



EcoLens: An AI-Powered Web Application for Enhanced Recycling and Waste Management in the Philippines

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Article History

Received: 18.07.2025
Accepted: 07.08.2025
Published: 24.09.2025

Abstract: This study presents EcoLens, an innovative AI-powered web application designed to support the United Nations Sustainable Development Goals (SDGs), particularly SDG 12: Responsible Consumption and Production, while contributing to SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), SDG 14 (Life Below Water), SDG 15 (Life on Land), and SDG 17 (Partnerships for the Goals). Addressing the critical solid waste management crisis in the Philippines—where approximately 35,580 tons of garbage are generated daily [12]. EcoLens promotes sustainable practices through enhanced recycling, waste segregation, and environmental education. The application integrates Convolutional Neural Networks (CNNs) via TensorFlow.js for real-time image recognition and classification, complemented by a recycling database with disposal instructions, facility mapping, and a gamified reward system. System evaluation using the ISO/IEC 25010 quality model with 102 participants demonstrated strong performance (scores: 76 for performance, 82 for accessibility, 100 for best practices, 82 for SEO) and high user acceptance (Likert means 4.44–4.71). By combining AI-driven technology, education, and behavioral incentives, EcoLens provides a scalable, SDG-aligned solution that advances waste reduction, environmental stewardship, and sustainable urban development in the Philippines.

Keywords: Artificial intelligence, recycling application, waste management, image recognition, sustainable development, environmental technology.

Cite this article:

Sampelo, A. L.; Uy, C. C. C.; Almosara, A. J. G.; Chua, C. M. N.; and Ayo, E. B., (2025). EcoLens: An AI-Powered Web Application for Enhanced Recycling and Waste Management in the Philippines. *ISAR Journal of Multidisciplinary Research and Studies*, 3(9), 46-52.

1. Introduction

The United Nations Sustainable Development Goals (SDGs) provide a global framework for addressing interconnected environmental, social, and economic challenges. Among them, SDG 12: Responsible Consumption and Production emphasizes reducing waste generation, enhancing recycling, minimizing reliance on single-use plastics, and promoting resource efficiency to reduce environmental impact. However, effective waste management extends beyond SDG 12 and intersects with other goals, including SDG 11 (Sustainable Cities and Communities) through cleaner and more resilient urban systems, SDG 13 (Climate Action) by reducing greenhouse gas emissions from

landfills, SDG 14 (Life Below Water) and SDG 15 (Life on Land) through the prevention of plastic leakage and land pollution, SDG 4 (Quality Education) by fostering environmental literacy, and SDG 17 (Partnerships for the Goals) by strengthening collaboration among government, businesses, and communities [8][9][10].

In the Philippines, the urgency of these goals is underscored by the country's escalating waste crisis. Generating an estimated 14.66 million tons of solid waste annually, with the National Capital Region (NCR) as a primary contributor, the Philippines ranks among the largest waste producers in Southeast Asia [2][11]. This volume of waste, driven by rapid urbanization, population growth, and consumption patterns, poses serious threats to environmental sustainability, public health, and climate resilience. Despite



existing measures such as plastic bans, composting initiatives, and recycling programs, challenges remain due to inconsistent policy implementation, limited infrastructure, and persistent knowledge gaps in proper waste segregation.

EcoLens seeks to address these challenges by leveraging artificial intelligence, image recognition, and gamification to enhance recycling education and behavior. Through its integrated platform, EcoLens empowers individuals, schools, and communities to make informed waste management decisions while fostering long-term behavioral change. Beyond improving recycling efficiency, EcoLens aligns with multiple SDGs by reducing landfill emissions, promoting environmental education, and encouraging cross-sector partnerships. By merging technology with sustainability, EcoLens represents a scalable solution to the Philippines' waste crisis and a practical contribution to global sustainable development.

2. Literature Review

Existing recycling applications have demonstrated varying degrees of effectiveness in promoting sustainable waste management behaviors. iRecycle, developed by Earth911, provides a comprehensive recycling directory and material detection capabilities but lacks real-time updates and personalized tracking features, limiting its potential for sustained user engagement [4]. Similarly, Recycle Right offers valuable educational resources and local council information but relies on static web-based platforms without interactive technologies such as image recognition or reward systems [7].

