

Maritime Economic Transformation through Marine Engineering Innovation

Aerin Regina Putri^{1*}, Putri Adelia Z²

¹Global Scholarly Research Institute, Indonesia

²Universitas Hasanuddin

*Correspondence author: aerinregina2@gmail.com

Abstract

Maritime economic transformation is one of the important strategies in encouraging sustainable economic growth, especially for archipelagic countries with large potential for marine resources. Innovation in the field of marine engineering plays a significant role in increasing efficiency, productivity, and added value in the maritime sector. This article discusses the role of marine engineering innovation in driving maritime economic transformation through the development of coastal and offshore infrastructure, the use of modern marine technology, and the improvement of the quality of human resources. The discussion shows that the integration of marine engineering innovation with maritime economic policies is able to strengthen competitiveness, create entrepreneurial opportunities, and support sustainable blue economy development.

Keywords: Maritime Economy, Marine Engineering, Technological Innovation, Sustainable Development, Blue Economy

1. Introduction

The maritime sector has a strategic role in the global and national economy, especially for countries with large sea areas and long coastlines. The sea functions not only as a geographical space, but also as an economic resource that supports various productive activities, such as marine transportation, port management, fisheries, offshore energy, and marine tourism. These activities contribute significantly to economic growth, job creation, and increased connectivity between regions and countries [1].

Despite its great potential, the development of the maritime economy still faces various

challenges. Degradation of marine and coastal environments, limited maritime infrastructure, and low utilization of technology are the main obstacles in optimizing this sector. In addition, climate change and the increasing intensity of extreme marine events demand a more adaptive and sustainable approach to development. These challenges show that maritime economic development cannot be carried out conventionally, but requires innovation that is able to integrate technical, economic, and environmental aspects [2].

In this context, marine engineering has an important role as a field that bridges the needs of economic development with the complex characteristics of the marine environment. Through technological innovation, marine engineering not only functions as an engineering discipline, but also as a driver of maritime economic transformation. Innovations in offshore structure design, sustainable coastal protection, utilization of renewable marine energy, and digitalization of maritime systems open up new opportunities to improve the efficiency, competitiveness, and sustainability of the maritime economy. Therefore, the discussion of the role of marine engineering innovation in the transformation of the maritime economy is important to understand the direction of maritime development in the future [3].

2. Materials and Methods

The descriptive method is used to describe the development of marine engineering and its contribution to various maritime economic activities, such as marine infrastructure development, coastal area management, marine transportation, and the utilization of marine resources. Through a systematic description, it can be understood how marine engineering develops in line with economic needs and increasingly complex marine environmental challenges. Furthermore, an analytical approach is used to delineate the linkage between marine technology innovation and increased efficiency, productivity, and sustainability of the maritime sector [4].

Discussion materials were obtained through extensive literature search, including reference books, scientific journal articles, policy reports, development planning documents, and other publications relevant to maritime economics, marine engineering, technological innovation, and sustainable development. These sources include national and global perspectives, providing a comprehensive picture of the position and role of the maritime sector in the modern economy. This cross-source approach allows for a more comprehensive understanding of the dynamics of maritime economic transformation in various regional contexts [5].

The analysis process is carried out by identifying various forms of innovation in marine engineering, such as the development of adaptive maritime infrastructure, the use of digital technology and marine monitoring systems, and the application of environmentally friendly concepts in marine engineering. These innovations are then linked to aspects of economic growth, operational efficiency, increased competitiveness, and environmental sustainability. Through this approach, the role of marine engineering can be understood not only as a technical field, but as an integral part of a maritime economic system that is intertwined with social, environmental, and policy aspects of development [1].

This descriptive-analytical approach allows for an integrated understanding of how marine engineering innovations contribute to driving structural and sustainable transformation of the maritime economy. By placing marine engineering within the broader framework of development, this discussion confirms that the progress of the maritime sector is highly dependent on the ability to integrate technological innovations with economic needs and long-term sustainability principles [6].

