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Systematic Analysis of Potential Marine Renewable Energy for Coastal Ecological Balance on Bawean Island: A Review

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***Abstract*— Bawean Island displays significant natural potential with abundant natural resources and natural beauty that is attractive for tourism and industrial development. However, this potential is threatened by various environmental and socio-economic problems such as limited availability of clean water, erosion of coastal structures, accumulation of rubbish, economic challenges, and low levels of community education. To overcome these challenges, an integrated and sustainable approach is needed that involves the government, community, and other related parties in sustainable natural resource management and considers ecological, economic, and social aspects. Systematic analysis is carried out to understand the potential of coastal natural resources and the problems that threaten the ecosystem. An integrated and sustainable approach is needed, involving collaboration between government, society, and related parties. The integration of new technologies, including renewable energy technologies, was identified as a potential solution to several specific problems, such as waste management and clean water supply. An integrated and sustainable approach is analyzed by involving collaboration between government, society, and related parties. With collaboration and a deep understanding of the challenges and potential of Bawean Island, it is hoped that a sustainable coastal ecological balance can be achieved for the welfare of the environment and local communities.**

Keywords— Bawean Island, Coastal Ecological Balance, Marine Renewable Energy, Management of Coastal Resources, Technology Integration.

I. INTRODUCTION

Indonesia is an archipelago nation made up of over 17,504 islands, has a coastline that extends to 95,181 km, and a sea area that covers more than 70% of its total territory [1]. With a population estimated to exceed 242 million people in 2006, it is known that around 60% of Indonesia's population lives along coastal areas [2]. As a developing country, Indonesia has shifted its focus from agriculture to industry, with many industrial areas growing in coastal areas. Growth in Indonesia's coastal areas is taking place rapidly because these areas offer spaces with high accessibility and lower costs compared to land areas [3], [4]. Large cities in Indonesia, such as Jakarta, Surabaya, Semarang, Medan, and Makasar, attract almost 60% of the total population, most of whom live in coastal areas [5]. The role of Indonesian coastal cities covers various aspects, such as potential as natural resources, industrial and port areas, fishing centers, tourism destinations, and residential locations. However, behind the several successes in coastal development that have been mentioned, there are still several areas that, of course, require special attention so that the potential of coastal natural resources can be properly utilized.

One of the areas that is the main focus of this article is Bawean Island, which is an archipelago in Indonesia and attracts attention with its strategic location as well as being rich in potential natural resources. Natural resources such as sand, stone, and soil can support the development of the construction, mining, and plantation industries. In addition, its strategic location between Java and Madura Island, with important port routes, opens up opportunities for the fishing, tourism, and logistics industries [6]. The agricultural potential of this island is also large, with the possibility of developing oil palm, coffee, and corn, which can support the agricultural industry and reduce food shortages [7]. Bawean Island's tourism potential cannot be ignored either, with its natural beauty, cultural heritage, and other tourist attractions that can attract tourists. This island is also surrounded by several small islands, such as Menuri Island, Noko Island, and Karangbila Island [8], which add to its natural and cultural tourist attractions. Despite having great potential in the tourism and natural resources sectors mentioned previously, Bawean Island also faces several challenges that need to be addressed for sustainable progress. One of the main problems is the lack of effective promotion and promotion strategies, which is an obstacle to optimizing Bawean Island's tourism potential. In addition, industrial development such as construction, mining, and plantations has caused environmental damage and pollution, increasing the risk of natural disasters and environmental change [9]. Infrastructure problems are also an obstacle, with several problems such as limited road access and limited ports and airports. Management of endemic animals such as

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Bawean deer is also not optimal, with several obstacles to maintaining and interacting with these animals. In addition, the lack of a diverse tourism industry, as well as education and health problems, are also the main focus of overcoming challenges on Bawean Island [10].

To address these problems, it is necessary to develop a comprehensive strategy that includes infrastructure development, sustainable management of natural resources, effective tourism promotion, and development of diverse industries as well as strengthening the education and health sectors. With an integrated and comprehensive approach, Bawean Island can overcome the challenges it faces and move towards sustainable and inclusive development. Good infrastructure, such as roads, bridges and ports, also supports the development of the logistics industry and local economy. Advances in education and health, including the development of schools, hospitals and healthcare facilities, will help reduce poverty and improve the well-being of local communities. In addition, the potential for technological development, such as innovation, information technology and communication technology, can bring great benefits in developing the technology industry and local economy. In developing a strategy for Bawean Island, it is important to consider these factors and integrate them into a comprehensive strategy. An effective strategy must have long-term goals, situation analysis, resource allocation, strategy development and implementation, and monitoring and evaluation. Therefore, a systematic analysis was carried out to overcome the main problems faced by the coastal areas of Bawean Island while simultaneously discovering the potential for New Renewable Energy which will influence the success of the ecological balance of the coast and be able to have a beneficial impact on the coastal communities of Bawean Island.

A. Bawean Island

Bawean Island, situated in the Java Sea roughly 135 kilometers north of Gresik City and about 80 miles north of Paciran in Lamongan Regency, East Java, spans between latitudes 5°43' and 5°52' South and longitudes 112°34' and 112°44' East. It falls under the administrative jurisdiction of Gresik Regency, as illustrated in Figure 1. With a population of around 107,000 people, the majority of the population comes from the Bawean tribe, but there is also a blend of tribes from Java, Madura, Kalimantan, Sulawesi, and Sumatra that shape the local culture and language. Most of the island's inhabitants are fishermen [11], farmers, or work as migrant workers in Malaysia and Singapore. The language commonly used is Bawean which is similar to Madurese. Bawean Island is also known for its stunning natural beauty and rich marine resources. The area is divided into two sub-districts, Sangkapura and Tambak, each containing villages that contribute to the local economy, with a total area of 197.42 km^2 which covers 16.572% of the Gresik Regency area. Sangkapura has an area of 118.72 km^2, while Tambak has an area of 78.7 km^2. This island consists of seven islands in Sangkapura and five islands in Tambak and is divided into 17 villages in Sangkapura and 13 villages in Tambak as shown in Table 1.

TABLE 1.
BAWEAN ISLAND STATISTICAL DATA IN 2023 [12]

Data	Sangkapura District	Tambak District
Number of villages	17	13
Number of islands	7	5
Area (km^2)	118,72	78,7
Total population	53122	53122
Population density per km2	447,46	385,43

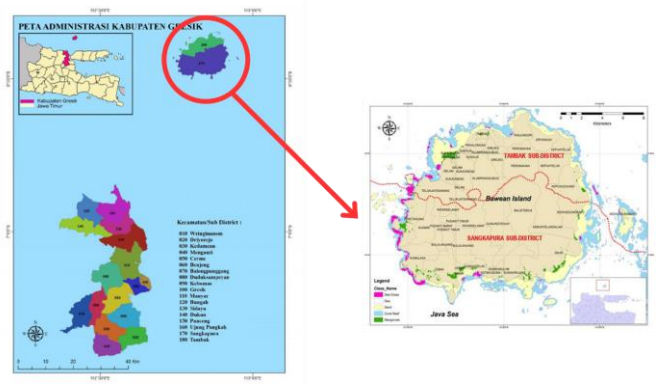

Figure 1. Map of Bawean Island [12], [13]

B. Potential of Coastal Natural Resources on Bawean Island

Bawean Island presents extraordinary potential from its coastal natural resources. Especially from the aspect of rich biodiversity to the amazing beauty of coral reefs [6], this island is a major attraction for tourism. Activities such as snorkeling and diving promise further development of the tourism sector. Not

only that, the waters around Bawean Island are also home to various types of fish, offering opportunities for fishing and fisheries resource management. Meanwhile, on land, agricultural and livestock potential also fills the list of blessed resources. Coral reefs found in locations such as Pulau Cina and Pulau Noko stand out as focal points for development [14], while mangrove forests exist as important environmental guardians. Along with increasing tourist interest in exotic beaches such as Gili Island, Bawean Island faces great potential in the tourism industry [15]. Even though it is still not fully utilized, the existence of coral reefs is the main reason for local and international tourists to visit Bawean Island. Several other potentials also need to be discussed in detail to have a comprehensive understanding of the potential that has the possibility of being exploited and has a good influence on coastal areas.

