



BLUEGENIC: Transforming marine plastic waste through AI drone surveillance as a solution for sustainable energy and maritime security

Sendi Kurnia Putra^{1,*}, Nur Hafifa¹

¹ *Departement of Public Administration, Faculty of Social and Political Sciences, Universitas Maritim Raja Ali Haji, Tanjungpinang, Riau Islands, 29111, Indonesia.*

*Correspondence: skurniaputra@student.umrah.ac.id

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ABSTRACT

Background: The issue of marine plastic waste has become a tangible threat to the sustainability of marine ecosystems and national maritime security. This study aims to develop BLUEGENIC, a technology-based innovation that integrates marine surveillance using artificial intelligence (AI)-powered drones with the conversion of plastic waste into alternative fuel. **Methods:** The research employed a Research and Development (R&D) approach through several stages, including needs analysis, system design, concept testing, and validation of implementation potential. **Findings:** The results indicate that the routine deployment of AI drones in priority maritime areas can map between 50–200 tons of marine plastic waste annually. The collected waste is then processed using the pyrolysis method, capable of producing 13,000–14,000 liters of alternative fuel per month from approximately 16.7 tons of plastic. In addition to contributing to waste reduction and clean energy transition, BLUEGENIC engages the younger maritime generation in research, education, and technological operations. **Conclusion:** The program also demonstrates economic potential through a blue economy approach and offers opportunities for cross-sectoral collaboration. This study emphasizes the importance of regulatory support and stakeholder synergy in the implementation of BLUEGENIC. **Novelty/Originality of this article:** The novelty lies in the synergy between AI-drone technology and plastic waste-based alternative energy within the framework of sustainable ocean management and the empowerment of young human resources in the maritime sector.

KEYWORDS: AI drones; alternative energy; maritime security; marine plastic waste; pyrolysis.

1. Introduction

The issue of plastic waste in the oceans is a major global concern in efforts to achieve maritime security and sovereignty (Guggisberg, 2024). As the world's largest archipelago, Indonesia has a coastline of more than 108,000 km and a maritime area of 3.25 million square kilometers (Sui et al., 2020). This enormous potential makes the sea a vital resource that supports various strategic sectors, ranging from fisheries, tourism, energy, to international trade routes. However, behind the enormous opportunities offered by the marine and fisheries sectors, Indonesia faces a serious challenge, namely marine plastic pollution (Salsabila & Rudiany, 2025).

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According to Phelan et al. (2020), every year around 4.8 to 12.7 million tons of plastic enter the sea, and Indonesia is one of the five largest contributors of marine plastic waste in the world. This condition reflects a waste management crisis that has not been optimally addressed. Plastic waste mostly comes from land-based activities, including households, industries, and tourism, which have not been balanced with an efficient management system. The waste is carried by river currents and eventually pollutes the oceans, threatening marine life and ecosystems as a whole.

Data from the Ministry of Environment and Forestry shows that in 2021, national waste reached 68.5 million tons, and 11.6 million tons of that was plastic waste recorded in 2022 (Zainuddin, 2023). Plastic dominates the types of waste in Indonesia, with a very low recycling rate. This waste persists for hundreds of years in the ocean and breaks down into microplastics that enter the food chain.

These conditions damage marine ecosystems and biota such as turtles, fish, and seabirds, and have a direct impact on humans. The tourism sector suffers losses because polluted beaches are no longer attractive to tourists. The fisheries sector has experienced a decline in catches due to declining fish populations and damage to fishing gear. Microplastics found in fish and seawater also endanger human health as they can cause hormonal disorders, cancer, and other chronic diseases (Elisha & Felix, 2021).

The Indonesian government has responded to this situation by issuing Presidential Regulation No. 83 of 2018 concerning Marine Waste Management, which targets a 70 percent reduction in marine plastic waste by 2025 (Kamaruddin et al., 2022). This policy strengthens the legal framework and encourages synergy between parties in addressing marine pollution. However, the implementation of this policy still faces challenges such as limited human resources, funding, and weak monitoring and law enforcement systems.

To date, there are no regulations that comprehensively regulate the use of artificial intelligence and drone technology in maritime sector management, especially for monitoring marine plastic waste and maritime security (Wang et al., 2023). In fact, drone and artificial intelligence technologies have proven to be capable of addressing marine surveillance issues that are difficult for humans to reach. Drones can directly monitor marine areas, detect plastic waste through thermal cameras or satellite sensors, and are equipped with robotic arms to collect waste (Goddijn-Murphy et al., 2022). This research, combines drone-based visual monitoring and artificial intelligence to detect, map, and collect marine plastic waste efficiently and sustainably. BLUEGENIC strengthens marine surveillance and supports efforts to convert waste into environmentally friendly energy.