3. Results

Marine engineering innovations play a significant role in driving the transformation of the maritime economy through improving the quality, efficiency, and resilience of maritime

infrastructure. These innovations can be seen in the development of modern ports that implement technology-based planning and operation systems, coastal structures designed to be adaptive to abrasion and sea level rise, and offshore facilities that are able to operate safely under extreme sea conditions. The application of innovative engineering design allows for the optimization of the function of maritime infrastructure while reducing the risk of damage due to environmental factors. Infrastructure supported by cutting-edge technology directly contributes to increasing operational efficiency and reducing logistics costs, thereby strengthening the competitiveness of the maritime sector on a national and global scale [7].

3.1 Improved Efficiency of Maritime Infrastructure

The development of modern ports and marine structures designed with cutting-edge engineering approaches shows a significant increase in operational efficiency in the maritime sector. The application of adaptive structural design that takes into account wave dynamics, tides, and climate change allows maritime infrastructure to operate more optimally and resilient to extreme sea conditions. In addition, the use of corrosion-resistant materials, such as high-performance concrete, special-coated steel, and composite materials, has been proven to be able to extend the service life of infrastructure while reducing the frequency of repairs and operational disruptions.

Efficiency can also be seen from the reduction in maritime infrastructure maintenance costs. With more advanced construction and material technologies, maintenance costs can be reduced by about 15–25% compared to conventional infrastructure that still relies on traditional materials and designs. This cost reduction not only impacts operational budget savings, but also improves the reliability of infrastructure in the long run, so that shipping and logistics activities can take place more smoothly and sustainably [8].

In addition to the cost aspect, increasing port operational capacity is also an important impact of marine engineering innovation. The modernization of the dock system, the optimization of the port layout, and the integration of automation technology and port management allow an increase in loading and unloading capacity by about 20–30%. This increase in capacity directly contributes to the smooth flow of goods, the reduction of ship waiting times, and the increase in the productivity of the maritime logistics chain. On a broader scale, the efficiency of the maritime infrastructure strengthens the port's competitiveness as a major trade node and encourages sustainable maritime economic growth [9].

3.1.1 Optimization of Marine Resource Management Based on Digital Technology

The use of numerical modeling, real-time marine monitoring systems, and the application of automation in the field of marine engineering have brought significant changes in the planning accuracy and effectiveness of marine area monitoring. Numerical modeling allows simulation of oceanographic conditions, such as waves, currents, tides, and the interaction of structures with the marine environment, so that maritime infrastructure planning can be carried out more precisely before the construction stage. Through these simulations, various risk scenarios can be anticipated from the outset, so that the potential for design errors and technical inconsistencies can be minimized.

Sensor-based marine monitoring systems and satellite technology that operate in real-time also play an important role in supporting the management of marine areas. The data obtained in an ongoing manner allows for direct monitoring of marine environmental conditions and infrastructure performance, so that responses to changing conditions can be carried out quickly and precisely. The integration of monitoring data with automation systems allows the

monitoring process to be more efficient, reduces reliance on manual interventions, and improves operational safety in high-risk marine areas [10].

This data-driven approach has been shown to reduce the risk of structural failure and planning errors by about 20% compared to conventional approaches that rely on limited data and periodic observations. In addition to improving infrastructure reliability, the application of digital technology in marine engineering also contributes to the effectiveness of sustainable management of marine resources. Accurate and up-to-date information supports more responsible decision-making, both in infrastructure development and in the use of marine resources, so that the balance between economic interests and environmental conservation can be better maintained [11].

3.1.2 Development of the Renewable Marine Energy Sector

Innovation in marine engineering is driving the development of the marine energy sector as one of the important pillars in the transformation of the maritime economy. The development of wave energy technology, ocean current energy, and offshore wind energy opens up opportunities to utilize marine natural potential that has not been optimally utilized so far. Through an engineering approach that is adaptive to oceanographic characteristics and marine environmental conditions, marine energy technologies can be designed to operate more efficiently, safely, and sustainably.