1. Diversity of flora and fauna
   In an archipelago, of course, there are living creatures that are the original habitat of the area, as well as the potential diversity of flora and fauna that Bawean Island has. Based on the results of a botanical survey on Bawean Island by [16], a total of 197 plant accessions were gathered for ex-situ conservation at the Purwodadi Botanical Gardens in Pasuruan, East Java. This collection includes 692 specimens in various forms, such as seeds, plant cuttings, rhizomes, tubers, and bulbils, showcasing the floral diversity of Bawean Island. Additionally, several studies have also documented the diversity of flora and fauna along the coast, such as research by [17] which recorded 23 coral genera consisting of 10 families and 24 species of coral fish belonging to 14 families on Bawean Island, which can be an underwater attraction. Coral reefs on Bawean Island consist of various types, including hard coral reefs and soft coral reefs [18]. Hard coral reefs are the main component of Bawean Island and are an ecosystem that is very rich in biodiversity, surpassing other marine ecosystems. On the other hand, soft coral reefs are also present as an important component on this island, adding significant diversity to natural resources. These two types of coral reefs play a vital role in Bawean Island's marine ecosystem, not only as a home for various marine organisms but also as the main attraction for tourists who are interested in the unique underwater beauty. The seagrass beds on Bawean Island contain various types of fish, including those used for consumption and decoration. Apart from that, there are types of seagrass and macroalgae that are important components in balancing the marine ecosystem as a place for fishing activities and other biota [19].
2. Mangrove forest
   Mangrove forests on Bawean Island have an important role in protecting and restoring the environment from various threats of damage and coastal erosion. Bawean Island has various types of mangroves, including *Rhizophora lamarckii*, which dominates Sawah Laut Beach with an important value reaching 236.981%; *Seneratia alba*; and *Avicennia marina*, which are found in Daun Village; as well as *Pemphis acidula*, which grows on Sawah Laut Beach in Kusuma City Village. Other mangrove species, including *Rhizophora apiculate*, *Rhizophora stylosa*, *Rhizophora mucronata*, and *Ceriops tagal*, are also found distributed across various locations on Bawean Island. Apart from that, in Daun Village and Sukaoneng Village, there are also 14 types of trees that form the mangrove ecosystem, which are classified into 8 families [20]. According to research conducted by [21], local people use it for various purposes, of which 32% is used as building material, 17% as wood fuel, 2% as dye, 9% is believed to have spiritual powers such as amulets, 2% as ornamental plants, and 12% as food. Wood is the largest part used, reaching 62%, followed by bark (tannin) at 7%, fruit at 5%, leaves at 25%, and flowers at only 1%. This shows the importance of people's dependence on mangrove forests not only as a source of material materials but also as a spiritual element and a source of diverse life.
3. Fishery products
   Bawean Island is known for its abundant fisheries products, in line with the majority of the local population who depend on their livelihood as fishermen who actively catch fish every day. One of the main commodities from Bawean Island's fishery products is flying fish, with various types such as blue flying fish, gilig flying fish, and deles flying fish, which are the main ingredients for making pindang fish, a popular side dish commodity [22], [23]. Apart from flying fish, the coast of Bawean Island also contains various types of small pelagic fish, such as tuna, skipjack tuna and anchovies [24], [25]. The contribution of pelagic fish is very important to society, not only as the main source of protein, but also in supporting marine agriculture and providing a large economic contribution. Pelagic fish play an essential role in sustaining the marine ecosystem's balance by being a key component of the food chain and serving as prey for various predators. Apart from that, some fishery products have the potential for additional benefits in the economic aspect and as an alternative food source, such as the use of binggul fish bone waste to make crackers.
4. Tourism
   Bawean Island offers a variety of tourism potential which includes several important aspects as a promising tourism destination, including beautiful beaches, diversity of marine ecosystems, natural tourism, cultural tourism and ecotourism. Beaches such as Jhembangan Beach, Tanjung Gaang Beach, and Pasir Putih Beach are the main attractions for tourists who are looking for a place to relax and swim amidst the white sand and clear sea water

[26]. The diverse marine ecosystem around Bawean Island offers exciting marine tourism opportunities such as snorkeling, diving and scuba diving, with stunning coral reefs and an amazing diversity of marine life. Apart from that, Bawean Island also has extraordinary natural tourism potential such as mangrove forests, waterfalls and amazing natural scenery, which can be enjoyed through hiking, trekking or natural exploration activities [27]. With its high biodiversity, Bawean Island has the potential for responsible and sustainable ecotourism development, through activities such as observing marine biota, planting mangroves, or educational tours about environmental protection.

5. Development of New Renewable Energy Potential
   Bawean Island possesses significant potential for developing new renewable energy sources in its coastal areas. Various types of renewable energy can be harnessed in this region, including offshore ocean wave energy, wind energy, marine geothermal energy, tidal energy, solar energy, and wave energy. The development of new renewable energy potential on Bawean Island has been the focus of several studies and research, such as in research conducted by [28] which discusses optimizing the potential for renewable energy development and feasibility studies for ocean wave power. Despite this great potential, there are still several challenges that need to be overcome, including the availability of adequate funding, technology and infrastructure. To overcome these challenges, it is necessary to increase public awareness, increase investment and improve supporting infrastructure. With these steps, it is hoped that the development of new renewable energy on Bawean Island can run more smoothly and provide great benefits for the region [29].

C. Problems that arise on Bawean Island

The beauty and potential of Bawean Island is something that has the potential to be put to good use. However, exploiting this potential can produce the opposite if it is not managed well, due to various factors, most of which are caused by the local community. This is a very unfortunate incident because it can cover the potential of Bawean Island. The diversity and natural potential on Bawean Island is hampered by a lack of community harmony and solidarity which can result in suboptimal development [30]. This raises various problems that need to be considered carefully.

1. Availability of clean water
   Small island areas often experience difficulties related to providing clean water. This is caused by various factors such as limited water resources, environmental damage, climate change, and rapid population growth, often causing water crises on these small islands [31]. Limitations in access to the technology needed for water treatment can also worsen the situation because sea water is water that is not suitable for daily consumption. In several island areas, the problem of a lack of clean water is serious and has an impact on residents' daily lives, health, and economic growth. Based on data from [32], the supply of clean water on Bawean Island is obtained from limited wells and springs, and water management from springs is not optimal because the paralon channels that carry water to villages do not meet guaranteed quality standards. Apart from that, there is no PDAM subsidy, and the lack of raw water sources in the service area further exacerbates the clean water crisis.
2. Erosion of coastal structures
   The erosion of coastal structures on Bawean Island is influenced by various factors involving complex interactions between human activities and natural phenomena. Development without considering environmental impacts, such as the construction of ports and settlements, is one of the main causes of coastal erosion. In addition, climate change also plays an important role by increasing the intensity of storms and destructive sea waves. Apart from that, the topographic and geological conditions of Bawean Island also increase its vulnerability to coastal erosion. The phenomenon of sea level rise is a serious threat that can worsen the situation, resulting in damage to coastal ecosystems, which are vital for the survival of this island [14]. Environmental changes, both natural and caused by human activities, can also accelerate the process of coastal erosion. One example of human activity that has the potential to trigger beach erosion is large-scale and illegal sand mining. The potential for iron sand in Sangkapura is a source of resource conflict between societies that are interested in economic gain without considering the environmental impacts that may arise [33]. Therefore, there is a need for awareness of the importance of conservation in mining areas to prevent damage to the surrounding environment, which in turn can reduce the risk of erosion of coastal structures, which is increasingly worrying [34].
3. Rubbish waste
   Rubbish accumulation on Bawean Island is a complex problem caused by a number of diverse factors. The need for waste management on Bawean Island is high due to daily needs, but infrastructure and effective waste management have not been taken seriously. This is proven by information from the Gresik Regency Central Statistics Agency [12], with the lack of facilitated waste disposal sites such as final disposal sites (TPA) also becoming a significant obstacle for the community in disposing of waste properly. Apart from these internal factors, the phenomenon of rising sea levels also contributes to the accumulation of rubbish on this island. Rising sea levels can cause a buildup of rubbish because the rubbish is carried by sea currents and winds, so it can also trigger floods [35]. The problem of waste

management on Bawean Island has also not been resolved properly due to obstacles such as a lack of land, equipment, and adequate management staff. Apart from internal factors in the form of a lack of infrastructure, external factors also play a role in the accumulation of waste on Bawean Island. One of them is human activities such as excessive consumption of consumer goods and the tendency to use disposable items obtained from migrant families outside the island, which also worsen the situation [36]. Increased tourism on this island also contributes to the increasing volume of waste, especially in tourist areas that are busy with visitors.

4. Society economy

The economic problems on Bawean Island are the result of a number of factors that influence the island's economic sustainability. One of the main problems is limited employment opportunities, limited economic opportunities, and a lack of livelihood diversification [37]. Even though the majority of Bawean Island's residents rely on fishing as their primary source of income, this sector is highly susceptible to price fluctuations and global economic conditions [38]. Infrastructure and accessibility constraints are also obstacles to developing the tourism sector and other industries on this island. Local economic stability is also affected by low levels of education and skills, which hinder community participation in more advanced economic sectors. Apart from that, the high level of unemployment, economic inequality, and dependence on government assistance are also challenges that must be overcome to improve the economy of Bawean Island. By identifying this problem and implementing appropriate policies, it is hoped that more sustainable and inclusive economic growth can be achieved on this island. Apart from that, other problems affecting the economy of Bawean Island include a lack of waste management, a lack of tourism development, a lack of investment, and a lack of attention to the development of traditional or historic housing and settlement areas [32]. Lack of attention to regulations related to the conservation of cultural heritage buildings, the environment in cultural heritage areas, and tourism in coastal areas are also factors that contribute to economic problems on Bawean Island.

