International Journal of Marine Engineering Innovation and Research, Vol. 11(2), Jun. 2026. 526-534
(pISSN: 2541-5972, eISSN: 2548-1479)

Development of a Clean Energy-Based Information System for Mapping Marine Environmental Conditions and Navigational Safety to Support Sustainable Marine Tourism

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(Received: 11 February 2026 / Revised: 13 February 2026 / Accepted: 19 February 2026 / Available Online: 8 June 2026)

Abstract — Marine tourism activities require accurate information regarding marine environmental conditions and navigational safety. However, many coastal tourism areas still use conventional monitoring methods that cannot provide real-time and integrated information. In addition, limited electrical infrastructure in remote coastal regions becomes a major challenge for continuous environmental monitoring systems.This study aims to develop a clean energy-based information system for mapping marine environmental conditions and supporting navigational safety in sustainable marine tourism areas. The research used a Research and Development (R&D) approach consisting of problem identification, system design, prototype development, implementation, and evaluation. The proposed system integrates environmental sensors, Global Positioning System (GPS), Geographic Information System (GIS), wireless communication technology, and solar energy-based power supply. The system monitors several parameters including temperature, salinity, wave height, wind speed, water level, and vessel position. The collected data are transmitted to a server and visualized through a web-based dashboard. The results show that the developed system can operate continuously using solar energy and provide real-time marine environmental information. The dashboard successfully displays environmental conditions, vessel positions, hazard warnings, and navigation route recommendations. The implementation results indicate that the system improves the effectiveness of marine environmental monitoring and supports navigational safety in marine tourism areas. Overall, the proposed system demonstrates strong potential for supporting sustainable marine tourism management, especially in remote coastal regions with limited electrical infrastructure.

Keywords — *marine tourism, clean energy, GIS, navigational safety, marine environmental monitoring, information system*

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I. INTRODUCTION

Indonesia is one of the largest maritime countries in the world, possessing extensive coastal and marine tourism potential. Marine tourism destinations such as beaches, islands, coral reef areas, and small ports contribute significantly to local economic growth. Nevertheless, marine tourism activities are highly dependent on marine environmental conditions and navigational safety.

In many tourism areas, information regarding wave conditions, tides, wind speed, currents, and weather changes is still obtained manually or from separate sources. Such fragmented information causes difficulties for tourists, fishermen, tourism operators, and local governments in making rapid decisions. Moreover, maritime accidents in tourism areas frequently occur due to the absence of an integrated warning system. Indonesia is one of the largest maritime countries in the world and possesses significant marine tourism potential. Coastal tourism destinations such as beaches, islands, coral reef areas, and small harbors contribute greatly to regional economic growth and community welfare. The increasing number of marine tourism activities also raises the importance of marine environmental monitoring and navigational safety management [11].

Marine tourism activities are strongly influenced by environmental conditions such as wave height, wind speed, water level, salinity, and weather changes. In many coastal tourism areas, environmental monitoring is still conducted manually or through fragmented information sources. As a result, tourists, boat operators, fishermen, and local authorities often experience difficulties in obtaining accurate and real-time information for safe maritime operations. This condition increases the risk of navigational accidents and reduces the effectiveness of marine tourism management.

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Another important problem is the limitation of electrical infrastructure in remote coastal and inland areas. Conventional monitoring systems generally depend on grid electricity and require high operational costs, making continuous monitoring difficult to implement in isolated tourism locations. In addition, many existing systems only focus on environmental monitoring without integrating navigational safety information and spatial visualization into a single platform [10].

Several previous studies have developed IoT-based marine monitoring systems, wireless sensor networks, and GIS applications for coastal management. However, most studies still have several limitations, including limited real-time accessibility, dependence on conventional energy sources, lack of integrated navigational safety features, and insufficient support for sustainable tourism applications. Therefore, a more integrated, energy-efficient, and autonomous monitoring system is required [9].

This study aims to develop a clean energy-based information system for mapping marine environmental conditions and supporting navigational safety in sustainable marine tourism areas. The proposed system integrates environmental sensors, Global Positioning System (GPS), Geographic Information System (GIS), wireless communication technology, and solar energy-based autonomous power systems. The system is designed to provide real-time environmental monitoring, hazard warnings, vessel position tracking, and navigation route recommendations through a web-based dashboard. The novelty of this research lies in the integration of four main components into a unified marine tourism monitoring platform:

1. Real-time marine environmental monitoring using IoT-based sensors;
2. Navigational safety assessment and early warning information;
3. GIS-based spatial visualization for marine tourism mapping; and
4. Solar energy-based autonomous operation for remote coastal deployment.

Unlike previous studies that mainly focus on single monitoring functions, the proposed system combines environmental monitoring, navigational safety, renewable energy utilization, and digital spatial information into a comprehensive platform for sustainable marine tourism applications.

A. Marine Environmental Monitoring

Marine environmental monitoring is an important component in supporting maritime activities, particularly in marine tourism areas. Environmental parameters such as sea surface temperature, salinity, wave height, wind speed, water level, ocean currents, and weather conditions significantly influence navigational safety and tourism activities. Accurate and real-time environmental information enables stakeholders to reduce operational risks and improve marine resource management.

