

SEAWAVES: A GREEN COMPUTING SOLUTION FOR SUSTAINABLE MARINE SAFETY EVALUATED USING ISO 14001 AND ISO 50001 PRINCIPLES

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Abstract: The use of Green Computing is a growingly important measure for reducing and optimizing the environmental impacts and energy usage of Information and Communication Technologies, as well as encouraging the development of sustainable systems. In the maritime industry, there are growing applications for both monitoring and communications technology to improve maritime vessel safety; however, there are insufficient studies to assess the sustainability of these systems. This study evaluated the SEAWAVeS (Sea Condition Emergency Alert and Warning Apparatus for Vessel Safety) system as a Green Computing solution for sustainable marine safety using principles adapted from ISO 14001 and ISO 50001. The research approach used in this study was descriptive-evaluative design utilizing documented system characteristics, operational observations, and actual performance testing. The evaluation focused on environmental sustainability, energy efficiency, reliability of communications, efficient use of resources, and lifecycle consideration. Battery endurance testing conducted using a Redmi Note 10 Pro smartphone revealed that the system operated for approximately 27 hours when dedicated solely to SEAWAVeS and 13 hours under normal smartphone usage conditions, indicating efficient utilization of mobile computing resources. The system's GSM/GPRS communication mechanism demonstrated operational reliability through a store-and-forward capability that preserves collected data during connectivity interruptions and automatically transmits the information once network access is restored. In addition, the system contributes to environmental sustainability by supporting accident prevention, enhancing environmental awareness through real-time monitoring and alerts, and utilizing commercially available Android devices that are maintainable, repairable, and compatible with existing electronic waste management practices. The findings indicate that SEAWAVeS exhibits key Green Computing characteristics, including energy-efficient operation, resource optimization, environmental responsibility, and sustainable technology utilization. Consequently, the system can be considered a Green Computing solution that contributes to sustainable marine safety and environmentally responsible maritime operations

Keywords Energy efficiency; Environmental sustainability; Maritime communication; Real-time monitoring; Vessel monitoring system

1. INTRODUCTION

The heavy usage of ICT to communicate and gather information has contributed to the world's increased demand for energy and has created a host of environmental issues as well [1-2]. As a result, there is now a critical need for Green Computing, a new approach to designing, developing, and using technology in an environmentally friendly manner. This environmentally sustainable technology solution promotes responsible use of computer resources by reducing energy consumption and promoting the recycling of electronic waste as well as supporting sustainable system operation [3-8]. At the same time, both marine transportation and the use of small boats, especially near coastlines and tourism hotspots, still encounter major issues related to safety [9], communication [10], and potential environmental risks [11-12], including accidents and oil spills. The marine environment generally provides



limited monitoring capability and poor communication infrastructure [13]; therefore, these issues are worsened. Sensor-based technologies and the communication networks of many new systems have been engineered to provide improved safety in all maritime environments through monitoring and surveillance [14]. Similarly, wireless sensing and monitoring technologies have been utilized for hazard detection and safety monitoring in maritime environments [15]. Recent advances in intelligent and autonomous monitoring systems have further demonstrated the potential of technology-driven solutions to enhance situational awareness and operational safety in marine settings [16]. Although recent advancements have been made, there still remains a need for low-cost monitoring solutions that also provide real-time vessel tracking and emergency response for small watercraft operating in coastal areas. To address this issue, the SEAWAVEs (Sea Condition Emergency Alert and Warning Apparatus for Vessel Safety) system was created to enhance marine safety and operational awareness [17-18].

Previous studies have shown that SEAWAVEs is a very effective tool for monitoring vessels, allowing users to track them in near real time and facilitating sustainable tourism operations at coastal destinations like Boracay Island [18]. However, there has been no research to establish the effectiveness of SEAWAVEs aligning to the principles of Green Computing [17]. All current research has been limited to describing how SEAWAVEs is used, deployed, and what type of system it provides, but there are insufficient studies addressing its impact on the use of energy and environmental sustainability. Therefore, there is a need for additional research based on today's expectations of all ICT-based solutions to not only have functional capacity but also be environmentally responsible and energy efficient.