5. Society education level

One of the problems that needs to be highlighted on Bawean Island is the relatively low level of education. This is caused by a number of factors that influence educational access, quality, and outcomes. One of the main problems is low participation in education, especially at the high school and college levels, which results in many children dropping out of school or not continuing their education at a higher level. This is proven by data obtained from the Gresik Regency Central Statistics Agency [12] which can be seen in Table 2, where the public's interest in pursuing higher levels of education is increasingly increasing, meaning that the number of students is decreasing in proportion to the higher levels of education. level of education. Limited educational facilities and infrastructure, including inadequate facilities and teaching staff, are also obstacles to providing quality education. High school dropout rates are also influenced by economic, social, and cultural factors in society, which influence motivation and opportunities to learn. Apart from that, the lack of access to higher education and job training that is in line with market needs is also a problem in increasing the level of education and skills of the people of Bawean Island [39]. It is necessary to identify problems and implement appropriate policies to create a more inclusive and quality educational environment so that people can have better opportunities to improve their quality of life and contribute to the island's economic and social development.

TABLE 2.
DATA ON EDUCATION LEVELS AND FACILITIES ON BAWEAN ISLAND [12]

Subdistrict	Level of education	Total (units)	Total number of teachers	The number of students
Sangkapura	TK/RA	17	60	519
	SD/MI	68	629	5365
	SMP/MTs	23	307	2715
	SMA/SMK/MA	19	263	2410
Tambak	TK/RA	13	43	405
	SD/MI	47	372	3017
	SMP/MTs	12	141	1247
	SMA/SMK/MA	8	105	1019

II. ECOLOGICAL BALANCE OF THE COASTAL BAWEAN ISLAND

Marine coastal ecology is an analysis that involves interactions between living organisms and their environment in coastal and marine areas, including ecosystems such as mangroves, coral reefs, seagrass, and sandy beaches, which have an important role in coastal and marine waters [39]. Coastal marine ecology also examines how organisms adapt to various factors, including light, body structure, gender, and olfactory senses, as well as environmental conditions such as physical and chemical properties. There is an emphasis on the significance of preserving a harmonious relationship between the requirements of coastal and marine ecosystems and the surrounding communities in the management of coastal and marine areas. The concept of maintaining ecological balance along the

coast is crucial in managing these areas effectively, advocating for behavior and management practices that align with the ecosystem's conditions and the needs of coastal communities. One approach that involves this concept is Coastal Human Ecology (CHE), which summarizes various theoretical and thematic approaches from the humanities and ecological sciences [40]. CHE combines social sciences, natural sciences, and humanities, addressing topics such as human adaptation to the coast, historical ecology of fisheries, marine governance, local food security, and local ecological knowledge systems. With the various characteristics analyzed in this multidiscipline, CHE has great potential to bridge the gap between the natural sciences and social sciences and is able to overcome various challenges in environmental management.

In discussing coastal ecological balance, it is necessary to understand the relationship between related problem factors and efforts to overcome these problems. Coastal ecological balance is a concept that refers to the role of each component in the ecosystem to maintain the continuity of life and achieve stable conditions. Various elements affecting the ecological equilibrium of coastal areas encompass the utilization of natural resources, the amalgamation of scientific fields, the collaboration of involved parties, and endeavors to address coastal challenges [41]. Utilization of natural resources must be carried out optimally and sustainably by considering all sectoral interests involved. The integration of scientific disciplines is also an important factor in managing coastal ecosystems and resources, involving various fields such as ecology, oceanography, engineering, economics, law, and sociology. Apart from that, integration of stakeholders or parties concerned is also needed to achieve effective management, with support from various aspects such as marine environmental management, climate change, and sustainable development of small islands. These factors are interrelated and must be considered comprehensively in an effort to understand and overcome problems that occur on the coast [42], so that the goal of maintaining ecological balance and achieving stable and balanced conditions can be achieved through integrated management.

A. Factors in Coastal Ecological Balance Problems

Factors involving coastal ecological balance problems include various conditions or elements that can cause imbalance, which can take the form of disturbances in the coastal ecosystem. These aspects include several sections that have been discussed in the previous section regarding the discussion of coastal natural resource potential and the problems that arise as a result of this potential. Therefore, an analysis of the relationship between problem factors that influence the ecological balance of coastal areas is carried out, such as unsustainable use of natural resources, conflicts between various sectoral interests, environmental degradation, climate change, coastal erosion, and so on [43]. The causes of this imbalance can come from various human activities and natural factors that influence coastal ecology [44]. A good understanding of these factors is important for identifying existing problems and developing appropriate management strategies to maintain the ecological balance and sustainability of coastal ecosystems. These factors can include various issues regarding resource availability, limited infrastructure, education and use of renewable energy, resource management and development, ecological balance, infrastructure limitations, and the government's role in facilitating the use of renewable energy. All of these factors are interrelated and have the potential to influence the ecological balance of coastal areas, so to understand this problem, it requires systematic analysis through a review of various literature to find relationships between factors that can lead to potential solutions.

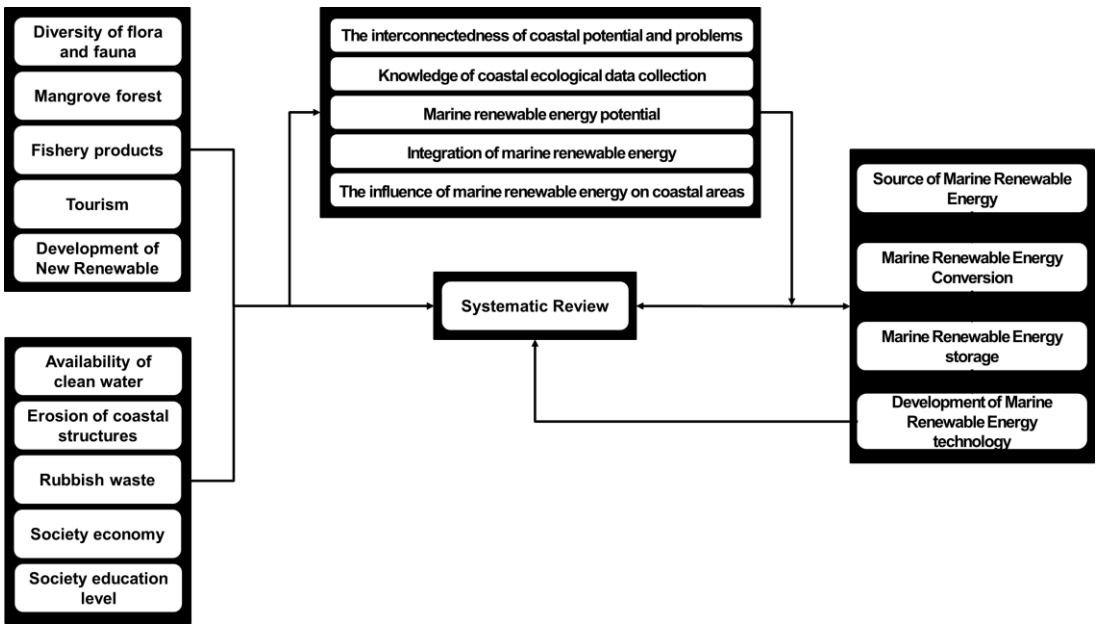

Figure 2. Diagram interconnection of coastal ecological balance

The diagram shown in Figure 2 illustrates the complex relationship between ecological, economic, and social factors that shape the ecological balance of the coast. Biodiversity, represented by diverse flora and fauna and mangrove forests, marks the foundation of ecosystem health that influences fisheries and tourism outcomes. This balance is important to sustain tourism, which provides economic value and fuels conservation initiatives. Conversely, emerging renewable energy sources present the opportunity to diminish reliance on fossil fuels and contribute to initiatives aimed at mitigating climate change. Nonetheless, the presence of clean water and the maintenance of stable coastal structures, free from erosion or debris accumulation, are indispensable factors for sustaining local livelihoods and economic endeavors. Social factors, such as people's level of education, also play a role in increasing participation and awareness of the importance of ecosystem conservation. Aligning environmental aspects with economic and social activities requires integrated management and in-depth understanding through systematic reviews. So that the collection of these reviews informs potential solutions and best practices for the development of renewable technology that is not only environmentally sound but also supports the community's economy and coastal ecological welfare.

B. Relationship Between Factors of Coastal Ecological Balance

In connection with the characteristics of the problem factors that have been discussed, it is necessary to carry out a detailed analysis of the interrelationships between these factors by considering various aspects that allow for interrelationships in both negative and positive impacts. The relationship between coastal ecological balance problem factors and coastal structural maintenance and sustainability involves several aspects that are interrelated and important to consider [45]. This gives rise to several processes consisting of a problem identification process followed by negative potential, positive potential, and treatment methods to overcome the potential that arises, along with the connectedness aspect of each problem factor and potential factor found in the coastal ecological balance, which can then be analyzed through the linkage diagram in Figure 3.

