software quality assessment. These include Functional Suitability, Performance Efficiency, Compatibility, Usability, Reliability, Security, Maintainability, and Portability, all crucial for evaluating the system's overall quality. Each feature ensures the system can meet user needs, perform efficiently, integrate seamlessly with other systems, and maintain security and reliability. This comprehensive evaluation helps guarantee the system's effectiveness, adaptability, and long-term usability in real-world environments.

Table 1: Component of ISO/IEC 25010 Questionnaire

Criteria	Indicator
Functional Suitability	Provides all necessary features for effective power consumption monitoring.
	Accurately performs intended functions related to monitoring power consumption.
	Functionalities are suitable for effectively monitoring power consumption.
Performance Efficiency	Responds to user queries and real-time data requests within an acceptable timeframe
	Utilizes network bandwidth without causing noticeable slowdowns.
	Handles substantial data volumes without compromising responsiveness.
Compatibility	Coexists with other systems in a shared environment without affecting performance.
	Integrates seamlessly with external devices and services, supporting its core objectives.
Usability	Uses familiar and appropriate terminology for understanding power consumption data.
	Allows users to monitor power consumption easily, set alerts, authenticate securely with OTP, and generate reports.
	Features a visually appealing user interface design.

Reliability	Continues to operate smoothly even in the presence of faults, ensuring consistent performance.
	Remains consistently accessible during regular usage hours.
	Recovers efficiently from incidents or outages, minimizing data loss and downtime.
Security	Protects the confidentiality of electricity consumption data and personal information.
	Ensures the accuracy and constancy of electricity consumption data.
	Securely traces user actions, maintaining accountability and system transparency.
Maintainability	Adapts well to different consumer needs and preferences.
	Efficiently assesses and identifies necessary changes for accurate monitoring and clear reporting.
	Implements automated testing mechanisms to ensure the system's durability and stability.
Portability	Effectively adapts to different hardware, software, and operational environments while maintaining core functionalities.
	Offers seamless web accessibility, allowing users to access features without installation.
	Replicates existing software solutions in similar operational environments, providing real-time monitoring.

RESULTS AND DISCUSSIONS

System Interface

Admin Side

The admin panel is a system's visual user interface for system administrators. The software offers solutions for systematically managing essential tasks, including user account administration, device management, cost control, and disseminating announcements.

Figure 1: Admin Page

Figure 1 illustrates the Admin Page, which provides an intuitive interface for managing the system's core functionalities. The navigation menu on the left side includes key sections such as Dashboard, Users, Devices, and Notifications. The Dashboard presents a real-time summary of energy consumption, cost reports, usage trends, and the number of connected devices, allowing admins to monitor system performance efficiently. The Users Page enables administrators to manage consumer accounts by displaying user details, including names, addresses, mobile numbers, product codes, total consumption, and cost estimates. This section also features a search function for quick user identification and an "Add User" button for seamless registration. Meanwhile, the Devices Page allows admins to register and monitor devices, modify kilowatt cost settings, assign unique product codes, and generate detailed consumption reports, ensuring smooth integration of consumer accounts with the system.

The Notifications Page enables administrators to generate, monitor, and send system notifications to users, ensuring precise and timely communication regarding power outages, warnings, and other updates. This feature enhances consumer engagement by keeping them informed of critical system alerts. The consumer-side functionalities complement these admin tools by providing users with real-time updates and access to personalized energy consumption insights, ensuring transparency and efficiency in electricity monitoring.

Consumer Side

The consumer side is a visual user interface specifically created for consumers. It provides efficient solutions for accomplishing essential activities such as estimating costs, tracking total consumption, and monitoring electricity usage. Users may view the administratively set cost per kilowatt, access detailed visualizations for consumption summaries, and monitor consumption

history. Further features encompass notifications and user profile administration, offering a comprehensive platform for effectively monitoring and controlling energy consumption.