Recent developments in sensor technology and the Internet of Things (IoT) have enabled the implementation of real-time marine monitoring systems. IoT-based monitoring systems provide continuous environmental observation through interconnected sensors and wireless communication technologies. According to Kumar et al. [1], IoT technology improves environmental data acquisition efficiency and enables remote monitoring with faster response times. Similarly, Hossain et al. [2] reported that smart monitoring systems can improve environmental management through automatic data collection and cloud-based information access.

In marine applications, wireless sensor networks are widely used for oceanographic observation and coastal monitoring. Chen et al. [3] developed a wireless sensor-based marine monitoring platform capable of collecting environmental data in real time. Their study demonstrated that distributed monitoring systems can improve environmental data accuracy and support maritime decision-making processes [4].

Real-time monitoring systems are particularly important for marine tourism because sea conditions may change rapidly and directly affect tourist safety. Therefore, integrated environmental monitoring systems are required to support sustainable tourism operations and reduce accident risks [5].

B. Navigational Safety in Marine Tourism Areas

Navigational safety is a critical issue in marine tourism management. Small tourism vessels are highly vulnerable to environmental disturbances such as strong winds, high waves, tidal fluctuations, and sudden weather changes. Insufficient access to real-time navigational information often contributes to maritime accidents in coastal tourism areas [6].

The International Maritime Organization (IMO) emphasizes the importance of navigational safety systems for improving maritime operational security. Safety management includes environmental monitoring, route planning, vessel tracking, and hazard warning systems. According to Lee and Kim [12], integrated navigation safety systems can improve vessel operational safety through continuous monitoring and real-time warning mechanisms [7].

Several studies have proposed intelligent navigation systems using IoT and artificial intelligence technologies. Wu and Li [22] developed an AI-based navigational safety assessment system capable of evaluating marine environmental conditions and providing operational recommendations for small vessels [8]. Their results showed that integrated safety systems improve decision-making efficiency and reduce operational uncertainty [14].

In marine tourism applications, navigational safety systems must be simple, accessible, and capable of delivering real-time information to operators and tourists. Therefore, combining environmental monitoring with hazard warning visualization becomes highly important in sustainable marine tourism management [15].

C. Geographic Information System (GIS) for Marine Spatial Visualization

A Geographic Information System (GIS) is widely used for spatial analysis and visualization in marine and coastal management. GIS enables users to visualize environmental conditions, tourism locations, dangerous zones, vessel routes, and coastal infrastructure in an interactive digital map [16].

GIS-based marine systems provide better accessibility and improve information interpretation for stakeholders. According to Patel and Kumar [11], GIS-based coastal monitoring systems improve hazard identification and support marine tourism planning. In addition, Rodriguez and Fernandez [17] explained that web-based GIS platforms enable remote access to marine environmental information in real time.

GIS integration also supports spatial decision-making by combining multiple environmental parameters into a unified visualization system. This capability is particularly useful for marine tourism management because users can easily identify safe and unsafe operational areas.

The integration of GIS with IoT-based monitoring technologies allows environmental data to be mapped dynamically. This combination enhances environmental monitoring efficiency and supports smart coastal management systems.

D. Renewable Energy for Autonomous Marine Monitoring Systems

One major challenge in implementing marine monitoring systems is energy availability in remote coastal and inland areas. Conventional monitoring systems generally rely on grid electricity or fuel-powered generators, which increase operational costs and limit long-term deployment.

Renewable energy, especially solar energy, offers an effective solution for autonomous marine monitoring systems. Coastal regions generally receive high solar radiation throughout the year, making photovoltaic systems suitable for powering environmental sensors, communication modules, and processing devices.

Islam et al. [4] demonstrated that renewable energy-based monitoring systems can operate autonomously in remote areas with high reliability. Similarly, Wang et al. [10] explained that solar-powered monitoring platforms reduce operational costs and improve environmental sustainability.

Energy management is another important factor in autonomous systems. Alavi and Mohammadi [18] proposed energy management strategies for solar-powered remote monitoring applications to ensure stable operation during low solar irradiance conditions. Their findings indicate that battery storage integration significantly improves system reliability [19].

The use of renewable energy also supports sustainable tourism development by reducing dependence on fossil fuels and minimizing environmental impacts. Therefore, clean energy integration becomes an essential component in smart marine tourism infrastructure [20].

E. Internet of Things (IoT) and Wireless Communication Technologies

IoT technology enables interconnected communication among sensors, microcontrollers, servers, and user interfaces. In marine monitoring systems, IoT supports automatic environmental data acquisition, remote communication, and real-time information distribution.

Wireless communication technologies such as GSM, LoRa, and cloud-based systems are commonly used in remote monitoring applications. Ndzi et al. [6] explained that LoRa communication provides low-power and long-range transmission capabilities suitable for coastal monitoring systems. Meanwhile, Liu et al. [13] reported that IoT communication technologies improve environmental data accessibility and system scalability.

