

Analysis of Ocean Wave Energy Utilization for Renewable Electricity Generation

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Abstract: The growing global demand for electricity, coupled with the depletion of fossil fuel reserves and increasing environmental concerns, has accelerated the development of sustainable and low-carbon energy sources. Among the available renewable energy resources, ocean wave energy represents a promising alternative due to its abundant availability and substantial energy potential, particularly in coastal and island regions. This study examines the potential of ocean wave energy as a renewable source of electricity and reviews the technologies employed for its conversion. Through Wave Energy Converter (WEC) systems, the kinetic and potential energy contained in ocean waves can be captured and converted into mechanical energy, which is subsequently transformed into electrical power. The utilization of ocean wave energy offers several potential benefits, including reduced greenhouse gas emissions, decreased dependence on fossil fuels, and increased energy diversification. Nevertheless, its large-scale implementation remains constrained by high capital and maintenance costs, variability in wave conditions, technological limitations, and the corrosive effects of marine environments. Continued technological innovation and further research are therefore essential to enhance conversion efficiency, system reliability, durability, and economic feasibility. The development of effective wave energy technologies could contribute significantly to a more resilient, sustainable, and environmentally responsible future energy system.

Keywords: Ocean Wave Energy; Renewable Energy; Electricity Generation; Wave Energy Converter; Coastal Regions

1. Introduction

The continuous growth in electricity demand has intensified the need for energy systems that are not only reliable but also environmentally sustainable. Electricity is fundamental to economic activity, industrial development, transportation, household consumption, and public services. However, the persistence of fossil-fuel-based electricity generation presents two major challenges: the finite nature of fossil resources and the environmental consequences associated with their use. In particular, the combustion of fossil fuels contributes substantially to greenhouse gas emissions and environmental degradation. Consequently, the transition toward renewable energy has become an increasingly important strategy for improving the sustainability and long-term resilience of modern energy systems [1].

Marine renewable energy is a promising but underutilized resource. As an archipelagic country with extensive marine areas, Indonesia has favorable conditions for developing ocean-based energy technologies. Among these resources, ocean wave energy is particularly promising because wave motion contains kinetic and potential energy that can be converted into electricity. This resource can support energy diversification and reduce dependence on fossil fuels, especially in coastal and island regions where conventional electricity infrastructure may be limited or costly to expand. Wave energy can be converted into electricity using *Wave Energy Converter* (WEC) technologies, including *oscillating water column*, *point absorber*, and *overtopping* systems. However, their performance depends on site-specific factors such as wave height, wave period, water depth, and environmental conditions. Wave energy development also faces challenges related to variable electricity generation, corrosion, extreme wave conditions, installation complexity, and high investment and maintenance costs. Therefore, evaluating wave energy requires consideration of both resource availability and technological and economic feasibility. Accordingly, this study analyzes the utilization of ocean wave energy for

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<https://doi.org/10.20956>

Received: 2026-05-25; Accepted: 2026-08-24; Published: 2026-08-29;

Journal of Wave Energy Systems and Technology | ISSN: -

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renewable electricity generation by examining its energy potential, conversion technologies, technical challenges, and prospects for supporting a more diversified and sustainable energy system [2].

2. Materials and Methods

This study employed a qualitative literature review method to examine the utilization of ocean wave energy for renewable electricity generation, focusing on wave energy potential, conversion technologies, and the technical, environmental, and economic factors affecting their implementation. Secondary data were obtained from relevant scientific publications, including peer-reviewed journal articles, conference papers, academic books, technical reports, and publications from recognized energy and marine research institutions, using keywords such as *ocean wave energy*, *wave energy conversion*, *Wave Energy Converter*, *renewable electricity generation*, *wave energy potential*, and *marine renewable energy* [3].

The literature was selected based on its relevance, scientific credibility, and contribution to understanding ocean wave energy, while studies unrelated to wave energy or its application to electricity generation were excluded. The selected literature was analyzed using thematic and comparative approaches by examining wave characteristics and energy potential, comparing WEC technologies based on their operating principles, conversion mechanisms, technological characteristics, and site suitability, and assessing factors affecting system performance, including wave variability, conversion efficiency, structural durability, corrosion, maintenance requirements, and installation conditions. Finally, the findings were synthesized to evaluate the feasibility of ocean wave energy based on resource potential, technological suitability, system reliability, and economic feasibility, providing a basis for identifying its opportunities and limitations, particularly in coastal and island regions [4].

3. Results

The analysis of the selected literature shows that ocean wave energy has considerable potential as a renewable source of electricity, particularly in coastal and island regions. The amount of energy that can be generated depends mainly on wave height, wave period, wave direction, and the consistency of wave conditions. Several *Wave Energy Converter* (WEC) technologies, including *point absorber*, *oscillating water column*, and *overtopping* systems, can be used to convert wave energy into electricity. Each technology has a different operating principle and requires specific site conditions; therefore, its suitability is strongly influenced by local wave characteristics, water depth, and environmental conditions. The results also indicate that variations in wave conditions can cause fluctuations in electricity output, while exposure to seawater, corrosion, and extreme wave conditions may affect equipment performance, durability, and system reliability [5].

In addition to technical factors, economic considerations play an important role in the development of wave energy systems. High investment, installation, operation, and maintenance costs remain challenges for large-scale implementation. However, improvements in WEC design, energy conversion efficiency, material durability, and system control have the potential to enhance system performance and economic feasibility. Overall, the findings indicate that ocean wave energy has promising potential for renewable electricity generation, but its successful implementation depends on the availability of suitable wave resources, appropriate WEC technology, reliable system performance, and economic feasibility. Thus, wave energy can contribute to renewable energy diversification, particularly in coastal and island regions with favorable wave conditions [6].