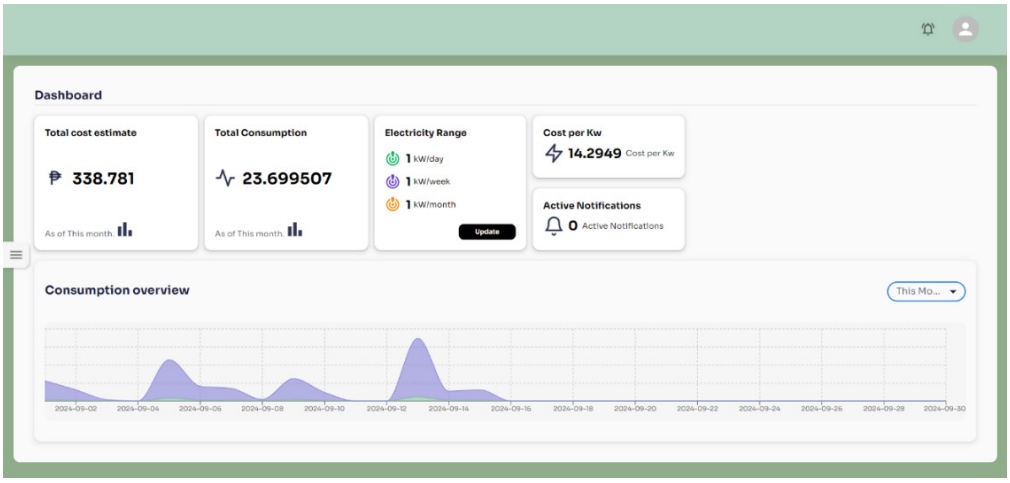

Figure 2: Consumer Page

Figure 2 illustrates the Consumer Page, which provides an intuitive interface for monitoring electricity consumption and managing expenses. The navigation menu on the left side includes key sections such as Dashboard, Consumption and Cost History, Notifications, and Profile. The dashboard presents a clear overview of the user's consumption, estimated total cost, and overall usage, empowering consumers to monitor their electricity patterns. Additional features include an adjustable electricity limit indicator, allowing users to set consumption limits and active notifications that alert them when nearing their limit. The Consumption and Cost History section enables users to view detailed records, including usage dates, product codes, and estimated costs, with a filter to analyze data over specific time ranges. Consumers can also stay informed through the Notification Page, where they receive essential updates from ORMECO or the Admin, including outage alerts and other critical information.

The Consumer Profile page allows users to manage and customize their personal and account details, such as name, address, email, and mobile number. This section provides options to update profile information and modify the background color for a more personalized experience. With these tools, consumers can effectively monitor and manage their energy usage, set consumption limits, and receive timely notifications while maintaining accurate and individualized profiles. These features work together to provide a seamless experience for users, ensuring they have the information needed to make informed decisions about their energy consumption and expenses.

Hardware Interface

Figure 3: Hardware Interface

present users with a clear display of real-time electrical settings. The voltage indicates the quantity of electricity entering the home or available for utilization. The current, expressed in amperes, indicates the amount of electricity flowing through the circuit, whereas the power, measured in watts, reflects the energy consumption of each connected device. The interface monitors kilowatt-hours (kWh) of electricity usage, providing an average

amount used over time. This interface enables effective monitoring of household energy consumption by gathering real-time data, which is also transmitted to the software for processing. The software computes the estimated expenses based on energy usage data, enabling users to monitor their costs and make wise decisions regarding their electricity consumption.

System Evaluation Result

Table 2 comprehensively evaluates the eVolta system using the ISO/IEC 25010 quality model, a widely accepted framework for assessing software product quality (ISO/IEC, 2011). The results indicate strong performance across all criteria, with an overall mean of 3.625. Among these, usability was the most highly rated attribute (mean = 3.677), suggesting that respondents found the interface intuitive and easy to navigate. In contrast, performance efficiency received the lowest score (mean = 3.535), which may reflect occasional system lag or slower data processing, particularly during peak usage, when internet connectivity is unstable. It suggests a need for backend optimization or internet-related adjustments to improve responsiveness. Direct user feedback further supports the quantitative data, with one respondent noting, "The system is very helpful and easy to use. It helps us track electricity consumption clearly, so we can decide whether to reduce our usage to avoid high bills." Incorporating such feedback emphasizes the system's positive impact on decision-making and energy savings.

Table 2: Summary Result of Evaluation using ISO/IEC 25010

Criteria	Mean	Rank	Verbal Interpretation
Functional Suitability	3.647	3	Strongly Agree
Performance Efficiency	3.535	8	Strongly Agree
Compatibility	3.635	5	Strongly Agree
Usability	3.677	1	Strongly Agree
Reliability	3.567	7	Strongly Agree
Security	3.637	4	Strongly Agree
Maintainability	3.630	6	Strongly Agree
Portability	3.670	2	Strongly Agree
Overall Mean	**3.625**		**Strongly Agree**

CONCLUSION

The study concludes that the cloud-based eVolta system facilitates real-time electricity monitoring, allowing consumers realistic cost estimations and significant insights into their consumption patterns. The notification system instantly notifies consumers when their usage approaches the set limit, enabling them to implement measures that reduce energy and minimize expenses. It allows efficient communication by disseminating important announcements from ORMECO and informing consumers about updates and services. Furthermore, implementing a One-Time Password (OTP) authentication mechanism enhances security by preventing illegal access to consumer data. Also, the system generates comprehensive reports and detailed visualizations of electricity consumption, allowing consumers to make good decisions. Based on ISO/IEC 25010, the evaluation results supported the system's quality, usability, and overall effectiveness.

To enhance the eVolta system, it is recommended to prioritize integrating predictive notifications that alert consumers before reaching consumption thresholds and offer actionable energy-saving tips. Additionally, multi-channel authentication can significantly strengthen data protection, such as OTP via email or authenticator apps combined with biometric or facial recognition technologies. Improving data visualization with historical comparisons and suggestions for real-time usage will also promote more informed and efficient consumption. While future developers should continue aligning with ISO/IEC 25010 standards to ensure quality and adaptability, research may also explore the integration of renewable energy monitoring and advanced analytics. Overall, eVolta holds substantial potential as a model system for energy conservation in Oriental Mindoro, offering a scalable solution for regions facing similar electricity management challenges.

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