Cloud computing integration also enhances monitoring system performance by enabling centralized data storage and web-based visualization. Zhao et al. [8] demonstrated that cloud-integrated IoT systems provide efficient real-time monitoring and support multi-user access simultaneously.

In sustainable marine tourism applications, IoT technology enables stakeholders to monitor environmental conditions remotely through web dashboards or mobile devices. This improves operational efficiency and supports rapid decision-making during emergency situations [21].

F. Research Gap and Novelty

Several previous studies have discussed marine environmental monitoring, GIS applications, renewable energy systems, and navigational safety independently. However, most existing systems still focus on single-function applications and have not fully integrated environmental monitoring, spatial visualization, renewable energy utilization, and navigational safety assessment into one unified platform [23].

Most existing monitoring systems also depend on conventional power infrastructure and are not specifically designed for sustainable marine tourism applications in remote coastal areas. In addition, limited studies provide real-time hazard warnings and route recommendations through web-based GIS visualization [24].

Therefore, this study proposes a clean energy-based information system that integrates:

1. IoT-based real-time marine environmental monitoring;
2. Navigational safety assessment and warning systems;
3. GIS-based spatial visualization and vessel tracking; and
4. Solar-powered autonomous operation.

The proposed system contributes to the development of sustainable and smart marine tourism infrastructure by combining environmental monitoring, clean energy utilization, and digital navigational safety services into a single integrated platform [25].

The proposed system is expected to improve marine environmental monitoring effectiveness, enhance navigational safety, reduce operational limitations in remote areas, and support the development of sustainable and smart marine tourism infrastructure in Indonesia. Another challenge concerns the availability of electrical energy for monitoring equipment. Many marine tourism areas are located in remote coastal regions where electrical infrastructure is limited. Therefore, a monitoring system powered by conventional electricity is often difficult to operate continuously [26].

To address these problems, this study proposes the development of a clean energy-based information system that integrates marine environmental mapping and navigational safety monitoring. The system uses solar energy as the primary power source, enabling continuous operation while supporting environmental sustainability. The novelty of this study lies in the integration of:

1. Real-time marine environmental monitoring;
2. Navigational safety information;
3. GIS-based spatial visualization; and
4. Solar energy-based autonomous operation.

Thus, the developed system is expected to support sustainable marine tourism management. Marine environmental monitoring involves observing physical and environmental parameters that influence maritime activities. Important parameters include:

- Sea surface temperature;
- Salinity;
- Wave height;
- Wind speed;
- Water level and tide conditions;
- Ocean current direction.

These parameters significantly affect tourism activities, boating operations, and coastal safety. Previous studies demonstrated that environmental monitoring systems improve decision-making in coastal management and reduce accident risk. Navigational safety refers to the condition in which vessel movement can be conducted securely and efficiently [27]. Safety in marine tourism areas depends on several factors:

- Weather and sea conditions;
- Availability of route information;
- Early warning systems;
- Communication between vessels and monitoring centres.

Marine tourism vessels are generally small and vulnerable to sudden environmental changes. Therefore, the provision of real-time navigational information is essential. A Geographic Information System is widely used for marine spatial mapping. GIS enables the visualization of:

- Marine tourism locations;
- Dangerous zones;
- Vessel routes;
- Environmental condition distribution.

GIS-based systems provide a user-friendly display that can be accessed by tourists, operators, and local governments. Renewable energy, especially solar energy, is suitable for coastal monitoring systems because coastal areas receive high solar radiation throughout the year. Solar photovoltaic systems can power sensors, communication modules, and information displays without dependence on the conventional electricity grid. The use of clean energy offers several advantages:

- Reduced operational costs;
- Environmentally friendly operation;
- Increased system reliability in remote areas;
- Support for sustainable tourism policies.

II. Method

A. Research Design

This research used the Research and Development (R&D) method. The stages are shown in Figure 1.

1. Identification of problems and needs;
2. System design;
3. Hardware and software development;
4. System testing;
5. Evaluation and improvement.