Technically, the artificial intelligence drones in the BLUEGENIC system are equipped with GPS-based automatic navigation, optical and infrared cameras, and machine learning algorithms that recognize the types and distribution patterns of plastic waste. The collected data is sent to a control center for analysis, then used in the process of transporting and processing waste into alternative fuels such as RDF (Refused Derived Fuel) or pyrolysis oil. This technology is highly effective when applied in strategic areas such as international shipping lanes, which are traversed by thousands of ships every day. These sea lanes often become accumulation points for marine debris due to global currents that carry waste from various regions (Dabrowska et al., 2021). The high volume of waste provides a great opportunity for converting waste into energy. In addition, the cost of drones is now much more affordable thanks to technological advances and mass production.

The implementation of BLUEGENIC can strengthen national maritime security. The artificial intelligence drone system is capable of detecting illegal activities such as illegal fishing, smuggling, and maritime border violations. With its dual functions of environmental monitoring and maritime security, BLUEGENIC directly supports Indonesia's maritime sovereignty. On the social and economic side, BLUEGENIC opens up new job opportunities in the field of environmentally friendly technology. Coastal communities are involved in drone operational training, waste management, and the production of alternative fuels from recycled materials. This encourages the growth of an inclusive and sustainable community-based blue economy. In addition, public education on the importance of keeping the sea free of plastic waste is an important part of this program (Salsabila & Rudiany, 2025).

Collaboration between the government, academia, the private sector, and the community is key to the success of BLUEGENIC. The government needs to immediately develop regulations that encourage the adoption of artificial intelligence and drone technology in the maritime sector (Aris Sarjito, 2023). Academics develop innovations and research, while the private sector strengthens investment and implementation of adaptive circular business models. With BLUEGENIC, Indonesia is leading the integration of technology in sustainable marine management. This program is in line with the Sustainable Development Goals, particularly point fourteen on marine ecosystems, point twelve on sustainable consumption and production, and point seven on clean and affordable energy. Indonesia is no longer just a contributor to marine plastic waste but a pioneer in technology-based solutions for marine conservation and energy transformation. BLUEGENIC is not merely an innovation project but a systematic movement toward clean, safe, and productive oceans.

2. Methods

This study uses a Research and Development (R&D) approach to design and develop BLUEGENIC, a drone-based and artificial intelligence (AI) system that aims to monitor and manage plastic waste in the ocean in a sustainable manner. The R&D method was chosen because this research is not only descriptive or analytical in nature, but also oriented towards the development of innovative products and systems that can be directly applied to solve real problems in the maritime sector (Sinzinkayo, 2023). This research began with a literature study and secondary data collection on the conditions of marine pollution, the volume of plastic waste in Indonesia, and national and international policies related to marine waste management.

The initial stages of the R&D method involved identifying needs and formulating problems, which included the suboptimal marine waste monitoring system and the minimal use of smart technology in marine waste management in Indonesia. Based on these findings, the researchers designed the BLUEGENIC system, which consists of a drone unit with plastic waste detection sensors, data processing using AI for waste location mapping, and waste conversion into alternative energy through pyrolysis technology. This system was developed considering the geographical characteristics of Indonesia, which has vast waters, dense shipping lanes, and an increasing threat of marine environmental damage.

The suitability of the R&D method in this study lies in its development orientation. BLUEGENIC is not only a concept but is also intended to be a system that can be tested and refined based on input from experts and potential users. This study also targets legal and public policy aspects, as there are currently no regulations specifically governing the use of drone and AI technology for marine waste monitoring. Therefore, support from the government is urgently needed to develop new regulations that not only guarantee the safety and legality of drone use in Indonesian waters but also support the integration of environmentally friendly technology into the national waste management agenda.

In addition to the government, the role of research institutions such as BRIN (National Research and Innovation Agency) is also crucial in supporting the technological and scientific development of this system. This cross-sector collaboration is expected to strengthen BLUEGENIC's position as a system model that is not only technically effective but also compliant with the legal and policy framework in Indonesia. Validation is conducted through expert reviews involving drone technology, maritime law, and environmental experts to ensure that the developed system is scientifically and practically sound.

3. Results and Discussion

The use of drone technology to monitor plastic waste in the ocean is now one of the innovative approaches contributing to sustainability efforts and improved maritime safety.

Research conducted by Escobar-Sánchez et al. (2022) in an article titled “Aerial and underwater drones for marine litter monitoring in shallow coastal waters” discusses the use of UAVs (Unmanned Aerial Vehicles) and ROVs (Remotely Operated Vehicles) in detecting and mapping plastic waste in coastal areas. The study shows that drones are highly effective in identifying various categories of waste, both floating on the surface and at the bottom of the water, with competitive performance compared to conventional methods such as boat patrols and diving.