Recent research has identified several critical gaps in recycling application development and evaluation. Some studies evaluated user engagement in recycling applications but did not focus specifically on student populations or educational settings, representing a significant gap in understanding how these technologies perform in academic environments [14]. Some explored image recognition integration but failed to thoroughly examine technological challenges and limitations, particularly regarding accuracy under varying environmental conditions [13].

There are studies that investigated how recycling applications overcome behavioral barriers but did not address long-term engagement strategies, which are crucial for fostering sustained environmental behaviors [3]. Their study highlighted the

importance of understanding user motivation but lacked practical implementation of engagement mechanisms such as gamification or reward systems.

These literature gaps indicate a need for comprehensive research that addresses student-specific needs, explores advanced technological implementations, and emphasizes long-term user engagement. The current study addresses these limitations by developing EcoLens as an integrated solution that combines AI-powered image recognition, educational resources, and gamification elements specifically designed for academic communities.

3. Methodology

3.1 Research Design

This study employed a mixed-methods approach combining quantitative and qualitative research techniques to comprehensively evaluate EcoLens' design, functionality, and impact on recycling behaviors. The research design focused on developing, testing, and evaluating a web application incorporating computer vision, image recognition, recommendation systems, and gamification features using the Agile Development Model for iterative development and continuous system refinement.

3.2 Participants

The study targeted 102 technology students from Centro Escolar University, selected through stratified random sampling to ensure representative participation across different academic levels and technical backgrounds. This sample size provided adequate statistical power for evaluating user acceptance and system performance across multiple criteria.

3.3 Technical Implementation

EcoLens was developed using TensorFlow.js as the primary machine learning framework, implementing Convolutional Neural Networks (CNNs) for image recognition and material classification. The system architecture integrated React Native for the user interface, PHP for backend development, and JavaScript for dynamic frontend functionalities. The Camera API enabled real-time material analysis and database matching for recycling instructions and center locations.

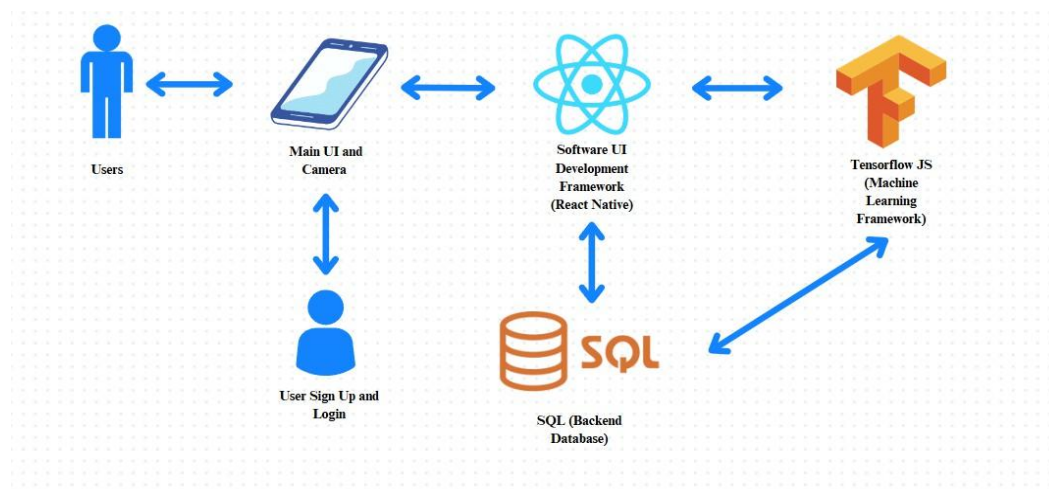


Fig. 1. Software Architecture

3.4 Data Collection and Evaluation

Data collection was conducted through pre- and post-usage surveys, structured questionnaires, interviews, and behavioral observations. The evaluation framework adhered to the ISO/IEC 25010 software quality model, assessing functionality, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability. Performance testing utilized Google Lighthouse for comprehensive application assessment, while manual testing evaluated image recognition accuracy under various environmental conditions including lighting variations, object orientation, and background complexity.