This study will evaluate the energy performance and environmental impact of SEAWAVEs as a Green Computing solution for sustainable marine safety using principles from internationally recognized standards such as ISO 14001 and ISO 50001. The study aims to measure energy efficiency of the system by means of performance indicators, such as battery use and the behavior of the system. Additionally, this research evaluated some of the many advantages that the system provides environmentally. They consist of cutting down pollution, utilizing available resources in an optimum way, and encouraging the sustainability of the marine industry. The data were collected and analyzed using an analytical method that assessed the actual functional efficiency and identified characteristics of the system.

The findings of this study are expected to benefit multiple stakeholders. For researchers and academics, it contributes to the growing body of knowledge on Green Computing and sustainable ICT applications in marine environments. For developers and system designers, it provides insights into integrating energy-efficient and environmentally sustainable practices in system design. For policymakers and maritime authorities, the study offers evidence on the potential of technology-driven solutions to enhance marine safety while supporting environmental protection. Additionally, coastal communities and tourism stakeholders may benefit from improved safety systems that indirectly contribute to environmental preservation.

The scope of this study is limited to the evaluation of the SEAWAVEs system based on its documented features and actual operational performance. The assessment focuses on energy efficiency and environmental sustainability aspects aligned with ISO 14001 and ISO 50001 principles. Furthermore, the study does not cover other system attributes such as usability, security, or software quality, as the primary focus is on Green Computing evaluation.

Overall, this research extends existing work on SEAWAVEs by providing a sustainability-oriented perspective, positioning the system not only as a marine safety solution but also as a viable Green Computing implementation for sustainable marine operations.

2. MATERIALS AND METHODS

This study employed a descriptive-evaluative research design to assess the sustainability characteristics of the SEAWAVEs system as a Green Computing solution for sustainable marine safety. The evaluation focused on two key dimensions of Green Computing: environmental sustainability and energy efficiency, which are consistent with the principles embodied in ISO 14001 Environmental Management Systems and ISO 50001 Energy Management Systems. The study adapted relevant principles and indicators as an analytical framework for evaluating the system's sustainability performance [5-8].

2.1. Data Sources

The evaluation was conducted primarily using actual operational observations, system testing, and performance measurements of the SEAWAVEs platform. Additional technical information regarding the system architecture, communication mechanisms, monitoring functions, and alerting capabilities was obtained from system documentation and implementation records.

The SEAWAVEs system consists of an Android-based mobile platform integrated with location and communication technologies that enable real-time vessel tracking, monitoring, and emergency alert generation. Figure 1 illustrates the overall architecture of the SEAWAVEs system, showing the interaction among the onboard Android device, GPS module, GSM/GPRS communication network, server infrastructure, and monitoring platform. The system utilizes GPS for location acquisition and GSM/GPRS technologies for data transmission between the onboard device and the monitoring platform [17,19]. In addition, the system incorporates a web-based monitoring component that provides users with real-time information regarding vessel status and environmental conditions [17].