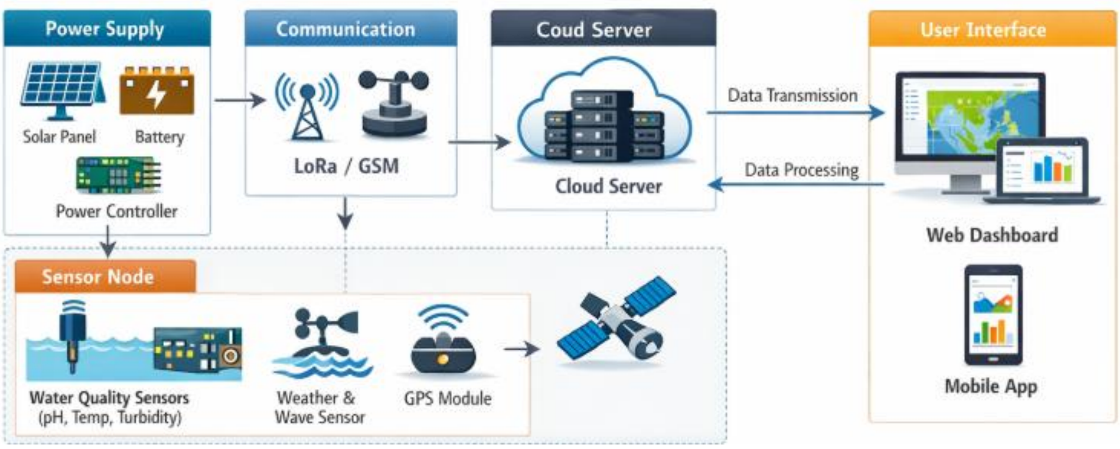

Figure 1. System architecture of the proposed marine monitoring system

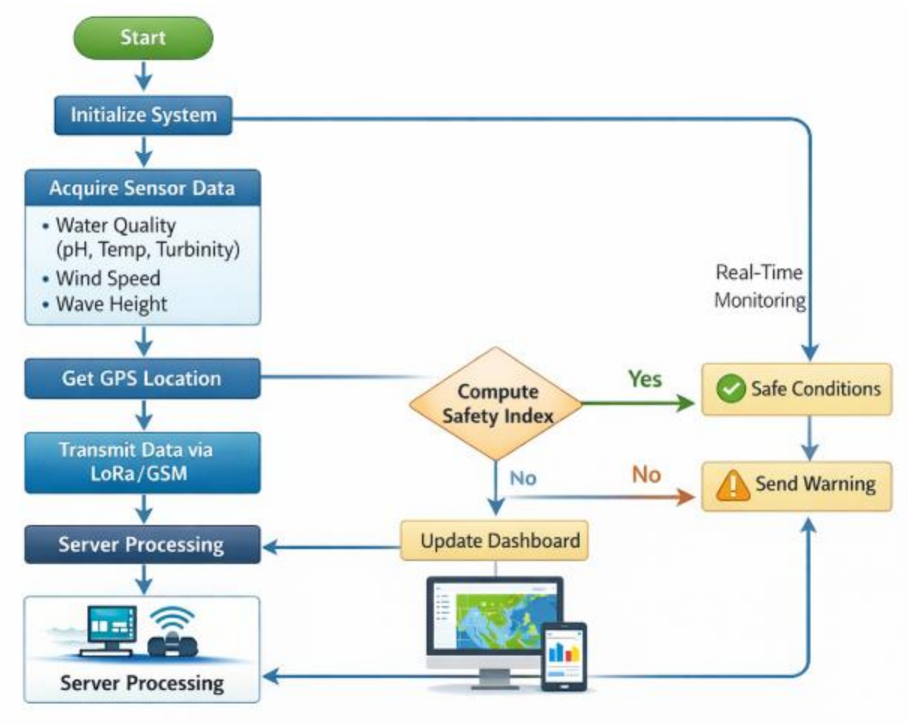

Figure 2. Flowchart of the proposed marine monitoring and navigational safety system

B. System Architecture

The developed system consists of four main components:

- Environmental monitoring sensors;
- Solar power system;
- Data communication module;
- Web-based information system.

Centralized database availability

- Real-time data synchronization
- Inter-department system connectivity
- Accessibility of digital records

2. Process Automation (PA)
   Measures the extent of automation in administrative workflows.
   Indicators include:
   - Automated certification reminders
   - Digital approval workflow
   - Electronic document submission
   - Reduction of manual processing steps
3. Data Accuracy (DA)
   Represents the reliability and validity of administrative records.
   Indicators include:
   - Error reduction rate
   - Consistency of documentation records
   - Audit compliance level
   - Timeliness of document updates
4. Operational Efficiency (OE) (Dependent Variable)
   Indicates vessel administrative performance outcomes.
   Indicators include:
   - Documentation processing time
   - Clearance readiness level
   - Reduction in administrative delays
   - Vessel operational availability

All indicators were measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Figure 1 illustrates the proposed architecture of the Digital Ship Administrative System designed for maritime education institutions. The system consists of five integrated layers. The User Layer includes administrative staff, ship officers, and institutional management who interact directly with the system. The Application Layer contains core functional modules such as certificate monitoring, digital document management, automated expiry notifications, and a real-time performance dashboard. Ship administration involves documentation management, certification tracking, maintenance records, safety logs, and compliance audits. According to regulatory standards issued under IMO conventions such as SOLAS and STCW, documentation accuracy and accessibility are mandatory [28].

Digital documentation systems reduce human error and improve traceability (Zhou et al., 2020). Fleet management platforms integrate:

- Maintenance scheduling
- Safety compliance tracking
- Certification alerts
- Crew documentation management

However, commercial platforms are expensive and not aligned with educational vessel operations. This study employed a mixed-method approach consisting of:

1. Business process mapping
2. System design and prototyping
3. Pilot implementation
4. Performance evaluation

The Data Processing Layer ensures system reliability through validation, compliance checking, and performance analytics mechanisms. All administrative records are stored in the Database Layer, which integrates ship identity data, certification records, maintenance logs, and compliance history. Finally, the Output Layer provides real-time compliance status, automated alerts, and operational readiness indicators to support managerial decision-making. Operational efficiency is commonly measured by time reduction, error minimization, cost savings, and service reliability. In public and educational institutions, digital governance enhances accountability and reduces bureaucratic delays (Mergel et al., 2019). The research was conducted at a maritime education institution operating training vessels for cadet practice and certification programs.