In line with this, BLUEGENIC research offers a further approach through the integration of AI-based drones that not only serve to monitor and map plastic waste, but are also connected to a waste processing system that converts waste into alternative fuel (BBM) through pyrolysis to support a sustainable energy transition. With accurate, real-time, spatial and temporal data-based monitoring, BLUEGENIC is expected to become the basis for decision-making in optimizing plastic waste collection, especially in strategic areas such as international shipping lanes, industrial areas, and coastal regions of the archipelago.

To support implementation in the field, specific regulations on the monitoring and utilization of AI drones in the maritime sector need to be offered, including: establishing operational standards for drone flights in waters, licensing mechanisms for the use of drones for environmental monitoring, integrating drone data with the national maritime data center, and strengthening the legal framework to support the security, safety, and sustainability of this technology. These regulations are important so that innovations such as BLUEGENIC can run in a targeted and legal manner and provide optimal benefits for marine environmental conservation and national energy security (Nadine et al., 2025). The updates to this research compared to previous research are outlined in the following table:

Table 1. Research updates

Aspect	Previous Research (Topouzelis et al., 2022)	BLUEGENIC's Novelty
Drone Functions	Limited to the monitoring and mapping of plastic waste	Expanding the functions of AI drones for automatic detection, classification, mapping, and supporting maritime security
Technology Integration	Not yet utilizing advanced AI	Employing AI (CNN/YOLO) and spatio-temporal data to enable real-time detection, volume estimation, and prediction of plastic waste distribution patterns
Regulatory Dimensions	Does not address legal or maritime regulatory aspects	Proposes a novelty through the strengthening of regulations and policies grounded in AI-based data as a basis for maritime surveillance and law enforcement
Socio-Economic Impact	Focus on environmental aspects	Contributing to the circular economy by processing waste into alternative fuel via pyrolysis.

AI drones are an innovation in unmanned aircraft technology equipped with artificial intelligence (Petrovski & Radovanović, 2022). In the maritime sector, these drones are very useful for monitoring sea conditions, detecting plastic waste piles, and mapping waste distribution in real time (Duangsuwan & Prapruetdee, 2024). The use of AI drones helps improve the effectiveness of surveillance in large water areas such as coasts, ports, and shipping lanes, while also supporting environmental conservation programs (Camastra et al., 2023).

In the context of safe and equitable maritime surveillance, the application of Artificial Intelligence (AI)-based technology such as maritime drones is an important breakthrough that supports the enforcement of maritime environmental laws. The availability of visual and spatial data from AI drones can strengthen the implementation of evidence-based law enforcement principles in coastal areas and national waters. This technology is capable of recording and identifying objects in real-time, while also transmitting location information with a high degree of accuracy through an integrated GPS system.



Fig. 1. AI-based drone design

The use of AI-based maritime drones not only serves to monitor illegal activities such as destructive fishing, waste disposal, or territorial violations, but also helps identify sources of pollution spread over a wide area. With a combination of high-resolution cameras and multispectral sensors, this system can distinguish between different types of objects or materials on the sea surface, such as plastic from wood or organic waste. This facilitates handling according to the characteristics of the waste and the urgency of the problem at hand. From a law enforcement perspective, the visual data generated by AI drones is valid evidence that can be used in court or in investigations. Documentation based on photos, videos, and location coordinates enables the government and law enforcement agencies to build strong arguments against marine environmental violations. In addition, this system also supports transparency in public oversight, thereby increasing public trust in government policies in the marine sector.

Furthermore, the application of AI-based maritime drones is in line with efforts to achieve the Sustainable Development Goals (SDGs), particularly goal 14 on marine ecosystems. By combining technological innovation, law enforcement, and environmental sustainability, this solution is a strategic pillar in realizing safe, fair, and sustainable marine management in Indonesia.

The system used in this innovation is a quadcopter or hybrid fixed-wing drone, designed to cover large and hard-to-reach sea areas. These drones weigh around 3–6 kg, can fly for 45–90 minutes, and can be controlled from a distance of 10–20 km, making them ideal for patrolling coastal areas and pollution-prone zones (Pfeiffer et al., 2023). This device is designed as a modern solution to support monitoring, research, and law enforcement activities in aquatic areas, especially the sea. Equipped with the latest technology, this device is capable of providing accurate data, clear visuals, and precise positioning. The three main components that make this device superior are a high-resolution RGB camera, a multispectral sensor, and a GPS system with a digital compass. The synergy between these three components allows users to obtain a comprehensive picture of field conditions, whether for scientific, operational, or legal purposes.

The first component is a high-resolution RGB camera capable of recording images up to 4K quality. This feature plays an important role in documenting visual conditions in detail, both in the form of photos and videos. The high resolution ensures that every object, whether large such as ships or small such as debris, can be seen clearly. This documentation is very useful as legally accountable field evidence, especially in cases of territorial violations or marine pollution. In addition, the visual quality produced also supports educational activities, scientific publications, and official reports to authorities and the public.