4. Discussion

The findings indicate that ocean wave energy has meaningful potential as a renewable electricity source, particularly in coastal and island regions, although its performance depends strongly on local wave characteristics such as wave height, wave period, and seasonal variability. In Indonesia, wave conditions are influenced by the monsoon system, resulting in significant spatial and seasonal differences in wave-energy potential. Therefore, long-term resource assessment is essential for identifying suitable locations and selecting appropriate *Wave Energy Converter* (WEC) technologies. Different WEC configurations respond differently to wave conditions, making site-specific design more appropriate than the use of a single standardized technology. Optimization of device geometry, power take-off (PTO) systems, and control strategies can further improve energy capture and operational stability. However, variations in wave conditions can still cause fluctuations in

electricity output, highlighting the importance of advanced control systems, wave prediction, and appropriate energy management when integrating wave power into electrical grids [7].

The reliability of WEC systems is also affected by harsh marine conditions, including seawater exposure, corrosion, extreme waves, and repeated mechanical loading, which may increase maintenance requirements and reduce equipment lifetime. At the same time, improving structural survivability may involve a trade-off with energy capture under normal operating conditions. In Indonesia, these challenges are particularly relevant because, despite extensive marine resources and several regions with promising wave-energy potential, large-scale commercial deployment remains limited. In addition, high capital, installation, and maintenance costs continue to affect the economic feasibility of wave energy. Therefore, future development should integrate long-term resource mapping, site-specific technology selection, WEC and PTO optimization, durable materials, and techno-economic assessment. Such an integrated approach can improve system reliability and feasibility while supporting the diversification of Indonesia's renewable electricity supply [8].

5. Conclusion

This study concludes that ocean wave energy has significant potential as a renewable source of electricity, particularly in coastal and island regions with favorable wave conditions. Its effectiveness depends on the characteristics of the available wave resource and the suitability of the selected *Wave Energy Converter* (WEC) technology. Since different WEC configurations have different operating characteristics, advantages, and limitations, site-specific technology selection is essential to achieve effective energy conversion. However, the development of wave energy remains challenged by variable wave conditions, harsh marine environments, equipment durability, and relatively high investment and maintenance costs, which can affect energy output, system reliability, and economic feasibility [9].

Overall, ocean wave energy can contribute to renewable energy diversification and reduce dependence on fossil-fuel-based electricity generation. In Indonesia, further development should focus on detailed site assessment, long-term wave-resource evaluation, technology optimization, and pilot-scale implementation. Improvements in WEC design, conversion efficiency, control systems, and material durability are also necessary to enhance system reliability and economic feasibility. These efforts can support the development of wave energy as a more sustainable and reliable component of Indonesia's future renewable electricity system [10].

References

- [1] L. Xu et al., "Resilience of renewable power systems under climate risks," *Nat. Rev. Electr. Eng.*, 2024, doi: 10.1038/s44287-023-00003-8.
- [2] N. Nandalianadhira, M. Hermanto, and R. A. Saputra, "Assessment of Small-Scale Offshore Wave Energy Potential Near Enggano Island for Local Sustainability and Energy Independence," in *IOP Conference Series: Earth and Environmental Science*, 2026. doi: 10.1088/1755-1315/1585/1/012023.
- [3] H. Bouhrim, R. Nechad, and I. Hajjout, "Ocean Wave Energy Conversion: A Review," *J. Mar. Sci. Eng.*, 2024, doi: 10.3390/jmse12111922.
- [4] A. Majidi, V. Ramos, P. R. Santos, L. Neves, and F. Taveira-Pinto, "Power Production Assessment of Wave Energy Converters in Mainland Portugal," *Renew. Energy*, 2025, doi: 10.1016/j.renene.2025.122540.
- [5] K. G. S. M. Rathnapriya et al., "Development of a Point Absorber Type Wave Energy Converter Optimised for Sri Lankan Wave Conditions," *Eng. J. Inst. Eng. Sri Lanka*, 2026, doi: 10.4038/engineer.v59i2.7744.
- [6] M. Bertrand, G. Giannini, A. Majidi, C. Senocq, P. Rosa-Santos, and D. Clemente, "Wave Energy Conversion to Decarbonize Offshore Aquaculture: Multi-Level Techno-Economic Analysis for a Case Study in Peniche, Portugal," *Energies*, 2025, doi: 10.3390/en18225934.
- [7] S. Beselly, M. Sajali, K. Murakami, and M. Syabana, "Assessment of wave energy resources and optimal WEC site selection on the south coast of Malang East Java," in *IOP Conference Series: Earth and Environmental Science*, 2026. doi: 10.1088/1755-1315/1593/1/012044.
- [8] A. Ziaei, H. Said, and J. Ringwood, "Health-Aware Economic Model Predictive Control of Wave Energy Converters Based on a Reliability Metric," *IEEE Open J. Control Syst.*, vol. 5, pp. 227–242, 2026, doi: 10.1109/ojcsys.2026.3685925.
- [9] W. Sabry, M. Abdel-Basset, K. Sallam, I. Alrashdi, and I. Radwan, "A Robust Framework for Assessing Sustainable Technologies for Efficient Wave Energy Harvesting at Potential Plant Sites," *Int. J. Energy Res.*,

- vol. 2025, 2025, doi: 10.1155/er/1089528.
- [10] D. Satrio *et al.*, "Modified Floater of Heaving Device Wave Energy Converter (WEC)," *Pomorstvo*, 2025, doi: 10.31217/p.39.1.10.