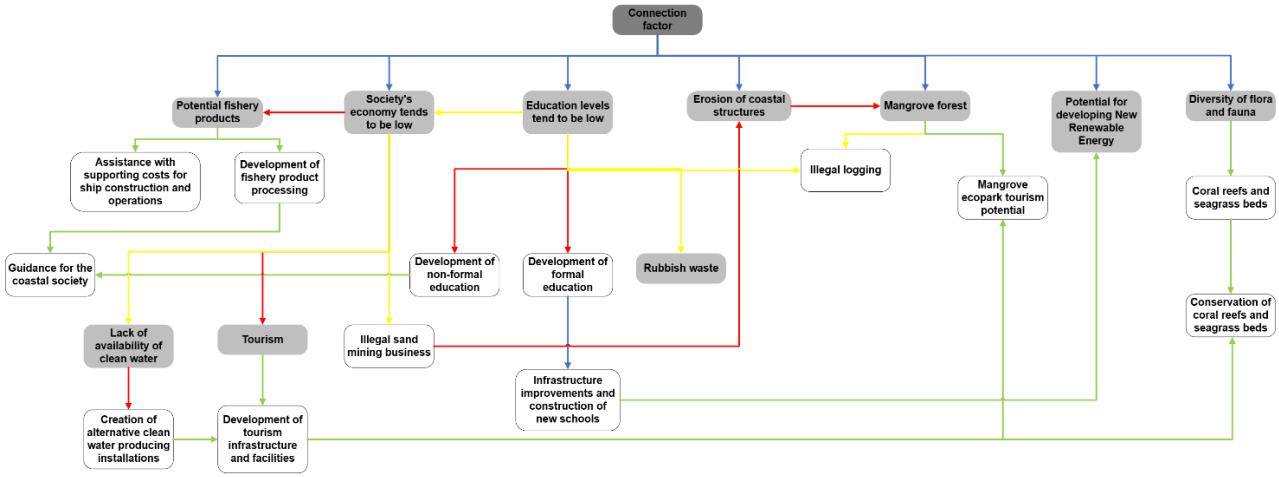

Figure 3. Diagram of the interconnection between factors of coastal ecological balance problems

The linkage diagram shown in Figure 3 illustrates the relationship and complexity of issues that influence the ecological balance of the coast, with colored lines that map the influence between various factors. At the core of this network diagram is the potential of coastal resources such as fishery products, which are vital for the community's economy and directly influence the education level of the population. Sustainable fisheries practices not only support economic stability but also promote systematic resource management [46]–[48], so this has a good impact on increasing public awareness and education. In line with these good impacts is a diversity of ecological sustainability integrated with tourism, but if this is not utilized properly, it can cause negative impacts and be threatened by businesses such as illegal sand mining, highlighting the struggle between environmental conservation and economic needs. Erosion of coastal structures and accumulation of rubbish are two critical issues that negatively affect mangrove forests [49], [50], so it can be a factor that reduces the vitality of coastal ecosystems and limits their ability to function as natural protection. This relationship shows that uncontrolled human activities, including the emergence of mangrove logging activities, can damage natural habitats and local biodiversity. A proactive approach to education, both formal and non-formal, can be a balance driver and play a key role in building the knowledge infrastructure necessary for ecosystem conservation. Therefore, consideration of building new schools and improving educational facilities is expected to encourage increased awareness and the skills needed to protect and manage coastal resources.

Meanwhile, the creation of clean water management installations and private facility infrastructure shows a commitment to improving quality of life and environmental sustainability [51]. Coral reefs and seagrass meadows, intricately connected to a variety of plants and animals, serve as indicators of ecological stability and underscore the significance of conserving and safeguarding marine environments. The utilization of new and renewable energy sources, such as wave energy from mangroves, serves as a bridge between the

utilization of natural resources and the innovation and adoption of alternative energy technologies to address ecological challenges. Green lines depict positive connections that strengthen ecological elements; yellow symbolizes the flow of resources and financial support; and red lines mark problems that have a detrimental impact. Neutral relationships or general functions are depicted with blue lines, which provide context for interactions between broader factors. Therefore, the illustration depicted in the diagram can demonstrate the significance of implementing a comprehensive management approach that takes into account social, economic, and environmental aspects simultaneously, aiming to establish a resilient and enduring ecological equilibrium.

III. DISCUSSION

The ecological balance of the coastline on Bawean Island needs special attention considering the great potential and challenges faced by the region. The comprehensive analysis conducted encompasses diverse facets, ranging from the assessment of coastal natural resource potential to the identification of challenges endangering ecosystem equilibrium. Bawean Island is known for its extraordinary natural wealth, especially in terms of biodiversity and the beauty of coral reefs. The attractive coral reefs and diversity of surrounding flora and fauna are the main attractions for tourism. However, the use of natural potential must be carried out wisely and sustainably to maintain the sustainability of coastal ecosystems. One of the main problems facing Bawean Island is the availability of clean water. Limited water resources and a lack of clean water treatment infrastructure have caused a water crisis in several island areas. Climate change also worsens the situation by increasing the risk of flooding and coastal erosion, which can pose serious threats to coastal ecosystems. Apart from that, waste management is also a complex problem because the lack of infrastructure and awareness of the importance of good waste management have led to the accumulation of waste on the island. Followed by the phenomenon of rising sea levels, which also contributes to the spread of waste in coastal areas. On the other hand, economic and educational issues also need to be considered. This is due to limited employment opportunities and low levels of education, which have hampered economic growth and the welfare of the people of Bawean Island. So, efforts need to be made to increase the level of education and skills in the community, which is very important to creating a more inclusive and quality environment. To maintain the ecological balance of coastal areas, an integrated and sustainable approach is needed, involving cooperation between the government, community, and various related parties to overcome existing problems. Natural resource management must be carried out optimally and sustainably, taking into account ecological, economic, and social interests. The ecological balance of the coastline on Bawean Island is a valuable asset that needs to be preserved for environmental sustainability and community welfare. With good awareness and cooperation, Bawean Island has great potential to become an example in managing natural resources and preserving the coastal environment.

By analyzing ecological balance, starting from understanding the potential of coastal natural resources, which is then linked to the problems that arise as a result of this potential, it can produce a diagram of the relationship between problem factors, which has several main objectives, namely, to understand and overcome problems that occur on the coast so that this ecosystem can be maintained in a stable and balanced condition. By implementing a comprehensive and systematic approach, it is hoped that coastal management that is sustainable and resilient to environmental change can be realized. This comprehensive approach was carried out systematically, armed with an analysis of the relationship between potential factors and coastal problems on Bawean Island, which was then supported by knowledge about collecting ecological data on tropical coastlines in areas adjacent to Bawean Island. So, this approach can then be linked to several potential new renewable energies or marine renewable energy, which could be a potential option for integration on Bawean Island with several systematic considerations through its influence on coastal areas through several similar studies carried out on coasts that are identical to the characteristics of Bawean Island.

One potential that can be taken into consideration for integration into the waste problem on Bawean Island is considering various solutions to overcome plastic pollution in the form of new technology to prevent and collect marine plastic pollution. To achieve a comprehensive understanding of plastic pollution remediation technology in marine ecosystems, an inventory has been created as a tool for researchers, industry, NGOs, and government, as carried out by [52] which involved a review of internet resources to identify technologies aimed at reducing plastic pollution, compiling a catalog of 39 distinct technologies, encompassing both prevention methods and suggestions for future research, taking into account the viability, cost, and efficiency of deploying cleanup and prevention technologies, serves as a reliable resource for the public to enhance their understanding of plastic waste characteristics. Apart from that, waste management is also another potential that is important to consider. Several studies have discussed waste management through the Waste Disposal Site or Tempat Pembuangan Sampah (TPS) service, as carried out by [53] with a method for determining waste collection based on land availability and optimizing services at each TPS, which is supported by the number of TPS to increase the effectiveness of waste management methods [54]. A simple waste processing system with a zero-waste concept can also be applied to deal with potential threats from marine debris, which can damage the potential of tourist villages, and more useful waste management strategies. This waste management system must also be supported by community empowerment and local government participation so that it runs optimally.

In determining considerations for the integration of renewable energy as the utilization of coastal resources, comprehensive and reliable data is needed as one of the

aspects that supports the characteristics and suitability of a type of technological development so that the function of the technology can be useful and have a good impact. A solution that can be considered is to conduct a review of coastal urban ecology, such as research by Fadzil *et al.* [55] by discussing the shortcomings of studies that only focus on interdisciplinary studies that face geographic bias and tend to focus on ecological aspects with minimal consideration of the social dimensions in coastal urban areas. Then efforts were made to expand the diversification of research in urban ecology, including social-ecological research, aimed at supporting coastal development in various countries. This effort can also be developed with island management planning, as in research Hidayah *et al*. [56] which addresses the lack of comprehensive data regarding the biophysical conditions of small islands, which can hinder sustainable development. This collection of data then becomes one of several supporting factors in determining the choice of coastal resource technology. One important candidate for developing coastal resource technology is a clean water treatment process based on water desalination with various aspects of consideration and innovation that are in line with current developments, as can be seen in Table 3. This solution is one that is widely applied on small islands, considering the abundant availability of sea water, which needs to be processed to make it an alternative to clean water. Seawater desalination technology holds significant potential for development along the coast of Bawean Island to address the shortage of clean water alternatives. Several methods for developing desalination technology that can be carried out include thermal energy storage (CSP) and multi-stage flash (MSF), which are effective especially in coastal areas with high solar intensity and allow integration of solar heat utilization through solar panels [57]; electrocoagulation technology to reduce the levels of dissolved substances in seawater [58]; and reverse osmosis (RO) and seawater reverse osmosis (SWRO) [58]–[61] that are suitable for use in coastal areas with quite large areas of land. The development of seawater desalination technology can help reduce the shortage of clean water in coastal areas such as Bawean Island and reduce dependence on fossil fuels, which can pollute the environment. However, this effort requires investment and support from both the government and the community and must be carried out efficiently while paying attention to the environmental impacts that may arise.