The second component is a multispectral sensor that functions to distinguish material types based on their reflection spectrum characteristics. This technology enables the device to identify materials such as plastic, wood, or organic matter floating on the sea surface. This capability is highly relevant in marine environmental management programs, as waste types can be immediately classified and appropriate handling measures applied. For

example, plastic requires special management due to its non-biodegradable nature, while organic waste can be handled using different methods. With multispectral sensors, the identification process can be carried out quickly, even in less than optimal lighting conditions.

The third component is GPS and a digital compass that serve to determine location coordinates with precision. Modern GPS technology combined with a digital compass enables high-accuracy position tracking, even in open sea areas with minimal visual markers. This feature not only supports navigation but also provides spatial data that can be used to map the monitoring area. This precise coordinate information is crucial in maritime law enforcement, especially to ensure that surveillance is conducted within the boundaries of legal jurisdiction in accordance with national regulations and international law.

These three components work together seamlessly. The RGB camera provides high-quality visual data, the multispectral sensor provides information about material types, while the GPS and digital compass ensure that all findings are accurately measured. This integration makes the device a highly effective tool for activities such as marine patrols, ecosystem research, pollution control, and maritime event documentation. With this combination of technological sophistication, the device not only improves work efficiency in the field but also strengthens the validity of the data collected. This makes it a relevant solution for government agencies, researchers, environmental organizations, and private parties engaged in the maritime sector. The efficiency of work referred to includes the device's ability to reduce search time, speed up the object identification process, and minimize human error in data collection. In addition, the accuracy and validity of the data produced are very important in ensuring that every finding in the field can be accounted for, whether in the context of academic research, policy making, or legal proceedings related to violations in maritime areas. For government agencies, this device can be a strategic tool in maritime surveillance programs, fisheries law enforcement, and marine pollution control. For researchers, this technology provides a rich, detailed, and measurable source of data to support scientific studies. Meanwhile, environmental organizations can use it to monitor the impact of human activities on marine ecosystems and educate the public. Even private entities such as fishing or marine tourism companies can use it to ensure that their operations comply with sustainability standards. Thus, this technology is not merely a technical innovation, but also an important instrument for supporting the overall sustainability of marine resources.

The drone navigation system is also equipped with automatic return-to-home, obstacle avoidance, live streaming, and Firebase and Google Maps API integration for interactive storage and mapping of waste location data. At the core of this system is a Convolutional Neural Network (CNN)-based AI detection engine, namely the YOLOv8 algorithm. This algorithm is an advancement of YOLOv5, which has been proven effective in detecting beach waste with a mAP precision of 0.67 (Pfeiffer et al., 2023). YOLOv8 offers significant improvements in real-time accuracy and efficiency, enabling it to identify objects such as plastic bottles, plastic bags, or straws on the sea surface (Sohan et al., 2024).

The results from this drone are aerial images and location coordinates, which are immediately processed by AI to generate a heat map of plastic waste distribution. This information plays a vital role in determining the priority locations for cleanup by field officers and providing real-time visual evidence for stakeholders. It enables the monitoring of pollution-prone areas such as ports, industrial areas, and international shipping lanes, in accordance with the principle of maritime sovereignty in national law. More than just a technological tool, the use of AI drones supports environmental law enforcement within the framework of public policy and the principles of sustainable marine management. The spatial information generated by drones can be used as a basis for drafting marine zoning regulations, evaluating pollution violations, and supporting legal reports to international institutions in accordance with the provisions of UNCLOS 1982 and Law No. 32 of 2009 concerning Environmental Protection and Management (Ramos et al., 2024).

Table 2. BLUEGENIC tools and materials

Main raw materials	Supporting materials	Equipment
Marine Plastic Waste (LDPE, HDPE, PP) (Food Packaging, Plastic Bags)	1. Clean Water 2. Gas/Electricity 3. Zeolite Catalyst	1. UAV Drone, HD Camera, AI System (YOLOv8) 2. Computer 3. Pyrolysis Reactor 4. Condenser 5. Oil Storage Container 6. Hose & Valve 7. Gloves 8. Ice Cubes

The process of producing fuel from marine plastic waste begins with the detection and collection of plastic waste in coastal areas or on the sea surface, either through visual monitoring or with the help of simple tools such as cameras. Common types of plastic found include plastic bags (LDPE), soap bottles (HDPE), and straws (PP), which are then collected and taken to a processing facility. Next, the waste is sorted to separate plastics suitable for pyrolysis, such as LDPE, HDPE, and PP, and then washed with clean water to remove salt, mud, and dirt so that they do not interfere with the next process. Once clean and dry, the plastic is placed in a closed pyrolysis reactor heated to a temperature of 350°C to 500°C without oxygen, causing it to melt and produce hydrocarbon vapor. The vapor is fed into a condenser to be cooled into liquid oil, which is then filtered to separate any remaining solids or impurities. The pyrolysis oil is then stored in a closed container and can be used as an alternative fuel, for example, for simple diesel engines, generators, or other energy needs.