3.5 Statistical Analysis

Quantitative data were analyzed using descriptive statistics including mean, median, standard deviation, and percentage calculations. Likert scale responses were evaluated using central

tendency measures and variability assessments. Qualitative insights were derived from user feedback, open-ended responses, and observational data through thematic analysis.

4. System Design and Implementation

4.1 Conceptual Framework

The EcoLens conceptual framework was designed to promote sustainable waste management through an integrated approach combining AI-powered recognition, educational resources, and behavioral incentives. The system architecture follows a user-centric design where materials are captured via device cameras, processed through CNN models for classification, matched against a comprehensive recycling database, and presented with actionable guidance and nearby facility locations.

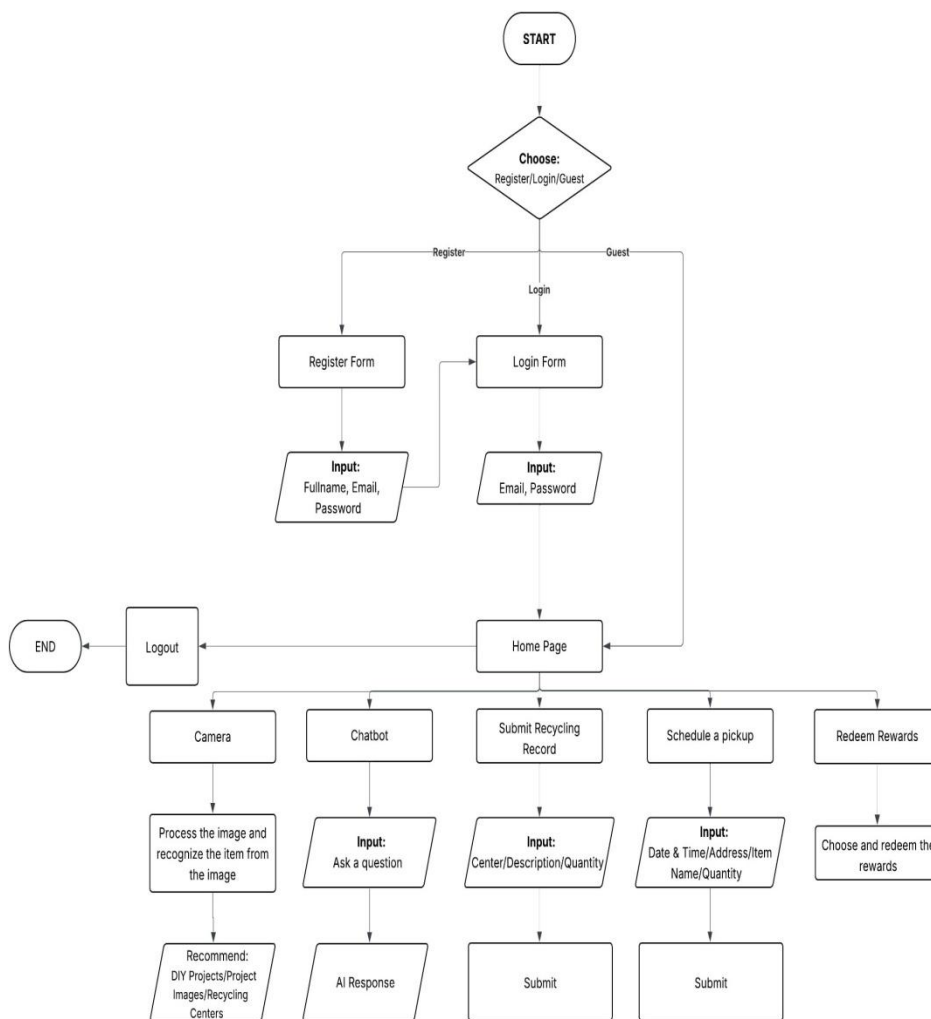


Fig. 2. Flowchart

4.2 Core Features

EcoLens incorporates several key features designed to enhance user engagement and recycling effectiveness. The image recognition system utilizes TensorFlow.js-powered CNNs to analyze captured images and identify material types and recyclability status. The recommendation system provides personalized guidance based on material identification, local

recycling infrastructure, and user preferences. A point-based reward system encourages continued participation by awarding points for recycling activities and eco-friendly project submissions, with redeemable rewards available at designated recycling centers.