TABLE 3.
PREVIOUS RESEARCH REGARDING WATER DESALINATION TECHNOLOGY IN COASTAL AREAS

Author(s)	Method	Consideration Aspects	Innovation
Santos., 2024 [62]	Reverse osmosis	• Energy efficiency • Operational performance • Environmental sustainability • Resistance to natural hazards • Community involvement in water conservation efforts	• Utilization of advanced materials • Autonomous systems • Real-time monitoring technologies • Modular and adaptable infrastructure design
Jacobson *et al.*, 2024 [63]	Reverse osmosis	• Energy efficiency • Cost effectiveness • Environmental impact • Water quality requirements • Availability of feed water sources	• Desalination Assisted Carbon Concentration and Carbon Dioxide Removal as promising techniques for ocean-based atmospheric carbon extraction • Estimates a potential removal of 3.8 tons of CO_2/year globally
Sztekler *et al.*, 2024 [64]	• Reverse osmosis (RO), • Multiple-effect distillation (MED) • Ion exchange (IX) systems	• Energy consumption • Water purity requirements for specific applications such as electrolysis • Ability to condense brine and extract salt in solid form	• Hybrid zero fluid discharge desalination system • Integrating various desalination technologies to achieve a high level of water purity • Minimize the generation of liquid waste
Hussein *et al.*, 2024 [65]	Reverse osmosis	• Cost • Environmental impact • Technical feasibility, compatibility with membranes • Overall sustainability	• Development of bionic solutes with high selective permeability • Use of protein-based solutes mixed with metal nanoparticles • Continued progress in high osmolarity towing solutions
Zhang *et al.*, 2024 [66]	Solar-driven seawater	• Energy usage • Environmental repercussions • Maintenance expenses for equipment • Technological limitations • Resource accessibility • Sustainability considerations • Specific requirements of the site	• A novel method that repurposes waste from hemp fiber production for solar-powered seawater desalination

Ma *et al.*, 2023 [67]	Vacuum membrane distillation	• Energy consumption • Environmental impact • Fresh water production rate • Efficiency and complexity of equipment • Operating and maintenance costs • Suitability for integration with other technologies like OTEC	• Ocean Thermal Energy Conversion combined with a vacuum membrane distillation (VMD) desalination system exclusively driven by OTEC
Ohlund *et al.*, 2024 [68]	Combination of first-pass SWRO (single-stage) with partial second-pass BWRO (two-stage)	• Water intake volume requirements • Requirements for the quality and volume of brine discharge • Requirements for the disposal of treated wastewater • Energy consumption • Cost	• Increasing seawater desalination by reusing potable wastewater to provide new water supplies
Ye *et al.*, 2024 [69]	Air-water interface solar heating	• Energy efficiency • Cost effectiveness • Environmental impact, scalability • Resource availability	• Explored the formation of reactive oxygen species especially H_2O_2 during solar evaporation • Development of halogenated by-products on the surface of the evaporator

Based on previous research regarding coastal water desalination, Table 3 highlights various approaches and innovations in coastal water desalination technology, which provides a comprehensive picture of the challenges and solutions in developing water desalination, taking into account various aspects such as energy efficiency, environmental impact, costs, and sustainability. The most common approach is the water desalination method using the reverse osmosis (RO) method. Santos [62] and Jacobson *et al.* [63] emphasizing the significance of energy efficiency and cost-effectiveness in RO utilization by developing innovations like advanced materials and desalination-assisted carbon concentration (DACC) to mitigate environmental impacts. A study by Hussein *et al.* [65] introduced the concept of developing bionic solutes to improve the overall performance of RO technology. Besides that, Sztekler *et al.* [64] integrate various desalination technologies, such as ion exchange (IX) systems, RO, and multiple-effect distillation (MED), to achieve a high level of water purity while minimizing liquid waste. Zhang *et al.* [66] and Ma *et al.* [67] explore innovative approaches by utilizing solar power for seawater desalination with consideration of technological and sustainability constraints. Other studies from Ohlund *et al.* [68] and Ye *et al.* [69], propose a more specific approach, such as a combination of desalination with ocean thermal energy conversion (OTEC) and solar heating of the water interface, to increase energy efficiency and pay attention to environmental impacts as a strategy and innovation in coastal water desalination technology. So, today's technological development is focused on environmentally friendly goals and supporting coastal ecological balance through the development of solutions that are efficient, sustainable, and can be adapted to meet increasing water needs.

TABLE 4.
PREVIOUS RESEARCH REGARDING ELECTRICAL POWER GENERATION RESOURCES IN COASTAL AREA

Author(s)	Method	Consideration Aspects	Innovation
Jin *et al.*, 2024 [70]	Floating photovoltaic systems	• Efficiency • Cost • Durability • Suitability for marine environments	• Combining floating photovoltaic systems with offshore wind turbines to enhance electricity generation • Boosting energy generation density in spatial terms • Minimizing fluctuations in seasonal output
Garcia *et al.*, 2024 [71]	Utility-scale photovoltaic power plants	• Efficiency • Cost • Durability • Suitability for a particular location	• Utilizing satellite imagery from sentinel missions to assess the impact of large-scale photovoltaic power plants on local vegetation and humidity
Mohamed *et al.*, 2024 [72]	Polycrystalline solar panels	• Efficiency • Cost • Available space • Environmental conditions	• Innovative operational performance assessment specific to the coast with a focus on rooftop pv systems

Elkadeem *et al.*, 2024 [73]	Photovoltaic panels	• Efficiency • Cost • Durability • Suitability for specific applications	• An integrated optimization and control strategy for large-scale hybrid power systems combining solar, wind, battery, and grid sources • Ensuring a sustainable and clean energy supply
Gonocruz *et al.*, 2024 [74]	Hybrid solar panel battery energy storage system	• Cost effectiveness • Efficiency • Durability • Installation requirements • Available space	• Optimizing the electricity supply mix by considering the operating time of thermal power plants • Coordinating energy sources to further enhance the transition to renewable energy • Reduce coal energy generation
Howe *et al.*, 2020 [75]	Π-type floating breakwaters wave energy converters	• Hydrodynamic performance • Wave energy extraction efficiency • Integration with maritime structures • Operating capabilities in a variety of sea conditions	• Combining multiple oscillating water column (OWC) wave energy converters with floating breakwaters to enhance wave attenuation and energy extraction efficiency in irregular sea conditions
Ciappi *et al.*, 2022 [76]	Rigid piston approach	• Potential wave energy at the location • Specific wave power available • Water depth • Wave climate type • Overall energy conversion efficiency of the owc system	• Creation of a wave-to-wire analytical model for oscillating water column (OWC) wave energy converters, emphasizing the use of the rigid piston method for hydrodynamic, thermodynamic, and aerodynamic analyses
Liu *et al.*, 2024 [77]	Gravity-based OWC wave energy converter	• Hydrodynamic and aerodynamic performance • Interaction with incoming waves • Operating efficiency • Overall performance evaluation	• Conducting an experimental study of a standalone OWC plant in a wave tank, examining its interactions with incoming waves, wave distribution patterns, reflection ratios, and operational performance
Liu *et al.*, 2023 [78]	Isolated OWC model with generic cubic air chamber and impulsed turbine model	• Incident wave angle, height, period, and rotation speed of the turbine model • Wave distribution characteristics around the OWC model under various test conditions	• Experimental testing of isolated OWC models in various wave scenarios • Analyze the characteristics of wave distribution • Predicting the annual energy production of OWC power plants under different sea conditions

Apart from using solar sources as an alternative to electric power, wave energy can also be used as an alternative source of electricity [79]–[81] in the form of technology. Oscillating Water Column (OWC) offers promising potential as an alternative for generating electrical power in tropical coastal areas in the form of Ocean Wave Power Plants [82]–[84] like the existing prototype at Baron Beach, Yogyakarta, where its characteristics are similar to the waters around Bawean Island, and its ability to produce stable electricity output. Several developments in alternative electrical power on the coast have been carried out, such as research in similar fields, which can be seen in Table 4. The approaches covered include the use of floating photovoltaic panels, wave power plants, and energy storage systems. Jin *et al.* [70] and Gonocruz *et al.* [74] explore the use of floating photovoltaic panels and hybrid energy storage systems to increase efficiency and durability while considering cost and available space factors. Garcia *et al.* [71] place emphasis on analyzing the environmental impacts of utility-scale photovoltaic power plants using satellite imagery, while Mohamed *et al.* [72] and Elkadeem *et al.* [73] assess the performance of photovoltaic panels in coastal environments. Additionally, explore wave energy solutions like floating breakwater wave energy converters and oscillating water column (OWC) wave energy converters, as described by Howe *et al*. [75] and Liu *et al.* [77], offer an innovative solution to efficiently extract energy from ocean waves. Ciappi *et al.* [76] and Liu *et al.* [78] developed analytical models and conducted experimental studies to improve understanding of OWC system performance under various wave conditions. Various developments in research on alternative energy generation have a common focus point by emphasizing the importance of developing sustainable and efficient energy resources on the coast, as well as the complexity involved in considering various technical, environmental, and economic aspects.