Table 3. SWOT analysis

Strengths	Weaknesses	Opportunities	Threats
Multidimensional innovation: combining AI drone surveillance and plastic waste processing into alternative energy. Supporting global issues such as the SDGs: marine litter reduction and clean energy transition.	High costs for the procurement, operation, and maintenance of AI drones. The pyrolysis/plastic-to-fuel process still generates emissions that need to be properly managed.	Supporting the national Blue Economy program for sustainable utilization of the ocean. Opens opportunities for cross-sector collaboration (government, universities, startups, international organizations), such as Pertamina and the Ministry of Environment.	The potential for regulatory changes that may restrict the use of plastic waste-based fuels. The emergence of alternative technologies that are cheaper, faster, or more efficient.
Engaging the young maritime generation that is adaptive to digital and marine technologies.	Not all young generations possess technical competencies in the fields of AI and new energy.	Becoming a medium for education, research, and training for the young maritime generation.	Operational risks: drone damage caused by extreme weather, high waves, or signal interference.
Strengthening maritime security and mapping of marine areas.	Limited infrastructure for plastic waste processing in coastal areas.	Providing economic added value to coastal communities through the production of alternative fuels.	Increasing volumes of marine plastic waste that exceed monitoring and processing capacities.

BLUEGENIC's innovation has a key strength in its multidimensional approach, which combines AI-based drone technology for marine surveillance with the processing of plastic waste into alternative fuel. This innovation also supports global agendas such as the Sustainable Development Goals (SDGs) and involves the younger generation of maritime professionals who are adaptable to technology. On the other hand, the weaknesses faced include high operational costs, limited waste processing infrastructure in coastal areas, and emissions still generated from the pyrolysis process. These weaknesses also include the uneven readiness of human resources in mastering the technology.

Table 4. Performance indicators

No	Target	Measurable success indicators/outputs
1	Reducing marine plastic waste	- Identify and monitor at least 50-200 tons of marine plastic waste per year through AI drone mapping for initial monitoring. - Reduce the volume of plastic waste in target areas such as beaches and the open sea by 15-30% within one year.
2	Development of alternative energy	- Establishment of a pilot plant/installation for processing plastic into alternative fuel. - With a target of collecting ± 16.7 tons of marine plastic waste per month, it is estimated that $\pm 13,000$–$14,000$ liters of alternative fuel can be produced per month through the pyrolysis process.
3	Utilization of technology and maritime security	Technically, BLUEGENIC will routinely operate at least 3–5 AI drones to monitor priority marine areas, thereby mapping the potential for marine plastic waste accumulation and detecting illegal maritime activities. Data from the drones will be displayed through a real-time monitoring dashboard, which can be used as a basis for formulating more targeted marine management strategies.
4	Empowering the young maritime generation	At least 7 students/young people are actively involved in the research, development, and operation of BLUEGENIC technology.
5	Blue economy support	- With a target of collecting ± 16.7 tons of marine plastic waste per month, it is estimated that $\pm 13,000$–$14,000$ liters of alternative fuel can be produced per month through the pyrolysis process. Based on the selling price of alternative fuel in the range of IDR 8,000–10,000 per liter, the potential revenue that can be generated reaches around IDR 100–140 million per month, thus providing significant economic added value for coastal communities. - Establishment of at least 3 strategic partnerships (with the government, private sector, universities, or NGOs) in the implementation of BLUEGENIC.
6	Contribution to SDGs	- Regular reporting on the program's impact on SDGs 7, SDGs 13, and SDGs 14. - Publication of at least 3 scientific articles, reports, or educational content about the BLUEGENIC program in the mass media or scientific journals.

Great opportunities are opening up because BLUEGENIC is in line with the national blue economy program and the potential for cross-sector collaboration with the government, state-owned enterprises, universities, and international institutions. In addition, this project can be a means of education, research, and training, as well as providing economic added value for coastal communities. However, threats remain, such as the possibility of more efficient alternative technologies emerging, regulatory changes that could limit the use of plastic waste-based fuels, and the risk of drone damage due to extreme sea conditions. If not anticipated, the increase in plastic waste volume could also exceed the capacity of this system.