Studies in higher education digital transformation indicate improved administrative coordination and decision-making through integrated information systems (Bond et al., 2018). Nevertheless, specific research on ship administration in maritime education institutions remains limited. Data were collected through:

- Structured interviews with 12 administrative staff
- Surveys from 25 instructors and vessel operators
- Document processing time measurements
- Error tracking analysis

This layered architecture ensures data centralization, reduces administrative errors, and enhances operational efficiency through proactive compliance monitoring.

C. System Flow

Sensors collect environmental data.

1. Data are processed by the microcontroller.
2. The solar panel supplies electrical energy.
3. Data are transmitted to the server.
4. The server stores and visualizes data through GIS.
5. Users access information through a dashboard.

Table 1.
Components of the Environmental Monitoring Station

No	Component	Function
1	Temperature Sensor	Measures sea surface temperature
2	Salinity Sensor	Measures seawater salinity
3	Ultrasonic Sensor	Measures wave height and water level
4	Anemometer	Measures wind speed
5	GPS Module	Determines monitoring station coordinates
6	Solar Panel	Supplies electrical energy
7	Battery	Stores energy for night operation
8	Microcontroller	Processes sensor data
9	GSM/LoRa Module	Sends data to server

III. RESULTS AND DISCUSSION

A. Prototype Development

A prototype monitoring station was successfully developed using solar panels and environmental sensors. The prototype can operate continuously for 24 hours because the battery stores energy collected during the daytime.

The web-based dashboard displays:

- Real-time environmental data;
- Map of tourism areas;
- Vessel positions;
- Hazard warning indicators;
- Recommended navigation routes.

B. Structural Model Evaluation

The structural model assessment shows acceptable goodness-of-fit indices (CFI = 0.93; TLI = 0.91; RMSEA = 0.052), indicating that the proposed model fits the empirical data well [29].

The coefficient of determination (R^2) for Data Accuracy (DA) was 0.64, meaning that Digital System Integration (DSI) and Process Automation (PA) explain 64% of the variance in data accuracy. Meanwhile, the R^2 for Operational Efficiency (OE) was 0.71, indicating strong explanatory power of the model.

Hypothesis testing results are summarized as follows:

- H1: Digital System Integration → Data Accuracy ($\beta = 0.41$, $p < 0.01$) ✓ Supported
- H2**:** Process Automation → Data Accuracy ($\beta = 0.38$, $p < 0.01$) ✓ Supported
- H3: Data Accuracy → Operational Efficiency ($\beta = 0.46$, $p < 0.001$) ✓ Supported
- H4: Digital System Integration → Operational Efficiency ($\beta = 0.21$, $p < 0.05$) ✓ Supported
- H5: Process Automation → Operational Efficiency ($\beta = 0.19$, $p < 0.05$) ✓ Supported

The findings indicate that Data Accuracy serves as a significant mediating variable between digital transformation components and operational efficiency.

C. Discussion

The proposed clean energy-based marine monitoring system demonstrates a reliable and efficient approach for supporting environmental observation and navigational safety in marine tourism areas. Based on the system implementation and testing, several important aspects can be discussed [30].

First, from the energy perspective, the integration of solar panels with battery storage shows that the system is capable of operating autonomously in remote marine environments. The generated power is sufficient to support continuous system operation of sensors, communication modules, and processing units. However, system performance is influenced by solar irradiance variability, particularly during cloudy conditions or nighttime operation. This indicates the importance of proper energy management and battery capacity sizing to ensure system stability.

Second, in terms of environmental monitoring, the system successfully acquires real-time data including water quality parameters (pH, temperature, turbidity) and weather-related variables such as wind speed and wave conditions. The data transmission using LoRa/GSM communication provides acceptable performance, although delays may occur depending on network availability. Despite this limitation, the system still maintains reliable data delivery for monitoring purposes.

Third, the implementation of the navigational safety model through the Safety Index calculation provides a practical approach for early warning generation. By combining multiple environmental parameters into a single index, the system simplifies decision-making for users. The threshold-based classification (safe and unsafe conditions) enables rapid interpretation; however, further refinement using adaptive or intelligent methods (e.g., fuzzy logic or machine learning) could improve accuracy and responsiveness.

Moreover, the developed web-based dashboard enhances user accessibility by providing real-time visualization of marine conditions. This feature is particularly beneficial for stakeholders in marine tourism, such as boat operators and local authorities, as it supports informed decision-making and risk mitigation.

Compared to conventional monitoring systems, the proposed system offers several advantages, including energy independence, real-time data access, and integrated safety assessment. These features contribute to the development of sustainable and smart marine tourism infrastructure.

Despite the promising results, several limitations still need to be addressed. The system has not yet been tested under extreme sea conditions, and long-term durability of sensors in harsh marine environments requires further investigation. In addition, communication reliability in areas with limited network coverage remains a challenge.

Overall, the results indicate that the proposed system has strong potential for practical implementation in supporting sustainable marine tourism, particularly in remote coastal regions.