The potential of other technologies is also possible to be applied on Bawean Island but integrated marine renewable energy (MRE) in coastal areas can have varying impacts on ecology. Beneficial outcomes include lowering greenhouse gas emissions and fossil fuel consumption, which can decrease pollution and its adverse effects on human health. However, this integration also brings negative impacts such as habitat damage and pollution due to turbines or tools from the technology being developed [85]–[87], which have the potential to disrupt the welfare of coastal communities.

The development of efficient technology and appropriate environmental impact measurements are very necessary to reduce the negative impacts. The process of measuring ecological impacts involves collecting and analyzing data as well as calculating estimates of the energy that can be produced. Factors such as changes in the function of coastal ecosystems, development without considering ecological principles, and pressure from human activities can influence the ecological impacts of marine energy utilization on coastal areas. A comprehensive approach that considers social, economic, and environmental factors in coastal area management is crucial for guiding technology development along the coast.

IV. CONCLUSION

Bawean Island displays extensive natural potential with stunning natural beauty and abundant natural resources, but it has not been fully utilized properly. This potential is threatened by damage due to human activities and environmental factors such as limited availability of clean water, erosion of coastal structures, and the accumulation of rubbish, accompanied by economic problems and low levels of public education. To overcome these challenges, strong awareness and cooperation between the government, community, and other related parties are needed. An integrated and sustainable approach is the key to maintaining the ecological balance of the coast. Effective and sustainable natural resource management, taking into account ecological, economic, and social dimensions, is essential for preserving environmental sustainability and the well-being of Bawean Island residents. The incorporation of innovative technologies, such as renewable energy, offers potential solutions to address various challenges, including waste management, the scarcity of clean water, and energy shortages. However, the application of this technology must be done with careful consideration and in accordance with the characteristics of Bawean Island. So, with a deep understanding of the potential and problems that exist on Bawean Island, as well as through collaborative efforts between various parties, it is hoped that the ecological balance of the coast can be maintained, and environmental sustainability and community welfare can be achieved.

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REFERENCES

[1] C. Kusmana, "Mangrove ecosystems of Asia: Status, challenges and management strategies," *Mangrove Ecosyst. Asia Status, Challenges Manag. Strateg.*, no. January, pp. 1–471, 2014, doi: 10.1007/978-1-4614-8582-7.

[2] S. S. Durand, "Study of Natural Resource Potential in the Coastal Area of South Minahasa Regency," *J. Perikan. Dan Kelaut. Trop.*, vol. 6, no. 1, p. 1, 2010, doi: 10.35800/jpkt.6.1.2010.107.

[3] A. Soemarmi and A. Diamantina, "The Concept of Archipelagic State in Efforts to Protect Indonesia's Fisheries Management Areas," *Masal. Huk.*, vol. 48, no. 3, p. 241, 2019, doi: 10.14710/mmh.48.3.2019.241-248.

[4] M. F. Arianto, "Coastal Area Potential in Indonesia," *J. Geogr.*, vol. 20, no. 20, pp. 1–7, 2020.

[5] M. Kristiyanti, "Empowering Coastal Communities through the ICZM Approach," *Pros. Semin. Nas. Multi Disiplin Ilmu Call Pap. UNISBANK ke-2 Tahun 2016*, no. 180, pp. 752–760, 2016.

[6] M. Z. Maghrobbi, "Characteristics of the Coastal Area of Bawean Island," *J. Kelaut.*, vol. 4, no. 1, p. 3, 2022.

[7] D. I. Faronny, B. Waluyo, A. Sutrisno, S. Sunardi, and D. Yudianto, "Sustainable Food House Area in Diponggo Village, Bawean Island as Model for Efforts Food Security and Provision of Nutrient Materials in Small Islands," *Proceeding Community Dev.*, vol. 2, p. 289, 2019, doi: 10.30874/comdev.2018.323.

[8] S. Wiryanti and M. Ali, *The Exoticism of Bawean: A Small Land in the Java Sea*. Surabaya: Airlangga University Press, 2023.

[9] Nadlir, W. R. Relasari, M. Oviasasti, T. S. Agung, S. Wulandari, and D. D. Nurdiana, "Development Analysis of the Bawean Deer Conservation Tourist Attraction in Pudakit Timur Village, Sangkapura, Gresik," *Nusant. J. Ilmu Pengetah. Sos.*, vol. 9, no. 4, pp. 1483–1490, 2022, doi: 2550-0813.

[10] D. Prasetyo and D. I. Setyadi, "Short Film Design with a Tourism Theme Using Storytelling Approach as a Promotional Medium for Bawean Island Tourism," *J. Sains dan Seni ITS*, vol. 6, no. 1, 2017, doi: 10.12962/j23373520.v6i1.22886.

[11] N. Mutmainnah, I. N. Asyiah, and I. L. Novenda, "Pemanfaatan Alat Tangkap Ikan Tradisional Oleh Nelayan Pulau Bawean Kabupaten Gresik," *J. Perikan. Trop.*, vol. 8, no. 1, p. 23, 2021, doi: 10.35308/jpt.v8i1.1923.

[12] W. Satriyo, "Gresik Regency in Numbers 2023," *Badan Pus. Stat. Kabupaten Gresik*, vol. 22, pp. 1–414, 2023.

[13] H. D. Armono, Sujantoko, Z. Hidayah, and N. I. Nuzula, "Hydro-oceanographic mapping to support coastal eco-tourism activities in Bawean Island, East Java," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 649, no. 1, 2021, doi: 10.1088/1755-1315/649/1/012036.

[14] Z. Hidayah, A. Romadhon, and Y. Witjarnoko, "Assessment of the Vulnerability of the Southern Coastal Area of Bawean Island to Sea Level Rise," *J. Perikan. Univ. Gadjah Mada*, vol. 20, no. 2, p. 79, 2019, doi: 10.22146/jfs.36109.

[15] M. A. F. Noor and A. Romadhon, "Analysis of Suitability and Environmental Carrying Capacity of Gili Noko Bawean Island as a Coastal Ecotourism Area," *Juv. Ilm. Kelaut. dan Perikan.*, vol. 1, no. 1, pp. 38–46, 2020, doi: 10.21107/juvenil.v1i1.6749.

[16] Trimanto and L. Hapsari, "Botanical survey in thirteen montane forests of bawean island nature reserve, East Java Indonesia: Flora diversity, conservation status, and bioprospecting," *Biodiversitas*, vol. 17, no. 2, pp. 832–846, 2016, doi: 10.13057/biodiv/d170261.

[17] C. S. U. Dewi, Sukandar, and C. J. Harsindhi, *Coral Reefs and Reef Fish of Bawean Island*. Malang: Universitas Brawijaya Press, 2018. [Online]. Available: https://books.google.co.id/books/about/Karang_dan_Ikan_Terumbu_Pulau_Bawean.html?id=6vdqDwAAQBAJ&redir_esc=y

[18] M. A. As'adi and G. MS, "Coral Reef Community Structure on Bawean Island, Gresik," 2020.

[19] LIPI, *Biodiversity Study in the Waters of Bawean Island*. 2011.

[20] Y. Yusra and H. Sulistiyowati, "Estimation of Carbon Stock in the Mangrove Ecosystem of Pasir Putih, Bawean Island, Sukaoneng Village," *Bioma J. Biol. dan Pembelajaran Biol.*, vol. 5, no. 2, pp. 112–120, 2020, doi: 10.32528/bioma.v5i2.4010.

[21] N. Fikroh, A. Hayati, and H. Zayadi, "Ethnobotany Study of Mangroves in Daun Village, Sangkapura District and Sukaoneng, Tambak, Bawean Island, Gresik Regency," *Jurmal Ilm. BIOSANTROPIS*, vol. 6, no. 1, pp. 26–31, 2021, doi: 10.33474/e-jbst.v6i2.293.

[22] S. B. Atmaja and D. Nugroho, "Reproductive Aspects of Layang Deles Fish (Decapterus macrosoma) and Siro Fish (Amblygaster sirm) for Management Consideration in the Java Sea," *J. Penelit. Perikan. Indones.*, vol. 1, no. 3, p. 1, 2017, doi: 10.15578/jppi.1.3.1995.1-10.

[23] A. Soedrijanto, T. Istiqomah, and F. D. Rizkina, "Consumer Acceptability Test of the Organoleptic Factors of Pindang Fish in Dedawang Village, Bawean Island, Indonesia," *Torani J.*

Fish. Mar. Sci., vol. 4, no. 1, pp. 25–38, 2020.

[24] U. Chodriyah and T. Hariati, "Small Pelagic Fish Catching Season in the Java Sea," *J. Penelit. Perikan. Indones.*, vol. 16, no. 3, pp. 217–223, 2010, doi: 10.29244/jmf.10.1.11-22.