The BLUEGENIC program is designed with a number of key objectives that have measurable and concrete indicators of success. One of the main goals is to reduce marine

plastic waste, which is pursued through the use of artificial intelligence (AI)-based drones to monitor and map water areas. The target is to identify and monitor at least 50-200 tons of marine plastic waste annually and reduce the volume of plastic waste by 15-30% in target areas such as beaches and the open sea within one year.

Furthermore, in terms of alternative energy development, BLUEGENIC aims to build a pilot plant unit capable of converting plastic waste into alternative fuel. With the collection of ± 16.7 tons of plastic waste per month, it is estimated that around 13,000–14,000 liters of fuel will be produced through the pyrolysis process each month. This demonstrates the program's capacity to provide energy solutions that are both environmentally friendly and economical. In terms of technology utilization and maritime security improvement, BLUEGENIC will routinely operate 3 to 5 AI drone units in priority sea areas. These drones will map plastic waste accumulation and detect illegal activities at sea. All surveillance data will be displayed in a real-time monitoring dashboard, which will be useful for formulating more precise and accurate sea management strategies.

BLUEGENIC is also committed to empowering the younger generation in the maritime sector. At least seven students or young people involved in maritime activities will be actively involved in the research, development, and operation of this technology, so that they are not only part of the solution but also gain practical learning. This involvement is designed to equip them with the latest technical skills, ranging from mastery of Artificial Intelligence (AI) technology, spatial data processing, automatic detection system programming, to the application of multispectral sensors on maritime drones.

Through this program, the younger generation will not only become users of technology, but also innovators who understand the entire process from upstream to downstream. They will gain direct experience in operating drones in the field, analyzing detection results, and compiling data-based reports that can be used as a basis for decision making. This approach is expected to foster a sense of ownership of marine conservation efforts while building strong human resources in the maritime sector.

Beyond technical aspects, youth involvement is also directed toward strengthening leadership capacity, cross-disciplinary teamwork, and scientific communication. Students will have the opportunity to collaborate with researchers, government officials, and environmental organizations, thereby understanding how technology can serve as a crucial instrument in public policy and the enforcement of marine environmental law (Escobar-Sánchez et al., 2021). By providing ample space for youth participation, BLUEGENIC not only focuses on short-term project success but also builds a long-term foundation for sustainable innovation. The synergy between cutting-edge technology and youth potential is expected to create an adaptive, independent, and highly competitive maritime ecosystem, in line with Indonesia's vision as a global maritime hub (Harasyn et al., 2022).

Contributions to strengthening the blue economy are also a concern. With a potential fuel production of 13,000–14,000 liters per month and a selling price of Rp 8,000–10,000 per liter, this program is estimated to generate approximately Rp 100–140 million per month in revenue. This creates significant economic added value for coastal communities. In addition, BLUEGENIC aims to establish at least three strategic partnerships with various parties, such as the government, private sector, universities, or non-profit organizations.

Finally, in the context of contributing to the Sustainable Development Goals (SDGs), BLUEGENIC directly supports the achievement of SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 14 (Life Below Water). This program will also produce at least three publications in the form of scientific articles, reports, or educational content to be disseminated through the mass media and scientific journals.

Indonesia's waters are currently facing a serious plastic pollution crisis. It is estimated that more than 620 thousand tons of plastic waste pollute Indonesia's seas every year, creating multiple impacts: from the destruction of marine ecosystems, threats to biota, a decline in the quality of marine tourism, to health risks for coastal communities (Candra et al., 2021). The author even witnessed this condition firsthand while standing on a coastline that was almost completely covered in plastic waste. This sight was not only saddening, but also a stark reminder that this crisis is real and urgent.



Fig. 2. Condition of marine plastic pollution

However, there is still no national regulation that comprehensively governs the mechanisms for detecting, mapping, and managing marine plastic waste in an adaptive and technology-based manner. Environmental law enforcement systems also remain limited to reactive measures and have yet to employ data-driven and artificial intelligence (AI)-based approaches. Therefore, the BLUEGENIC innovation emerged as a concrete response to policy gaps and the need for an integrated system grounded in both technology and law. The BLUEGENIC innovation holds significant potential as an integrated system for the efficient and sustainable detection, collection, and processing of marine plastic waste. This system combines two core technologies, (1) marine surveillance using AI drones based on YOLOv8, and (2) the conversion of plastic into fuel through high-temperature pyrolysis.

3.1 Detection of marine plastic waste by AI drones

The use of hybrid drones equipped with RGB cameras and multispectral sensors, combined with the YOLOv8 algorithm, demonstrates a high level of accuracy in detecting plastic objects on the ocean surface. According to Pfeiffer et al. (2023), the implementation of YOLOv5-based detection technology achieved a mean Average Precision (mAP) score of 0.67, whereas YOLOv8 has been shown to improve detection precision to over 0.75 for specific plastic objects, particularly PET bottles and HDPE bags.