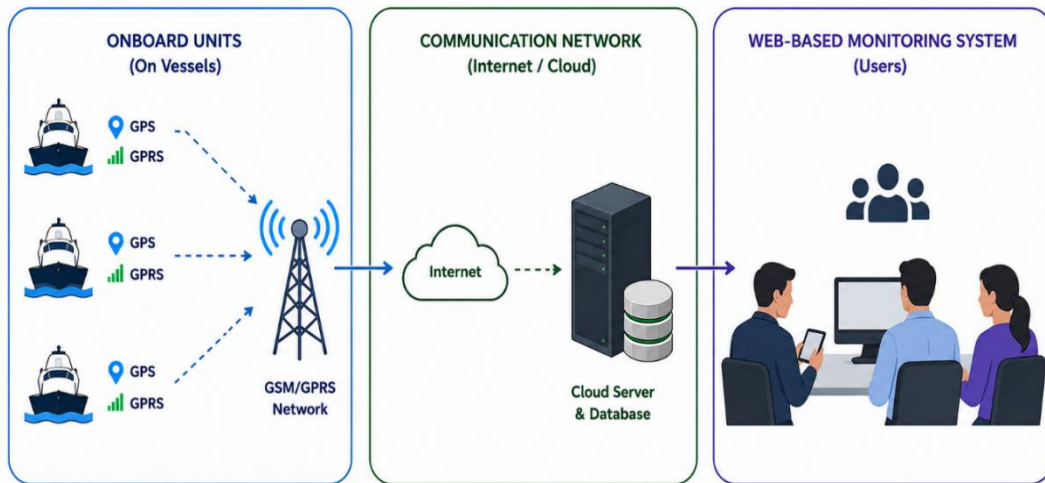


Figure 1. Overall architecture of the SEAWAVEs monitoring and alert system.

2.2. Evaluation Framework

The study adopted a Green Computing evaluation framework derived from selected principles of ISO 14001 and ISO 50001. ISO 14001 emphasizes environmental responsibility, pollution prevention, resource efficiency, and lifecycle thinking, while ISO 50001 focuses on energy performance, energy efficiency, and continual improvement of energy management practices [5-8].

Based on these principles and the operational characteristics of SEAWAVEs, the evaluation framework was organized into two major dimensions:

Environmental Sustainability

Contribution to pollution prevention and risk reduction;

Enhancement of environmental awareness through monitoring and alerts;

Resource efficiency through the utilization of existing mobile computing devices;

Lifecycle considerations, including maintainability and compatibility with established electronic waste management practices.

Energy Efficiency

Energy performance during system operation;

Efficiency of communication and data transmission mechanisms;

Utilization of energy-efficient mobile computing platforms;

Potential for future optimization and energy-performance improvement.

The evaluation indicators were established through a review of Green Computing literature and the guiding principles of ISO 14001 and ISO 50001 [3-8].

2.3. Data Collection Procedure

Data collection involved a comprehensive review of system documentation and actual operational testing of the SEAWAVEs platform. Particular attention was given to system features associated with environmental sustainability and energy efficiency.

To assess energy performance, actual operational testing was conducted using a Redmi Note 10 Pro Android smartphone configured to run the SEAWAVEs application. Battery endurance was observed under two operating conditions. In the first condition, the device was dedicated solely to the SEAWAVEs application, with no additional applications installed or running. In the second condition, the device was used under typical smartphone operating conditions with multiple applications installed and active. Battery life measurements were recorded to provide an empirical indication of the system's energy efficiency.

Information regarding communication efficiency, monitoring functionality, environmental contributions, and system architecture was validated against actual system operation. The study also considered system characteristics such as real-time monitoring capability, GSM/GPRS communication, automatic data synchronization after connectivity interruptions, and the use of a commercially available Android device platform [17-18].

2.4. Data Analysis

The collected data were analyzed through criterion-based evaluation. Each of the sustainability indicators was evaluated using documented evidence of the system's operational tests and specifications. The evaluation process used evidence-based methods, in which the observer could derive conclusions based on the characteristics of the system from their observation and through physical measurement of operational performance.

For the environmental sustainability dimension, qualitative analysis was conducted to determine how system functionalities support pollution prevention, environmental awareness, and sustainable marine operations. For the energy efficiency dimension, analysis focused on battery endurance, communication efficiency, resource utilization, and operational characteristics associated with energy consumption.

Findings were subsequently interpreted in relation to Green Computing principles and the sustainability objectives promoted by ISO 14001 and ISO 50001. The overall assessment was used to determine the extent to which SEAWAVEs can be considered a Green Computing solution that contributes to sustainable marine safety.

2.5. Scope and Limitations of the Evaluation

This evaluation reviewed only the SEAWAVEs system's operational performance, specifically its environmental sustainability and energy efficiency, and had no assessment of any other software quality characteristics described in ISO/IEC 25010 [20]. In addition, ISO 14001 and ISO 50001 were used to frame the evaluation process.

3. RESULTS AND DISCUSSION

This study evaluated the SEAWAVEs system as a Green Computing solution for sustainable marine safety using principles adapted from ISO 14001 and ISO 50001. The evaluation focused on environmental sustainability and energy efficiency based on documented system characteristics, operational observations, and actual performance data.