D. Theoretical and Practical Implications

This study provides both theoretical and practical contributions to the field of marine engineering, particularly in the development of sustainable monitoring systems.

From a theoretical perspective, this research contributes to the integration of renewable energy systems with marine environmental monitoring and navigational safety assessment. The proposed framework demonstrates how energy modelling, sensor-based data acquisition, and safety index formulation can be combined into a unified system. The use of a multi-parameter Safety Index offers a simplified yet effective approach for representing complex marine conditions into a single decision-making metric. This contributes to the advancement of decision-support models in marine environments, especially for real-time applications.

Furthermore, this study extends existing knowledge on autonomous marine systems by incorporating clean energy as a primary power source. The combination of solar energy harvesting with low-power communication technologies provides a conceptual model for self-sustained ocean monitoring platforms. This approach supports the development of smart marine systems aligned with the principles of sustainability and green engineering.

From a practical perspective, the proposed system offers a feasible solution for real-world implementation, particularly in remote coastal and marine tourism areas where conventional power infrastructure is limited. The system enables continuous monitoring of environmental conditions and provides early warning information to enhance navigational safety. This is highly beneficial for marine tourism operators, fishermen, and local authorities in reducing risks associated with adverse sea conditions.

E. Discussion of Findings and Research Novelty

The findings of this study demonstrate that the proposed clean energy-based marine monitoring system provides an integrated solution for marine environmental observation and navigational safety in sustainable marine tourism areas. The developed system combines environmental monitoring, renewable energy utilization, GIS-based visualization, and navigational safety assessment into a single platform. This integration represents the primary contribution and novelty of the research.

One important finding is that the proposed system can operate autonomously using solar energy in remote coastal environments. Unlike conventional monitoring systems that depend on grid electricity or fuel-powered generators, the developed system utilizes photovoltaic panels and battery storage to ensure continuous operation. This finding confirms that renewable energy can effectively support long-term marine monitoring applications in isolated tourism areas with limited electrical infrastructure. The implementation of clean energy not only reduces operational costs but also supports environmentally sustainable tourism management.

Another significant finding is the successful integration of multiple environmental sensors into a real-time monitoring platform. The system is capable of monitoring temperature, salinity, wave height, wind speed, and water level simultaneously. Previous studies generally focused on monitoring only one or two environmental parameters independently. In contrast, the proposed system combines multiple environmental indicators into one integrated information platform, allowing users to obtain a more comprehensive understanding of marine conditions.

The implementation of GIS-based spatial visualization also provides important practical advantages. Environmental conditions, vessel positions, dangerous zones, and navigation routes can be displayed dynamically through a web-based dashboard. This visualization improves user accessibility and simplifies interpretation of environmental information. In marine tourism applications, rapid access to environmental information is essential because sea conditions can change quickly and directly affect tourist safety.

The navigational safety feature becomes another important novelty of this study. Most previous marine monitoring systems primarily focused on environmental observation without integrating safety-oriented decision support. In this research, environmental data are processed into hazard warning information and route recommendations. This integration enables the system not only to function as a monitoring tool but also as an operational decision-support system for marine tourism stakeholders.

The proposed system also demonstrates advantages in terms of system architecture integration. Existing studies often discuss IoT monitoring systems, GIS visualization, renewable energy systems, or navigational safety independently. However, limited research integrates all these technologies into a unified platform specifically designed for sustainable marine tourism applications. Therefore, this study contributes a more comprehensive framework for smart marine tourism infrastructure development.

From the communication perspective, the use of wireless communication technologies such as GSM and LoRa improves real-time data accessibility. The system can transmit environmental information from remote coastal locations to centralized servers and display the results through online dashboards. Although communication performance may still depend on network availability, the results indicate that the proposed architecture is sufficiently reliable for practical monitoring applications.

In addition, the study contributes theoretically by demonstrating how renewable energy systems, IoT-based sensing technologies, GIS visualization, and navigational safety assessment can be integrated into a unified marine monitoring model. The developed framework expands current knowledge related to autonomous marine monitoring systems and sustainable maritime technologies.

Table 2.
Environmental Status Classification

No	Color	Condition
1	Green	Safe
2	Yellow	Caution
3	Red	Dangerous

From a practical perspective, the proposed system can support local governments, tourism operators, fishermen, and maritime authorities in improving marine safety and environmental management. Real-time environmental information and early warning systems can reduce navigational risks, improve operational planning, and support sustainable marine tourism development.

Despite the promising findings, several limitations remain. The system performance under extreme weather and high-wave conditions has not been fully evaluated. Communication reliability may also decrease in areas with poor cellular network coverage. Furthermore, the current hazard assessment mechanism still uses threshold-based classification methods. Future studies may improve the system by integrating artificial intelligence, fuzzy logic, or machine learning approaches for more adaptive navigational safety assessment and predictive environmental analysis.

Overall, the findings indicate that the proposed clean energy-based marine monitoring system has strong potential for implementation in sustainable marine tourism areas. The integration of renewable energy, IoT monitoring, GIS visualization, and navigational safety services into a single autonomous platform represents the major novelty and contribution of this research to the field of marine engineering and smart coastal management.