Drones integrated with an automatic reporting system are capable of transmitting real-time waste location coordinates to a central database, which are then mapped into heatmaps of waste distribution. This feature significantly enhances the effectiveness of field operations and enables governments as well as environmental organizations to take immediate action. Moreover, the system supports the generation of digital reports that can be used as legal evidence of environmental pollution, making this technology not only technically useful but also strategically valuable in the context of modern maritime law (Ramos et al., 2024).

Furthermore, the development of drones based on lightweight AI models, such as SS-YOLOv8, also shows considerable potential. This model achieves a mAP50 of up to 80.1% with an extremely low inference speed (0.12 ms), making it ideal for drones that require high computational efficiency under field conditions (Wang et al., 2023). This advantage reinforces the relevance of the BLUEGENIC detection system for large-scale marine surveillance, even in areas that are difficult for humans to access.

The use of this technology enables continuous monitoring, generating a long-term database for analyzing trends in marine pollution (Ditria et al., 2022). Such historical data can be integrated with machine learning-based predictive models to forecast future

locations and intensities of pollution, thereby facilitating earlier mitigation efforts. The integration of drone technology, multispectral sensors, and modern AI opens significant opportunities for marine pollution control programs grounded in accurate, rapid, and legally accountable data, while also serving as a strategic step toward sustainable marine resource management.

3.2 Conversion of plastic waste into energy through pyrolysis

The pyrolysis process applied in BLUEGENIC is designed to convert marine plastic waste into liquid fuel (pyrolysis oil), synthetic gas, and solid residue. According to Faussonne and Cecchi (2022), marine plastics such as LDPE, HDPE, and PP can yield pyrolysis oil with characteristics similar to marine gas oil at temperatures between 400–500 °C. The oil yield can reach 80–87%, depending on the type of plastic and the operating temperature.

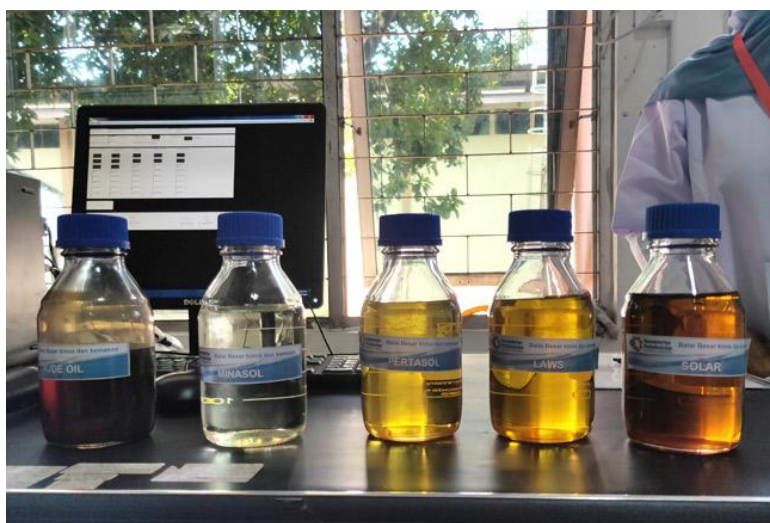


Fig. 3. Oil processed from marine plastic

The use of zeolite catalysts has been proven to enhance process efficiency and improve the quality of the resulting fuel. One study demonstrated that combining PP plastic with fly ash-based catalysts can produce pyro-oil with a high calorific value and low residue content (Medaiyese et al., 2024). In addition, integrating AI-based machine learning systems into pyrolysis reactors can automatically optimize temperature and reaction time parameters (Nasriani & Jamiolahmady, 2024).

The efficiency of this process enables non-recyclable plastic waste to be effectively converted into an energy source, while simultaneously reducing dependence on fossil fuels. Within the framework of national energy policy, this approach supports the transition toward green energy and a circular economy in the maritime sector.

3.3 Implications for law enforcement and maritime security

The BLUEGENIC innovation also carries strategic value within the framework of environmental law and maritime sovereignty. Data obtained from drones are not only utilized for field operations but also serve as evidence-based tools for prosecuting marine pollution violations under Law No. 32/2009 and the principles of UNCLOS 1982. The application of spatial data from AI-powered drones can be used as the basis for marine zoning, reporting pollution incidents to legal authorities, and promoting environmental law literacy among coastal communities (Balsi et al., 2025).

In other words, BLUEGENIC addresses not only technical, social, and environmental challenges but also makes a tangible contribution to building a modern and responsive integrated maritime surveillance system. By employing AI drones for monitoring and detecting marine plastic waste in coastal areas, BLUEGENIC leverages pyrolysis technology

to convert plastic waste into alternative fuels that can be utilized by fishers and communities in remote islands. The system is further supported by IoT-based data integration, enabling real-time monitoring, AI-driven data analysis, and transparent, accountable reporting to relevant stakeholders.