3.1. Energy Efficiency Assessment

One of the primary objectives of Green Computing is to reduce energy consumption while maintaining system functionality [3-4]. To assess the energy efficiency of SEAWAVEs, battery endurance testing was conducted using a Redmi Note 10 Pro smartphone configured to run the application.

The results revealed that when the device was dedicated exclusively to the SEAWAVEs application, the system remained operational for approximately 27 hours on a single charge. Under normal smartphone usage conditions, where multiple applications were installed and running concurrently, the device maintained operation for approximately 13 hours.

Table 1. Battery endurance of the SEAWAVEs system.

Operating Condition	Battery Endurance
Dedicated SEAWAVEs operation	27 hours

Typical smartphone usage with multiple applications	13 hours
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The observed battery performance demonstrates that the system can sustain prolonged operation using commercially available mobile hardware. This finding is particularly important for marine applications where uninterrupted monitoring may be required over extended periods. The ability to operate continuously for more than one day under dedicated deployment conditions suggests that the system exhibits efficient utilization of mobile computing resources. Furthermore, the use of an Android smartphone eliminates the need for specialized high-power hardware, thereby reducing both energy requirements and equipment costs.

The energy efficiency of SEAWAVeS is also supported by its architecture. Instead of deploying multiple dedicated devices for sensing, processing, communication, and display, the system consolidates these functions into a single mobile platform. Such resource consolidation aligns with Green Computing principles that advocate efficient utilization of computing resources while minimizing energy consumption [3-4].

3.2. *Communication Efficiency and Operational Reliability*

Communication reliability is essential for maritime safety systems, particularly in coastal and offshore environments where connectivity interruptions frequently occur. The SEAWAVeS system employs GSM/GPRS communication to transmit monitoring data and alerts between vessels and the monitoring platform [17].

A notable feature of the system is its ability to retain collected data during periods of signal loss and automatically transmit the stored information once network connectivity is restored. This store-and-forward capability ensures continuity of data collection and minimizes information loss during communication disruptions.

The use of GSM/GPRS technology offers several sustainability advantages. First, GSM/GPRS infrastructure is already widely deployed, reducing the need for additional communication hardware. Second, the technology supports relatively low-bandwidth data transmission, making it suitable for continuous monitoring applications while maintaining efficient use of communication resources. These characteristics contribute to both operational reliability and resource efficiency, which are consistent with the objectives of ISO 50001 concerning efficient utilization of energy-related resources [7-8].

3.3. *Environmental Sustainability Assessment*

Environmental sustainability was evaluated based on principles derived from ISO 14001, including pollution prevention, environmental awareness, resource efficiency, and lifecycle considerations [5-6].

The primary environmental contribution of SEAWAVeS stems from its role in enhancing marine safety. By providing real-time monitoring of vessel status and sea conditions, the system enables early detection of potentially hazardous situations. Through timely alerts and warnings, SEAWAVeS assists vessel operators in making informed decisions that may prevent accidents and associated environmental consequences, including fuel leakage, vessel damage, and marine pollution. Figure 2 illustrates the alerting mechanism of the SEAWAVeS system. The application generates multiple alert levels based on real-time sensor measurements and vessel conditions. These alerts provide immediate situational awareness to operators, enabling timely responses to potentially hazardous situations and reducing the likelihood of maritime accidents.



Figure 2. SEAWAVEs alert interface showing Yellow Alert, Orange Alert, and Red Alert conditions generated from real-time vessel monitoring parameters.

In addition to accident prevention, the monitoring platform contributes to environmental awareness by providing users with real-time situational information. The availability of tracking information, sea condition data, and alert notifications promotes proactive decision-making and encourages responsible vessel operation. Similar benefits were reported in previous studies that highlighted the system's role in supporting safe and sustainable marine activities, particularly within tourism-oriented coastal environments such as Boracay Island [18]. Figure 3 presents the SEAWAVEs monitoring dashboard used for real-time vessel tracking and situational monitoring. The interface provides users with visual information regarding vessel location and movement, thereby supporting timely decision-making and enhanced operational awareness.



Figure 3. SEAWAVEs monitoring dashboard showing real-time vessel tracking and monitoring activities.