[25] H. Widiyastuti, T. Noegroho, and N. Pangaribuan, "Characteristics of Small Pelagic Mini Purse Seine Fisheries in Rembang, Central Java," *Mar. Fish. J. Mar. Fish. Technol. Manag.*, vol. 14, no. 1, pp. 53–64, 2023, doi: 10.29244/jmf.v14i1.44310.

[26] R. D. B. Marpaung, S. H. Laksono, and B. Oktafiana, "Explorative Design with Monoline Technique on the Transformation of Beach Resort Sites on Noko Gili Bawean Island," *Tekstur (Jurnal Arsitektur)*, vol. 4, no. 1, pp. 21–30, 2023, doi: 10.31284/j.tekstur.2023.v4i1.4141.

[27] S. Sukandar, C. S. U. Dewi, and M. Handayani, "Utilization of Traditional Fishing Gear by Fishermen on Bawean Island, Gresik Regency," *Depik*, vol. 6, no. 3, pp. 205–213, 2017, doi: 10.13170/depik.6.3.7024.

[28] R. Muhartono, M. Mira, E. S. Luhur, and S. H. Suryawai, "Institutional Analysis of Energy Management as a Support for Marine Energy Development Policies," *J. Kebijak. Sos. Ekon. Kelaut. dan Perikan.*, vol. 4, no. 1, p. 43, 2014, doi: 10.15578/jksekp.v4i1.218.

[29] R. Muhartono and H. Suryawati, "Development of Renewable Energy for Small Islands," pp. 19–27, 2016.

[30] Rosidin, "The Values of Harmony in the Local Wisdom of Bawean Community, Gresik," *Al-Qalam*, vol. 21, no. 1, p. 129, 2016, doi: 10.31969/alq.v21i1.211.

[31] H. Jocom, D. D Kameo, I. Utami, and A. I. Kristijanto, "Water and Conflict: A Case Study in South Central Timor Regency," *J. Ilmu Lingkung.*, vol. 14, no. 1, p. 51, 2016, doi: 10.14710/jil.14.1.51-61.

[32] Pemkab Gresik, "Problems and Analysis of Strategic Issues," *RPJMN Kab Gresik 2016-2020*, 2016.

[33] K.- Karimah and I. Irjan, "Investigation of Iron Sand Prospects in Sungai Topo Village, Sungai Teluk Village, Sangkapura District, Gresik Regency using Magnetic Method," *J. Fis. Indones.*, vol. 22, no. 1, p. 17, 2020, doi: 10.22146/jfi.v22i1.49349.

[34] I. P. P. Salmon, "Actor Contestation in Marine Tourism Management: A Study at Dalegan Beach, Gresik," *Anterior J.*, vol. 23, no. 1, pp. 62–68, 2024, doi: 10.33084/anterior.v23i1.6224.

[35] R. Nisa and H. Wibisana, "Flood Risk Area Mapping as a Flood Risk Mitigation Effort in Bawean Island, Sangkapura District, and Tambak District with Information Systems," *Indones. J. Appl. Sci. Technol.*, vol. 5, no. 1, pp. 1–14, 2023, [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK558907/

[36] M. I. Sholik, Nus, F. Rosyid, K. Mufa'idah, T. Agustina, and U. R. Ashari, "Migration as Culture (Exploration of Social System in Bawean Island Community)," *Cakrawala*, vol. 10, no. 2, pp. 143–153, 2016, [Online]. Available: http://www.cakrawalajournal.org/index.php/cakrawala/article/view/39/37

[37] Y. Ernawan, "The Role of Kyai in the Divorce of Migrant Community in Bawean Island," *BioKultur*, vol. 5, no. 2, pp. 209–236, 2016.

[38] A. R. Patji, M. A. Humaedi, M. A. Marzuki, and S. Ali, "Survival Study: An Ethnographic Study of Culture." LIPI Press, pp. 1–140, 2010.

[39] H. Bulqiyah, S. Muadi, and G. T. I. Tawakkal, "Village Head Election and Marginal Community Participation: A Case Study on Bawean Island, Indonesia," *J. Wacana Polit.*, vol. 4, no. 1, pp. 68–80, 2019.

[40] S. Aswani, "Perspectives in coastal human ecology (CHE) for marine conservation," *Biol. Conserv.*, vol. 236, no. May, pp. 223–235, 2019, doi: 10.1016/j.biocon.2019.05.047.

[41] R. Hafsaridewi, B. Khairuddin, J. Ninef, A. Rahadiati, and H. E. Adimu, "Social-Ecological System (SES) Approach In Integrated Coastal Management," *Bul. Ilm. Mar. Sos. Ekon. Kelaut. dan Perikan.*, no. 021, pp. 61–74, 2018.

[42] R. L. Lekatompessy and E. E. Maturbongs, "Factors in Efforts to Address Coastal Erosion in the Coastal Area of Merauke Regency," *Dialogue J. Ilmu Adm. Publik*, vol. 3, no. 1, pp. 1–13, 2021, doi: 10.14710/dialogue.v3i1.10994.

[43] H. Manlea, L. Ledheng, and Y. M. Sama, "Factors Causing Coral Reef Ecosystem Damage in Wini Waters, Humusu C Village, North Insana District, North Central Timor Regency," *Bio-Edu J. Pendidik. Biol.*, vol. 1, no. 2, pp. 21–23, 2016, [Online]. Available: https://jurnal.unimor.ac.id/JBE/article/view/499

[44] O. M. Luthfi, V. L. Rahmadita, and D. Setyohadi, "Observing the Ecological Balance Condition of Coral Reefs in Sempu Island, Malang Using the Hard Coral Colony Area Approach (Scleractinia)," *J. Ilmu Lingkung.*, vol. 16, no. 1, p. 1, 2018, doi: 10.14710/jil.16.1.1-8.

[45] H. Al Imran, *Structural Maintenance & Beach Sustainability*, vol. 1, no. 1. Tahta Media Group, 2024.

[46] A. Suharsono *et al.*, "Supporting Marine Fishing Sustainably: A review of central and provincial government support for marine fisheries in Indonesia," *Int. Institue Sustain. Dev.*, no. July, 2021.

[47] L. Napitupulu *et al.*, "Trends in Marine Resources and Fisheries Management in Indonesia: A Review," *World Resour. Inst.*, 2022, doi: 10.46830/wrirpt.20.00064.

[48] A. Giron-Nava *et al.*, "Sustainable fisheries are essential but not enough to ensure well-being for the world's fishers," *Fish Fish.*, vol. 22, no. 4, pp. 812–821, 2021, doi: 10.1111/faf.12552.

[49] A. P. Cahyaningsih, A. K. Deanova, C. M. Pristiawati, Y. I. Ulumuddin, L. Kusumaningrum, and A. D. Setyawan, "Review: Causes and impacts of anthropogenic activities on mangrove deforestation and degradation in Indonesia," *Int. J. Bonorowo Wetl.*, vol. 12, no. 1, pp. 12–22, 2022, doi: 10.13057/bonorowo/w120102.

[50] H. Akram, S. Hussain, P. Mazumdar, K. O. Chua, T. E. Butt, and J. A. Harikrishna, "Mangrove Health: A Review of Functions, Threats, and Challenges Associated with Mangrove Management Practices," *Forests*, vol. 14, no. 9, pp. 1–38, 2023, doi: 10.3390/f14091698.

[51] P. T. Juwono and A. Subagiyo, *Integration of Watershed Management with Coastal Areas: Sustainability of Watershed Management to Ensure the Continuity of Coastal Resources*. Malang: UB Press, 2019.

[52] E. Schmaltz *et al.*, "Plastic pollution solutions: emerging technologies to prevent and collect marine plastic pollution," *Environ. Int.*, vol. 144, no. August, 2020, doi: 10.1016/j.envint.2020.106067.

[53] N. Fikriyah, C. Meidiana, and K. E. Sari, "Determination of Waste Collection System and Temporary Disposal Sites in Sawahmulya Village, Sangkapura," *Tata Kota dan Drh.*, vol. 14, no. 1, pp. 35–46, 2022, doi: 10.21776/ub.takoda.2022.014.01.5.

[54] R. P. Pratama and T. A. Rachmanto, "Urban Waste Management Performance in Gresik Subdistrict," *J. Indones. Sos. Teknol.*, vol. 4, no. 01, pp. 102–120, 2023, doi: 10.36418/jist.v4i1.573.

[55] N. A. Fadzil, A. A. Rahman, and A. Abdul-Rahman, "Social and Ecological Impacts of Marine Energy Development in Malaysia," *J. Eng. Sci. Res.*, vol. 6, no. 5, pp. 29–39, 2022, doi: 10.26666/rmp.jesr.2022.5.4.

[56] Z. Hidayah, D. M. Rosyid, and H. D. Armono, "Planning for Sustainable Small Island Management: Case Study of Gili Timur Island East Java Province Indonesia," *Procedia - Soc. Behav. Sci.*, vol. 227, no. November 2015, pp. 785–790, 2016, doi: 10.1016/j.sbspro.2016.06.146.