Beyond a technological innovation, BLUEGENIC emphasizes sustainability, inclusivity, and social justice in its implementation. The marine surveillance system is designed to be participatory, engaging local governments, fishing communities, and coastal populations as key stakeholders in decision-making and in benefiting from the innovation (O'Connor et al., 2024). This approach is expected to strengthen local capacities, create new opportunities for economic empowerment, and enhance collective awareness and responsibility for marine ecosystem protection.

Community involvement in this system is not merely symbolic but realized through operational training, knowledge transfer, and shared access to generated data. In this way, fishers and coastal residents can use detection outputs for productive activities such as planning more efficient fishing routes, monitoring water quality, or detecting potential environmental hazards at an early stage (Pietruszka-Ortyl et al., 2021).

From a sustainability perspective, BLUEGENIC ensures that the technology employed is energy-efficient, environmentally friendly, and supported by a maintenance system manageable by local resources. Inclusivity is also central, providing equal opportunities for women, youth, and vulnerable groups in coastal areas to participate in both operations and decision-making.

The principle of social justice is reflected in the equitable distribution of benefits. The data and outputs of this innovation are not limited to research or central government purposes but are also leveraged to strengthen local economies through new business opportunities, such as environmental monitoring services, marine tourism education, or community-based data management.

Through this participatory model, BLUEGENIC emerges not only as an advanced tool for maritime surveillance but also as a collaborative platform bridging technology, policy, and local wisdom. Ultimately, this model is expected to foster more adaptive, just, and sustainable ocean governance, while reinforcing Indonesia's role as a leader in marine innovation that prioritizes community well-being.

4. Conclusions

The BLUEGENIC innovation proves that a multidisciplinary approach based on technology and law can be a real and sustainable solution in addressing two major challenges in the maritime sector: the crisis of marine plastic waste pollution and the need for environmentally friendly alternative energy. Through the integration of high-precision AI drone surveillance and plastic waste conversion technology via pyrolysis, BLUEGENIC not only presents an innovative technical solution but also strengthens the role of technology in the enforcement of marine environmental law that is fair, transparent, and data-based.

The visual and spatial detection generated by drones enables accurate and efficient monitoring of marine areas, as well as providing a legitimate legal basis in encouraging action against marine pollution violations. On the other hand, the use of pyrolysis as a process of converting waste into renewable fuel shows that this technology also brings tangible benefits in the fields of energy and the circular economy.

By combining AI-based intelligent detection, spatial data processing, and pyrolysis control through machine learning, BLUEGENIC affirms the importance of collaboration between science, technology, and law in creating a safe, clean, and sustainable marine ecosystem. This innovation is not only relevant to current needs but also reflects Indonesia's vision as a maritime nation that upholds marine sovereignty, ecological justice, and sustainable innovation.

In line with the spirit of Maritime Harmony 5.0, BLUEGENIC becomes a representation that the future of Indonesian maritime affairs can be built through synergy between

technological sophistication and smart legal policies. This is the manifestation of the younger generation's contribution in building a maritime order that is not only modern but also responsible.

As for suggestions that can serve as evaluation material in this study, Optimization of AI Drone Technology and Plastic Waste Processing, one of the steps that can be taken is the development and adjustment of artificial intelligence algorithms, such as CNN and YOLO, which are specifically designed to detect and classify plastic waste in Indonesian marine areas. This effort is expected to improve the accuracy and effectiveness of monitoring, so that the data obtained become more comprehensive and reliable.

In addition, the refinement of the integration system between AI drones and the pyrolysis process is also an important priority. This integration aims so that data on the volume and types of plastic waste collected can be directly connected with the planning of alternative fuel production capacity, making the processing more efficient and measurable.

Not only that, Long-Term Research and Regulatory Impacts, in-depth studies need to be carried out to map legal gaps and formulate the need for new regulations governing the use of AI drones in maritime areas. This study includes aspects of the protection of monitoring data, the establishment of patrol boundaries, and the potential use of such data as legal evidence in the process of enforcing environmental regulations. In addition, further research is also important to analyze the economic and environmental impacts comprehensively.

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Biographies of Authors

Sendi Kurnia Putra, Departement of Public Administration, Faculty of Social and Political Sciences, Universitas Maritim Raja Ali Haji, Tanjungpinang, Riau Islands, 29111, Indonesia.

- Email: skurniaputra@student.umrah.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Nur Hafifa, Departement of Public Administration, Faculty of Social and Political Sciences, Universitas Maritim Raja Ali Haji, Tanjungpinang, Riau Islands, 29111, Indonesia.

- Email: nurhafifasty1@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: <https://scholar.google.com/citations?user=qAoi6woAAAAJ&hl=id>