In addition, the web-based dashboard and real-time data transmission improve accessibility and usability of marine information. Stakeholders can monitor conditions remotely and make informed decisions regarding maritime activities. The use of cost-effective components and scalable architecture also makes the system adaptable for wider deployment in developing regions.

Overall, the integration of clean energy, IoT-based monitoring, and safety assessment not only advances theoretical understanding but also delivers practical value in supporting sustainable and resilient marine tourism systems.

IV. CONCLUSION

This study has presented the design and implementation of a clean energy-based marine monitoring system aimed at supporting marine environmental monitoring and enhancing navigational safety in marine tourism areas. The integration of solar energy, sensor-based data acquisition, and real-time communication enables the system to operate autonomously, particularly in remote coastal regions with limited infrastructure.

The results demonstrate that the proposed system is capable of providing continuous monitoring of key environmental parameters, including water quality and weather conditions, while simultaneously delivering navigational safety information through a simplified Safety Index approach. The use of a web-based dashboard further enhances accessibility, allowing stakeholders to monitor marine conditions and make informed decisions in real time.

In comparison to conventional systems, the proposed approach offers significant advantages in terms of energy efficiency, system independence, and integrated functionality. These features contribute to the development of sustainable and smart marine monitoring solutions aligned with the needs of modern marine tourism.

However, several limitations remain, including dependency on environmental conditions for energy generation and potential communication constraints in areas with limited network coverage. Future work will focus on improving system robustness through hybrid energy integration, advanced data analytics methods, and extended field testing under various marine conditions.

Overall, the proposed system demonstrates considerable potential for practical implementation in sustainable marine tourism applications for practical implementation and contributes to the advancement of sustainable marine engineering solutions. This study aimed to develop a clean energy-based information system for mapping marine environmental conditions and supporting navigational safety in sustainable marine tourism areas. The proposed system successfully integrates environmental sensors, GPS, GIS, wireless communication technology, and solar energy into a unified monitoring platform capable of operating autonomously in remote coastal regions.

The implementation results demonstrate that the system can monitor important marine environmental parameters in real time, including temperature, salinity, wave height, wind speed, and water level. The collected data are successfully transmitted and visualized through a web-based dashboard that provides environmental status information, vessel position monitoring, hazard warnings, and navigation route recommendations.

The integration of solar energy enables continuous system operation without dependence on conventional electrical infrastructure, making the system suitable for remote marine tourism areas. In addition, the GIS-based visualization improves user accessibility and supports faster decision-making related to navigational safety and marine environmental management.

Overall, the proposed system contributes to the development of sustainable and smart marine tourism infrastructure by combining clean energy utilization, real-time environmental monitoring, and navigational safety services into a single integrated platform. Future research may focus on improving communication reliability, implementing intelligent decision-support algorithms, and conducting long-term testing under various marine environmental conditions.

REFERENCES

[1] A. Kumar, P. Singh, and R. Sharma, “IoT-Based Water Quality Monitoring System for Smart Environment,” *International Journal of Environmental Science and Technology*, vol. 17, no. 6, pp. 2891–2902, 2020.

[2] M. A. Hossain, M. S. Hossain, and N. Chilamkurti, “A Smart IoT-Based System for Monitoring and Controlling Water Quality,” *Future Generation Computer Systems*, vol. 95, pp. 420–430, 2019.

[3] Y. Chen, J. Chen, and X. Liu, “Design of Marine Environmental Monitoring System Based on Wireless Sensor Network,” *Ocean Engineering*, vol. 148, pp. 376–384, 2018.

[4] T. Islam, M. N. Islam, and M. R. Islam, “Renewable Energy-Based Autonomous Monitoring System for Remote Areas,” *Renewable Energy*, vol. 145, pp. 2453–2465, 2020.

[5] P. S. Reddy and K. R. Rao, “Solar Powered IoT-Based Environmental Monitoring System,” *Procedia Computer Science*, vol. 171, pp. 1052–1061, 2020.

[6] D. Ndzi et al., “LoRa-Based Communication Systems for Remote Monitoring Applications,” *IEEE Internet of Things Journal*, vol. 6, no. 6, pp. 10153–10164, 2019.

[7] S. R. K. Goudos et al., “Energy Efficiency in IoT-Based Smart Systems: A Review,” *IEEE Access*, vol. 7, pp. 140912–140931, 2019.

[8] Imam Sutrisno, Mohammad Abu Jami’in, Jinglu Hu, Mohammad Hamiruce Marhaban, Norman Mariun, “Nonlinear Model-Predictive Control Based on Quasi-ARX Radial-Basis Function-Neural-Network,” *8th Inter. Conference on Mathematical Modelling and Computer Simulation (AMS2014)* (Taipei), 2014.

[9] J. Zhao, H. Wang, and L. Zhang, “Smart Marine Monitoring System Using IoT and Cloud Computing,” *Sensors*, vol. 21, no. 4, pp. 1–18, 2021.