In general, the marine energy sector shows a potential contribution of around 10–15% to the maritime energy mix. This contribution is important in supporting the transition to a low-carbon energy system and reducing dependence on fossil energy sources. The use of marine energy not only provides benefits in terms of energy security, but also supports efforts to reduce greenhouse gas emissions in line with the sustainable development agenda and the blue economy [12].

In addition to contributing to the provision of clean energy, the development of the marine energy sector also creates new economic opportunities, especially in coastal and archipelagic areas. The planning, construction, operation, and maintenance of marine energy installations encourage the formation of an economic value chain involving various sectors, such as the manufacturing industry, engineering services, logistics, and local labor. Thus, marine engineering innovations not only contribute to the diversification of energy sources, but also play a role in job creation, increasing the income of coastal communities, and strengthening a more inclusive and sustainable maritime economic structure [13].

3.1.3 Increased Competitiveness of the Maritime Economy

The integration of marine engineering innovations with logistics systems and the maritime industry plays an important role in increasing the competitiveness of the maritime sector as a whole. The application of marine engineering technology connected to modern logistics systems, such as smart ports, digital-based ship traffic management, and optimization of marine distribution networks, allows for the creation of a more efficient and coordinated supply chain. This integration helps reduce operational bottlenecks, accelerate the flow of goods, and improve the reliability of marine transportation services.

The efficiency of the marine supply chain resulting from the integration has a direct impact on reducing logistics costs. Optimization of port infrastructure design, increased loading and unloading capacity, and the use of data-driven automation and monitoring systems allow for a reduction in ship waiting times and operational costs. This reduction in logistics costs not only improves the internal efficiency of the maritime sector, but also strengthens connectivity between regions and supports the smooth distribution of goods on a national and international scale.

In the medium term, improved efficiency and integration of maritime systems is expected to contribute to an increase in the value of the maritime economy by about 5–10%. This contribution reflects the strategic role of marine engineering as a driver of innovation-based maritime economic transformation. With a more efficient logistics system and an integrated maritime industry, the maritime sector can function more competitively in supporting trade, industrial growth, and sustainable economic development [14].

4. Discussion

The transformation of the maritime economy is largely determined by the ability to integrate marine engineering innovations into a comprehensive development strategy framework. Marine engineering can no longer be understood solely as a discipline that focuses on aspects of the design and construction of marine infrastructure, but has evolved to become an integral part of the broader maritime economic system. In this context, marine engineering innovation plays a key role as the main driver of the modernization of the maritime sector through increasing efficiency, productivity, and competitiveness. The use of cutting-edge technology allows the maritime sector to adapt to global dynamics, such as increasing volume of maritime trade, climate change, and the increasing demands for logistics efficiency.

The role of marine engineering innovation as a catalyst for economic transformation can be seen from its ability to accelerate the adoption of new technologies in various maritime subsectors. Innovations in port design, offshore structures, and marine transportation systems are driving the creation of a more integrated maritime economic ecosystem. Adaptively designed and technology-based infrastructure not only improves operational performance, but also expands investment opportunities and innovation-based maritime industry development. Thus, marine engineering contributes directly to the formation of a more resilient and future-oriented maritime economic structure.

In addition to having an economic impact, marine engineering innovations also have significant implications for environmental sustainability. An engineering approach that considers ecological aspects allows the use of marine resources to be carried out more responsibly. The application of environmentally friendly technology in coastal protection, coastal area management, and the development of renewable marine energy shows that maritime economic growth can go hand in hand with efforts to preserve marine ecosystems. This approach is in line with the principles of the blue economy that places environmental sustainability as the main foundation in the development of the marine and maritime sectors.

Within the framework of the blue economy, marine engineering innovation serves as an instrument to balance economic and ecological interests. Coastal engineering that is adaptive to climate change, the use of marine energy as a source of clean energy, and the use of technology-based marine monitoring systems are examples of how marine engineering approaches can support long-term economic growth without causing environmental degradation. Thus, marine engineering not only plays a role in creating economic value, but also in maintaining the sustainability of marine resources for future generations.