4.3 Hardware and Software Specifications

System development and testing were conducted across multiple hardware configurations to ensure compatibility and performance

optimization. Hardware evaluation included configurations ranging from entry-level laptops (AMD Ryzen 3 3250U, 12GB RAM, integrated graphics) to high-performance desktops (Intel Core i7-10750H, 16GB RAM, GTX 1650, 1TB SSD). Software evaluation encompassed TensorFlow.js (rated Excellent for ML capabilities), PHP (Excellent for backend operations), JavaScript (Good for frontend functionality), Google Gemini APIs (Fair for chatbot integration), Visual Studio Code (Excellent for development environment), and React Native (Excellent for user interface development).

4.4 Development Process

The Agile Development Model facilitated iterative development through seven key phases: Planning (feature identification and scope definition), Design (UI/UX creation using Canva), Development (coding using Visual Studio Code), Testing (functionality and performance validation), Deployment (system packaging and preparation), Review (user feedback collection and analysis), and Launch (final implementation and release). This approach enabled continuous improvement and user feedback integration throughout the development lifecycle.

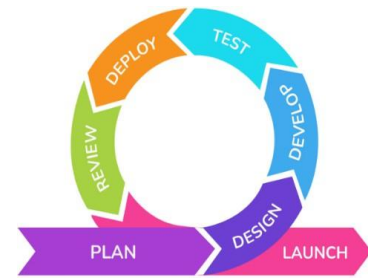


Fig. 3. Software Development Process

5. Results and Discussion

5.1 Performance Testing Results

Google Lighthouse performance evaluation revealed an overall performance score of 76, accessibility score of 82, best practices score of 100, and SEO score of 82. Key performance metrics included First Contentful Paint (0.9 seconds), Largest Contentful Paint (0.9 seconds), Total Blocking Time (420 milliseconds), Cumulative Layout Shift (0.026), and Speed Index (2.0 seconds). These results indicate strong performance with opportunities for optimization in JavaScript execution efficiency and image optimization.