The system also demonstrates resource efficiency through its use of an Android smartphone as the primary computing platform. The integration of sensing, processing, communication, and monitoring functionalities within a single device minimizes the need for additional specialized hardware. This approach reduces material consumption and supports efficient utilization of existing technological resources.

3.4. Lifecycle Considerations and Sustainability

Lifecycle thinking is an important component of environmental management systems [5-6]. The SEAWAVEs platform benefits from utilizing commercially available Android devices that are widely supported, maintainable, and repairable. The availability of spare parts, repair services, and technical support contributes to extended device usability and reduces the likelihood of premature replacement.

Moreover, Android smartphones can be integrated into existing electronic waste management and recycling programs. Although the system itself does not introduce specific end-of-life disposal mechanisms, its reliance on standard consumer electronics enables the application of established e-waste management practices, thereby reducing potential environmental impacts associated with disposal.

3.5. Opportunities for Further Improvement

While the evaluation demonstrates that SEAWAVEs possesses several characteristics consistent with Green Computing principles, opportunities for further enhancement remain. The system currently operates in a continuous real-time monitoring mode while the application is active. Although this design supports immediate alert generation and situational awareness, it may result in continuous data processing and transmission.

Future versions of the system may benefit from the incorporation of adaptive transmission strategies, event-triggered communication, intelligent filtering mechanisms, or power-aware scheduling algorithms. Such enhancements could further improve energy efficiency while maintaining the operational effectiveness required for marine safety applications.

3.6. Overall Assessment

SEAWAVEs demonstrates multiple properties that correspond with criteria identified for Green Computing. These include long-lasting operational performance, efficient use of existing commercial mobile hardware, reliable low bandwidth communication capability, assistance with accident prevention that supports environmental sustainability, and compatibility with current lifecycle management processes. All of these properties demonstrate that SEAWAVEs not only serves its primary purpose of providing marine safety, but also provides a sustainable Information Technology platform.

The evaluation therefore supports the idea that SEAWAVEs is a green computing approach to achieving environmentally responsible marine safety through technology sustainability.

4. CONCLUSION

The results show that SEAWAVEs functions as a Green Computing System in relation to Energy Efficiency. SEAWAVEs was deployed on a dedicated Android Device and ran for approximately 27 hours on that device. SEAWAVEs was operated in a normal smartphone use mode for approximately 13 hours. The results of this operation can be interpreted as an efficient use of mobile computing resource while still allowing continuous monitoring and alerting capabilities. The fact that the sensing, processing, communicating and monitoring activities are all provided through a single Android platform will assist in optimizing the resources and reducing the energy needed to provide this functionality.

From an environmental sustainability perspective, SEAWAVEs contributes to marine safety through real-time monitoring, vessel tracking, and emergency alert generation. These capabilities support the prevention of maritime incidents that may result in environmental damage, while simultaneously promoting environmental awareness among users through timely access to sea condition and vessel status information. Mobile devices readily available on the market also supports maintainability, repairability, and compatibility with existing electronic waste management practices. As such, using these types of devices would help fulfill the lifecycle requirements of implementing sustainable technology.

The study further established that the system's GSM/GPRS-based communication mechanism provides reliable data transmission and incorporates a store-and-forward capability that preserves collected information during connectivity interruptions. This feature enhances operational resilience and supports continuous monitoring in environments where communication reliability may be limited.

Overall, the evidence gathered in this study supports the conclusion that SEAWAVEs functions as a Green Computing solution for sustainable marine safety. The system demonstrates energy-efficient operation, effective

utilization of existing technological resources, and meaningful contributions to environmental protection through enhanced marine safety and situational awareness. While opportunities for further optimization exist, particularly in adaptive data transmission and power management strategies, the current implementation already reflects key principles of sustainable and environmentally responsible computing. Consequently, SEAWAVEs may serve as a model for future Green Computing initiatives in maritime and other safety-critical application domains.

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Conflict of Interest

The author declares no financial or commercial conflict of interest. The technology evaluated in this study was developed through a publicly funded research project involving Aklan State University and its partner institutions. The evaluation was conducted independently and objectively based on documented evidence and actual system performance data.

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