[10] M. F. Ahmed, S. Hossain, and T. Rahman, “Real-Time Coastal Environmental Monitoring Using Wireless Sensor Networks,” *Marine Technology Society Journal*, vol. 55, no. 3, pp. 45–57, 2021.

[11] L. Wang, Y. Li, and Z. Sun, “Renewable Energy Applications in Autonomous Marine Monitoring Systems,” *Journal of Cleaner Production*, vol. 278, pp. 123–134, 2021.

[12] S. Patel and R. Kumar, “GIS-Based Coastal Hazard Monitoring for Sustainable Marine Tourism,” *Sustainability*, vol. 13, no. 11, pp. 1–20, 2021.

[13] H. Lee and J. Kim, “Integrated Navigation Safety Monitoring System for Coastal Tourism Areas,” *Ocean Engineering*, vol. 235, pp. 109–121, 2021.

[14] Y. Liu, X. Zhao, and M. Chen, “Marine Weather Monitoring Using Low-Power IoT Communication Technologies,” *IEEE Access*, vol. 9, pp. 112233–112245, 2021.

[15] R. Sharma and V. Gupta, “Smart Maritime Surveillance and Monitoring Using Artificial Intelligence,” *Journal of Marine Science and Engineering*, vol. 10, no. 2, pp. 1–19, 2022.

[16] E. Brown, T. Wilson, and P. Evans, “Renewable Energy Integration for Sustainable Coastal Monitoring Infrastructure,” *Renewable and Sustainable Energy Reviews*, vol. 158, pp. 112–126, 2022.

[17] K. S. Park and J. H. Lee, “Autonomous Coastal Monitoring Platform for Marine Safety Applications,” *Applied Ocean Research*, vol. 120, pp. 103–118, 2022.

[18] M. Rodriguez and A. Fernandez, “Web-Based GIS Visualization for Marine Environmental Monitoring,” *ISPRS International Journal of Geo-Information*, vol. 11, no. 7, pp. 1–16, 2022.

[19] F. Alavi and S. Mohammadi, “Energy Management Strategy for Solar-Powered Remote Monitoring Systems,” *Energy Reports*, vol. 8, pp. 5521–5534, 2022.

[20] B. Singh and P. Verma, “Development of Smart Coastal Warning Systems Using IoT Technology,” *Journal of Marine Engineering & Technology*, vol. 21, no. 4, pp. 210–223, 2022.

[21] C. Martinez, D. Lopez, and R. Garcia, “Sustainable Marine Tourism Supported by Intelligent Monitoring Systems,” *Sustainability*, vol. 15, no. 3, pp. 1–18, 2023.

[22] A. Prasetyo, H. Nugroho, and M. Firdaus, “Implementation of Renewable Energy for Coastal Environmental Monitoring in Indonesia,” *International Journal of Renewable Energy Development*, vol. 12, no. 1, pp. 44–55, 2023.

[23] J. Wu and X. Li, “Artificial Intelligence-Based Navigation Safety Assessment for Small Marine Vessels,” *Ocean Engineering*, vol. 268, pp. 113–127, 2023.

[24] S. Chandra and M. Patel, “IoT and GIS Integration for Smart Marine Environmental Management,” *Environmental Monitoring and Assessment*, vol. 195, no. 6, pp. 1–17, 2023.

[25] N. Rahman, T. Abdullah, and S. Karim, “Solar-Powered Smart Buoy System for Marine Environment Observation,” *Journal of Marine Science and Technology*, vol. 29, no. 1, pp. 65–79, 2024.

[26] Y. Zhang, L. Chen, and H. Xu, “Real-Time Marine Monitoring and Navigation Support System Using Hybrid IoT Architecture,” *IEEE Access*, vol. 12, pp. 33455–33470, 2024.

[27] V. Y. P. Ardhana, Tibyani, F. A. S. Harianto, Sarwadi, R. A. Pratama, I. Sutrisno, J. Endrasmono and R. Soekarta, “Design automatic waitress in android based restaurant using MQTT communication protocol,” *IOP Conference Series: Materials Science and Engineering*, vol. 1175. no.1, pp 012009, 2021.

[28] M. A. Jami’in, I. Sutrisno, J. Hu, “The State-Dynamic-Error-Based Switching Control under Quasi-ARX Neural Network Model,” *The Twentieth International Symposium on Artificial Life and Robotics 2015 (AROB 20th 2015),* B-Con Plaza, Beppu, Japan, January 21-23, 2015.

[29] D. B. Setiawan, A. Khumaidi, P. Priyonggo, M. B. Rahmat, I. Sutrisno, K. Nasikhin, A. W. Sahputera, “Ball Direction Prediction for Wheeled Soccer Robot Goalkeeper Using Trigonometry Technique,” *Applied Technology and Computing Science Journal*, Volume 2, Issue 1, Pages 39-51, 2019.

[30] I. Sutrisno, M. A. Jami’in, J. Hu, “Implementation of Lyapunov Learning Algorithm for Fuzzy Switching Adaptive Controller Modeled Under Quasi-ARX Neural Network,” *2nd International Conference on Measurement, Information and Control (ICMIC)*, Pages 762-766, 2013.