Nevertheless, the implementation of marine engineering innovations in the transformation of the maritime economy still faces various challenges. Limited investment is one of the main obstacles, especially in technology development that requires high initial costs. In addition, the technology gap between developed and developing regions can hinder the equitable distribution of the benefits of marine engineering innovation. Another challenge that is no less important is the need for human resources who have multidisciplinary competencies, who are

able to integrate technical, economic, and environmental aspects in the management of the maritime sector.

Therefore, close collaboration between government, industry, and educational institutions is a key factor in driving an inclusive and sustainable transformation of the maritime economy. The government plays a role in creating policies and regulations that support innovation, industry contributes through investment and technology application, while educational institutions play a role in human resource capacity building and applied research. This synergy between actors is expected to accelerate the adoption of marine engineering innovations, strengthen the competitiveness of the maritime economy, and ensure the sustainability of the development of the marine sector in the long term [15].

5. Conclusions

The transformation of the maritime economy through marine engineering innovation is an increasingly crucial strategy in encouraging sustainable economic growth in the midst of growing global dynamics. Innovations in the design and development of maritime infrastructure, such as modern ports, offshore structures, and adaptive coastal protection systems, have opened up opportunities to increase operational efficiency and optimize the use of marine resources. In addition, the application of digital technology in the planning, construction, and management of maritime infrastructure allows for more accurate, efficient, and data-driven decision-making processes, thereby increasing the competitiveness of the maritime sector as a whole.

The use of renewable marine energy, such as wave, current, and tidal energy, also shows great potential in supporting the transformation of an environmentally friendly maritime economy. The development of this technology not only contributes to the diversification of energy sources, but also in line with global efforts to reduce dependence on fossil energy and reduce carbon emissions. Thus, marine engineering innovation plays a dual role, namely as a driver of economic growth as well as an instrument to achieve environmental sustainability in the development of the maritime sector.

In the context of development, marine engineering serves as a link between economic needs and the characteristics of the marine environment which are dynamic, complex, and vulnerable to climate change. An integrated and innovative engineering approach allows maritime development to be carried out by considering technical, economic, and ecological aspects in a balanced manner. Through this approach, the maritime sector not only develops as a motor of economic growth, but also as a pillar of sustainable development that is able to maintain a balance between resource exploitation and the preservation of marine ecosystems.

Going forward, the success of maritime economic transformation is highly dependent on strengthening innovation capacity, improving the quality of human resources, and sustainable cross-sector collaboration. Investment in research and development, marine engineering education that is adaptive to technological developments, and synergy between government, industry, and academic institutions are key factors in accelerating the adoption of innovation. With the right policy support and solid cooperation, the maritime economy is expected to be able to grow in an adaptive, inclusive, and globally competitive manner, while making a real contribution to community welfare and the sustainability of the marine environment.

References

- [1] Y. Guo, M.-M. Yu, and K. F. See, "Developing a sustainable development goals index for OECD countries: An effectiveness-based hierarchical data envelopment analysis," *Environ. Sci.*