[57] N. Mehtari, M. Kahani, and M. Zamen, "Energy, environmental, and economic analysis of a new configuration multi-stage flash distillation unit coupled with steam power plant," *Case Stud. Therm. Eng.*, vol. 50, no. August, p. 103456, 2023, doi: 10.1016/j.csite.2023.103456.

[58] N. A. Rahman *et al.*, "Continuous electrocoagulation treatment system for partial desalination of tropical brackish peat water in Sarawak coastal peatlands," *Sci. Total Environ.*, vol. 880, no. March, 2023, doi: 10.1016/j.scitotenv.2023.163517.

[59] H. A. L. Ouali, M. I. Soomro, S. Touili, M. Eltaweel, and A. Alami Merrouni, "Performance investigation of seawater desalination system powered by central receiver concentrated solar thermal plant," *Appl. Therm. Eng.*, vol. 225, no. February, p. 120165, 2023, doi: 10.1016/j.applthermaleng.2023.120165.

[60] O. R. P. Mangosing *et al.*, "Techno-economic analysis on the production of domestic water using solar-driven membrane seawater desalination device in the Philippines," *Case Stud. Therm. Eng.*, vol. 41, no. November 2022, p. 102575, 2023, doi: 10.1016/j.csite.2022.102575.

[61] A. Liponi, A. Baccioli, D. Vera, and L. Ferrari, "Seawater desalination through reverse osmosis driven by ocean thermal energy conversion plant: Thermodynamic and economic feasibility," *Appl. Therm. Eng.*, vol. 213, no. February, p. 118694, 2022, doi: 10.1016/j.applthermaleng.2022.118694.

[62] E. Santos, "Innovative solutions for coastal and offshore infrastructure in seawater mining: Enhancing efficiency and environmental performance," *Desalination*, vol. 575, no. January, p. 117282, 2024, doi: 10.1016/j.desal.2023.117282.

[63] Y. Jacobson *et al.*, "Desalination brines as a potential vector for CO2 sequestration in the deep sea," *Desalination*, vol. 574, no. December 2023, p. 117234, 2024, doi: 10.1016/j.desal.2023.117234.

[64] K. Sztekler *et al.*, "Hybrid desalination system for Baltic Sea water: A preliminary study," *Desalination*, vol. 574, no. December 2023, 2024, doi: 10.1016/j.desal.2023.117269.

[65] S. T. Abdul-Hussein *et al.*, "Prospects of forward osmosis-based membranes for seawater mining: Economic analysis, limitations and opportunities," *Desalination*, vol. 579, no. December 2023, p. 117477, 2024, doi: 10.1016/j.desal.2024.117477.

[66] Y. Zhang, H. Watanabe, J. Shi, H. Morikawa, and C. Zhu, "Innovative mushroom-like hemp-based evaporators enhanced by biochar for efficient seawater desalination," *Desalination*, vol. 576, no. January, p. 117342, 2024, doi: 10.1016/j.desal.2024.117342.

[67] Q. Ma *et al.*, "Theoretical, numerical and experimental research on an innovative ocean thermal energy conversion coupled VMD desalination system," *Desalination*, vol. 571, no. May 2023, p. 117097, 2024, doi: 10.1016/j.desal.2023.117097.

[68] R. J. Ohlund, B. H. Dahdah, G. R. Guillen, and A. E. Childress, "Augmenting ocean water desalination with potable reuse: Concept feasibility in terms of cost and environmental impacts," *Desalination*, vol. 569, no. May 2023, p. 116941, 2024, doi: 10.1016/j.desal.2023.116941.

[69] M. Ye, X. Wang, W. Jin, Y. Yan, T. Zhang, and X. Liu, "Generation of H2O2 and halogenated by-products at the evaporator surface during seawater desalination based on air-water interfacial solar heating," *Desalination*, vol. 580, no. December 2023, p. 117499, 2024, doi: 10.1016/j.desal.2024.117499.

[70] Y. Jin *et al.*, "Geographically constrained resource potential of integrating floating photovoltaics in global existing offshore wind farms," *Adv. Appl. Energy*, vol. 13, no. January, p. 100163, 2024, doi: 10.1016/j.adapen.2024.100163.

[71] M. Á. Muñoz-García, L. Fialho, G. P. Moreda, and F. Baptista, "Assessment of the impact of utility-scale photovoltaics on the surrounding environment in the Iberian Peninsula. Alternatives for the coexistence with agriculture," *Sol. Energy*, vol. 271, no. January, 2024, doi: 10.1016/j.solener.2024.112446.

[72] K. Mohamed, H. Shareef, I. Nizam, A. B. Esan, and A. Shareef, "Operational Performance Assessment of Rooftop PV Systems in the Maldives," *Energy Reports*, vol. 11, no. January, pp. 2592–2607, 2024, doi: 10.1016/j.egyr.2024.02.014.

[73] M. R. Elkadeem *et al.*, "Techno-enviro-socio-economic design and finite set model predictive current control of a grid-connected large-scale hybrid solar/wind energy system: A case study of Sokhna Industrial Zone, Egypt," *Energy*, vol. 289, no. December 2023, p. 129816, 2024, doi: 10.1016/j.energy.2023.129816.

[74] R. A. T. Gonocruz *et al.*, "A multi-scenario evaluation of the energy transition mechanism in the Philippines towards decarbonization," *J. Clean. Prod.*, vol. 438, no. January, p. 140819, 2024, doi: 10.1016/j.jclepro.2024.140819.

[75] D. Howe, J. R. Nader, and G. Macfarlane, "Performance analysis of a floating breakwater integrated with multiple oscillating water column wave energy converters in regular and irregular seas," *Appl. Ocean Res.*, vol. 99, no. March, p. 102147, 2020, doi: 10.1016/j.apor.2020.102147.

[76] L. Ciappi *et al.*, "Wave-to-wire models of wells and impulse turbines for oscillating water column wave energy converters operating in the Mediterranean Sea," *Energy*, vol. 238, p. 121585, 2022, doi: 10.1016/j.energy.2021.121585.

[77] Z. Liu, C. Xu, K. Kim, X. Zhang, and D. Ning, "Hydrodynamic and energy-harvesting performance of an isolated oscillating water column device: An experimental study," *Coast. Eng.*, vol. 189, no. January, p. 104459, 2024, doi: 10.1016/j.coastaleng.2024.104459.

[78] Z. Liu, C. Xu, X. Zhang, and D. Ning, "Experimental study on an isolated oscillating water column wave energy converting device in oblique waves," *Renew. Sustain. Energy Rev.*, vol. 184, no. February, p. 113559, 2023, doi: 10.1016/j.rser.2023.113559.

[79] I. Alifdini, N. A. P. Iskandar, A. W. Nugraha, D. N. Sugianto, A. Wirasatriya, and A. B. Widodo, "Analysis of ocean waves in 3 sites potential areas for renewable energy development in Indonesia," *Ocean Eng.*, vol. 165, no. March, pp. 34–42, 2018, doi: 10.1016/j.oceaneng.2018.07.013.

[80] W. Kompor, C. Ekkawatpanit, and D. Kositgittiwong, "Assessment of ocean wave energy resource potential in Thailand," *Ocean Coast. Manag.*, vol. 160, no. March, pp. 64–74, 2018, doi: 10.1016/j.ocecoaman.2018.04.003.

[81] A. M. Contla *et al.*, "Extreme nonlinear waves in external gravitational-like potentials: Possible applications for the optical soliton supercontinuum generation and the ocean coast line protection," *Optik (Stuttg).*, vol. 161, pp. 187–195, 2018, doi: 10.1016/j.ijleo.2018.01.031.

[82] Faulincia, "Potential Study of Wave Power Plant with Oscillating Water Column Method in Kendari Waters, Indonesia," *Semin. Nas. Cendekiawan*, pp. 42–50, 2015, doi: 2460-8696.

[83] L. E. Safitri, M. I. Jumarang, and A. Apriansyah, "Potential Study of Wave Power Electricity with Oscillating Water Column System in the Coastal Waters of West Kalimantan," *Positron*, vol. 6, no. 1, pp. 8–16, 2016, doi: 10.26418/positron.v6i1.14536.

[84] M. Sidik and N. Sinaga, "Potential Utilization of Ocean Waves into Electrical Energy Using the Oscillating Water Column Method on Bawean Island, Gresik," *J. Energi Baru dan Terbarukan*, vol. 4, no. 2, pp. 132–144, 2023, doi: 10.14710/jebt.2023.17306.

[85] A. Djunaedi and M. N. Basuki, "Coastal Area Development Planning," *Media Sains*, vol. 10, no. 2, pp. 97–104, 2002.

[86] Y. Asyiawati and L. S. Akliyah, "Identification of the Impact of Coastal Ecosystem Function Changes on the Environment in the Coastal Area of Muaragembong District," *J. Perenc. Wil. dan Kota*, vol. 14, no. 1, pp. 1–13, 2016.

[87] S. Laming and M. Rahim, "The Impact of Coastal Development on Economy and Environment," *J. Sipil Sains*, vol. 10, no. September, pp. 133–140, 2020.