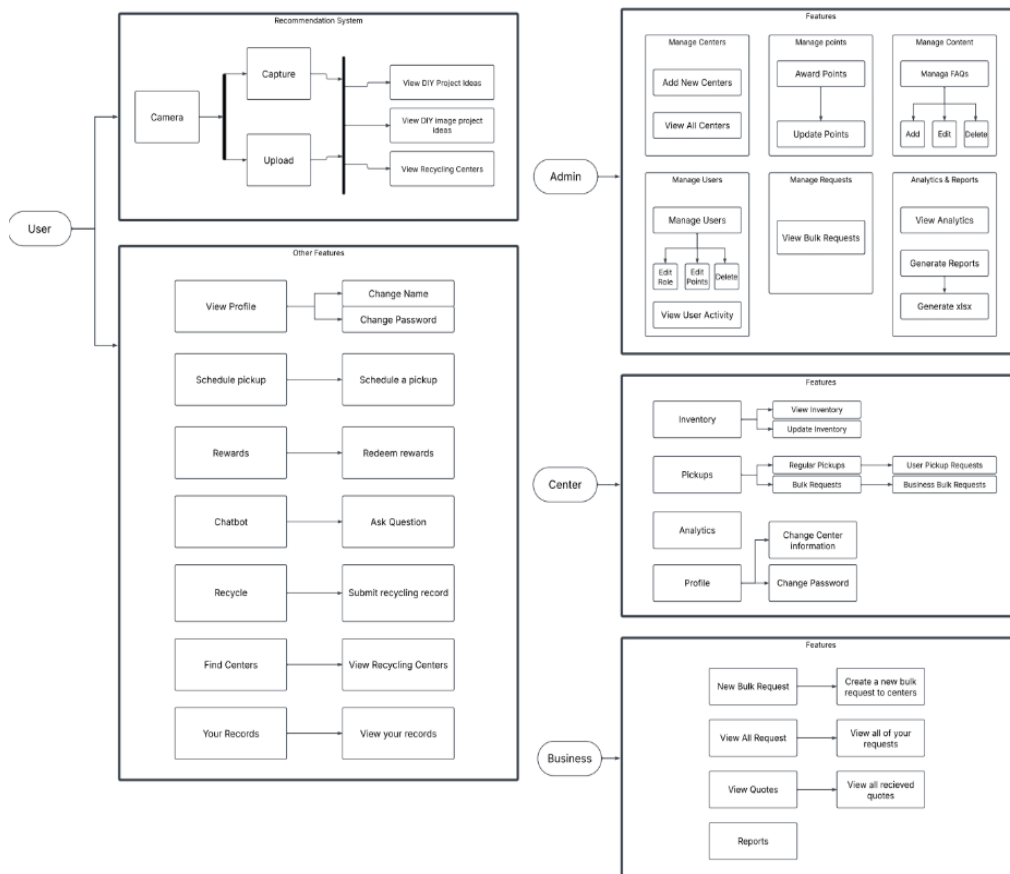


Fig. 4. Use Cases

5.2 User Acceptance Testing Results

User acceptance testing with 102 participants demonstrated consistently high satisfaction across all evaluated criteria. The results, measured on a 5-point Likert scale, showed remarkable user approval across multiple dimensions:

Table 1. User Acceptance Testing Results Summary

Evaluation Criteria	Mean Score	Standard Deviation	Interpretation
Functionality	4.59	0.14	Strongly Agree
Performance	4.44	0.62	Agree
Compatibility	4.58	0.55	Strongly Agree
Usability	4.54	0.55	Strongly Agree
Reliability	4.54	0.54	Strongly Agree
Security	4.27	0.71	Agree
Maintainability	4.44	0.59	Agree
Portability	4.71	0.49	Strongly Agree
Overall Satisfaction	4.40	0.60	Agree

5.3 Functionality Assessment

The functionality evaluation revealed exceptional performance in core features. Image recognition capabilities received the highest rating (mean = 4.71, SD = 0.51), indicating successful implementation of TensorFlow.js and CNN models. The chatbot functionality achieved outstanding user approval (mean = 4.75, SD = 0.46), demonstrating effective integration with Google Gemini APIs. The recommendation system scored highly (mean = 4.62, SD = 0.56), confirming the effectiveness of the material classification and guidance provision systems.

5.4 Performance and Compatibility Analysis

Performance testing indicated satisfactory application responsiveness with minimal lag or slowdowns (mean = 4.47, SD = 0.62). Memory management efficiency prevented crashes during prolonged use (mean = 4.48, SD = 0.57). Navigation difficulties were minimal (mean = 1.73, SD = 1.11), indicating intuitive user interface design. Compatibility testing revealed excellent camera integration (mean = 4.70, SD = 0.50) and seamless integration into daily recycling routines (mean = 4.56, SD = 0.59).

5.5 Security and Portability Evaluation

Security assessment showed generally positive user confidence in data protection (mean = 4.27, SD = 0.71), though this represented the lowest score among all criteria, indicating opportunities for enhanced security communication and implementation. Portability evaluation demonstrated excellent cross-browser compatibility (mean = 4.77, SD = 0.44) and responsive design across different screen sizes (mean = 4.65, SD = 0.54).

6. Alignment with the United Nations Sustainable Development Goals (SDGs)

EcoLens contributes to multiple Sustainable Development Goals (SDGs) beyond waste management. It advances SDG 4: Quality Education by providing accessible digital learning tools that build environmental awareness among students and communities. Through SDG 11: Sustainable Cities and Communities, it supports cleaner and more resilient urban environments by improving waste segregation and linking users to local recycling facilities. Central to its mission is SDG 12: Responsible Consumption and Production, which promotes proper segregation, reuse, and recycling practices. EcoLens also addresses SDG 13: Climate Action by reducing landfill waste and mitigating greenhouse gas emissions while fostering circular economy practices. Its impact extends to SDG 14: Life Below Water, as it helps prevent plastic leakage into waterways and marine ecosystems, and SDG 15: Life on Land, by protecting biodiversity through reduced land degradation and pollution. Finally, EcoLens reinforces SDG 17: Partnerships for the Goals by encouraging collaboration among universities, government agencies, NGOs, and recycling enterprises to sustain its reward system and broaden its reach. This multi-SDG alignment positions EcoLens as a comprehensive sustainability innovation that bridges technology, education, and policy to advance the global 2030 Agenda.