- Policy*, vol. 160, p. 103836, 2024, doi: <https://doi.org/10.1016/j.envsci.2024.103836>.
- [2] P. Morone *et al.*, “The European Bioeconomy strategy revision: an opportunity to go against the tide and secure a sustainable future,” *Clean. Circ. Bioeconomy*, p. 100204, 2026, doi: <https://doi.org/10.1016/j.clcb.2026.100204>.
- [3] W. Abu Jadayil, G. Shwaheen, M. Ramadan, and M. Alkhedher, “Beyond energy: Review of innovations in green technologies for resilience and environmental sustainability,” *Energy Reports*, vol. 13, pp. 5410–5426, 2025, doi: <https://doi.org/10.1016/j.egyr.2025.04.067>.
- [4] M. Mozuni and W. Jonas, “An Introduction to the Morphological Delphi Method for Design: A Tool for Future-Oriented Design Research,” *She Ji J. Des. Econ. Innov.*, vol. 3, no. 4, pp. 303–318, 2017, doi: <https://doi.org/10.1016/j.sheji.2018.02.004>.
- [5] B. Matovu, T. A. Mim, and B. Lutalo, “Where and how can Africa and India leverage the blue economy opportunities of the Indian Ocean region as a driver for sustainable development and partnerships?,” *Sustain. Futur.*, vol. 10, p. 101218, 2025, doi: <https://doi.org/10.1016/j.sftr.2025.101218>.
- [6] X. Li, H. Gao, C. Zhang, and X. Shi, “Multi-pathway nutrient replenishment mechanisms sustaining the transboundary green tides region in the Southern Yellow sea,” *Mar. Environ. Res.*, vol. 216, p. 107865, 2026, doi: <https://doi.org/10.1016/j.marenvres.2026.107865>.
- [7] J. Monios, “Chapter 2 - Environmental governance in shipping and ports: Sustainability and scale challenges,” in *Maritime Transport and Regional Sustainability*, A. K. Y. Ng, J. Monios, and C. Jiang, Eds., Elsevier, 2020, pp. 13–29. doi: <https://doi.org/10.1016/B978-0-12-819134-7.00002-2>.
- [8] M. Abbas and M. Shafiee, “An overview of maintenance management strategies for corroded steel structures in extreme marine environments,” *Mar. Struct.*, vol. 71, p. 102718, 2020, doi: [10.1016/j.marstruc.2020.102718](https://doi.org/10.1016/j.marstruc.2020.102718).
- [9] S. F. Ezzahra, B. Abdelouahad, M. Khalifa, and Q. Mohammed, “Optimizing Port Operations: Synchronization, Collision Avoidance, and Efficient Loading and Unloading Processes,” *Int. J. Adv. Comput. Sci. Appl.*, 2023, doi: [10.14569/ijacsa.2023.0140768](https://doi.org/10.14569/ijacsa.2023.0140768).
- [10] Y. Li, M. Ong, and T. Tang, “A numerical toolbox for wave-induced seabed response analysis around marine structures in the OpenFOAM® framework,” *Ocean Eng.*, 2020, doi: [10.1016/j.oceaneng.2019.106678](https://doi.org/10.1016/j.oceaneng.2019.106678).
- [11] A. Tzachor, O. Hendel, and C. Richards, “Digital twins: a stepping stone to achieve ocean sustainability?,” *npj Ocean Sustain.*, vol. 2, 2023, doi: [10.1038/s44183-023-00023-9](https://doi.org/10.1038/s44183-023-00023-9).
- [12] M. Garba, “Marine Renewable Energy and Economic Sustainability: Policy Frameworks for Scaling Offshore Wind and Tidal Power,” *Sprun J. Arts, Humanit. Soc. Sci.*, 2025, doi: [10.55559/sjahss.v4i7.538](https://doi.org/10.55559/sjahss.v4i7.538).
- [13] A. Gilau and P. Failler, “Economic assessment of sustainable blue energy and marine mining resources linked to African Large Marine Ecosystems,” *Environ. Dev.*, vol. 36, p. 100548, 2020, doi: [10.1016/j.envdev.2020.100548](https://doi.org/10.1016/j.envdev.2020.100548).
- [14] G. Xiao, Y. Wang, R. Wu, J. Li, and Z. Cai, “Sustainable Maritime Transport: A Review of Intelligent Shipping Technology and Green Port Construction Applications,” *J. Mar. Sci. Eng.*, 2024, doi: [10.3390/jmse12101728](https://doi.org/10.3390/jmse12101728).
- [15] Q. Shao, L. Chen, R. Zhong, and H. Weng, “Marine economic growth, technological innovation, and industrial upgrading: A vector error correction model for China,” *Ocean Coast. Manag.*, vol. 200, p. 105481, 2021, doi: [10.1016/j.ocecoaman.2020.105481](https://doi.org/10.1016/j.ocecoaman.2020.105481).