7. Limitations

Several limitations were identified during the development and evaluation of EcoLens. The image recognition system experienced reduced accuracy under certain environmental conditions,

including poor lighting, complex backgrounds, and unusual object orientations. While the system performed well under controlled conditions, real-world deployment may require additional training data and algorithm refinement to maintain consistent performance across diverse environments.

The study sample was limited to technology students from a single institution, potentially limiting the generalizability of results to broader populations with varying technological literacy levels. The chatbot occasionally provided inaccurate information regarding recycling center locations, indicating the need for improved database integration and real-time information updates.

Performance issues included high JavaScript execution times and suboptimal image optimization, contributing to longer loading periods on lower-specification devices. Accessibility challenges were identified, including insufficient color contrast, missing title elements, and visibility issues with certain interface elements, particularly affecting users with visual impairments or those using assistive technologies.

The point-based reward system, while conceptually sound, requires establishment of partnerships with local recycling centers and businesses to provide meaningful rewards and maintain long-term user engagement. The current implementation relies on theoretical reward structures that need real-world validation and sustainability assessment.

8. Conclusions and Future Work

8.1 Conclusions

EcoLens advances the objectives of **UN SDG 12: Responsible Consumption and Production** while contributing to broader sustainability goals in the Philippines. The application achieved strong user acceptance across all evaluation criteria, receiving particularly high ratings for functionality (4.59), compatibility (4.58), and portability (4.71). Through the integration of TensorFlow.js-powered image recognition, comprehensive recycling guidance, and gamification elements, EcoLens offers a holistic approach to fostering sustainable waste management behaviors.

The study effectively addressed key gaps in existing literature by focusing on student populations, applying advanced image recognition technologies, and embedding long-term engagement strategies through gamification. Performance testing confirmed acceptable application efficiency with opportunities for further optimization, while user acceptance testing validated its effectiveness in educational settings. These findings position EcoLens as a significant advancement in technology-driven environmental solutions, providing a scalable model for addressing waste management challenges in developing countries. Its ability to promote recycling awareness and deliver practical guidance highlights the transformative role of digital innovation in driving behavioral change and environmental stewardship.

Moreover, EcoLens illustrates how AI-powered applications can contribute directly to the SDGs by integrating technological innovation, education, and behavioral incentives into waste management systems. Beyond supporting **SDG 12**, it aligns with **SDG 4 (Quality Education)**, **SDG 11 (Sustainable Cities and Communities)**, **SDG 13 (Climate Action)**, **SDG 14 (Life Below Water)**, **SDG 15 (Life on Land)**, and **SDG 17 (Partnerships for**

the Goals), positioning the application as a comprehensive model for sustainable development in the Philippines.

Ultimately, EcoLens is not merely a recycling tool but a platform for sustainable transformation—empowering individuals, communities, and institutions to take meaningful action toward achieving the global 2030 Agenda.

8.2 Future Work

Future development should focus on enhancing image recognition accuracy through expanded training datasets incorporating diverse environmental conditions, lighting scenarios, and object orientations. Implementation of advanced image preprocessing techniques and alternative machine learning models may improve recognition reliability across varied real-world conditions.

Expanding the evaluation to include diverse populations beyond technology students would provide broader insights into application effectiveness across different demographic groups and technological literacy levels. Longitudinal studies tracking long-term behavior change and sustained engagement would validate the application's impact on recycling habits and environmental awareness.

Technical improvements should address performance optimization through JavaScript code refinement, image compression implementation, and caching strategy enhancement. Accessibility improvements including color contrast optimization, screen reader compatibility, and inclusive design principles would ensure broader user accessibility.

Partnership development with local recycling centers, educational institutions, and government agencies would enable real-world implementation of the reward system and provide sustainable incentive structures. Integration with existing waste management infrastructure and policy frameworks would enhance the application's practical impact and scalability potential.

Future research should also explore integration with emerging technologies such as blockchain for reward system transparency, IoT sensors for real-time recycling center capacity monitoring, and advanced natural language processing for improved chatbot functionality and multilingual support to serve the Philippines' diverse linguistic communities.

8.3 Video Demonstration Link for Software Presentation

The accompanying video provides a demonstration of the system's key functionalities:

1. [Ecolens \(link\)](#)

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