Journal of Clean Technology

REVIEW ARTICLE

Ocean Wave Utilization for Renewable Power Generation Using Wave Energy Converters (WECs): A Review

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Received: 24 May 2025, Revised: 23 June 2025, Accepted: 08 July 2025, Published: 01 August 2025

Abstract

The growing demand for electricity and the environmental impact of fossil fuel use have increased interest in renewable energy sources, including ocean wave energy. As a country with vast marine resources, Indonesia has significant potential to harness ocean waves as a clean and sustainable energy solution. This review explores various Wave Energy Converter technologies with a primary focus on the Oscillating Water Column system. The analysis covers ten recent studies that examine energy conversion efficiency, hydrodynamic performance, and field implementation. The findings indicate that the Oscillating Water Column system generally offers higher efficiency and greater operational stability than overtopping devices. Key factors influencing performance include wave height, wave period, chamber geometry, and turbine configuration. Case studies such as LIMPET in Scotland and OBREC in Italy provide evidence of real-world viability. Despite these advantages, challenges remain in terms of high construction costs, material durability in marine environments, and infrastructure limitations in coastal regions. This review highlights the importance of continued innovation, local adaptation, and policy support to enable the broader adoption of ocean wave energy, especially in island nations seeking to enhance energy resilience and reduce carbon emissions.

Keywords: energy conversion, ocean wave, Oscillating Water Column, renewable energy, wave energy converter

Introduction

Energy is an important aspect that supports the creation of a good quality of life, because almost all human activities and mobility every day are very dependent on the availability of sufficient and sustainable energy [1]. Energy is the capacity or ability to do an effort or cause a change [2]. In general, energy can be grouped into two types, namely based on its availability and based on its origin. When viewed from its origin, energy sources are divided into two, namely primary energy and secondary energy [3]. Primary energy can be further utilized by being processed into secondary energy, an example of which is electrical energy produced from biofuels [4]. Primary energy can be further utilized by being processed into secondary energy, an example of which is electrical energy produced from biofuels [5]. Secondary energy is a conversion of primary natural resources [6]. On the other hand, when viewed in terms of availability, energy is divided into two types, namely non-renewable energy and renewable energy, both of which are included in the primary energy category based on their origin, because they can be utilized directly according to their potential [3]. Non-renewable energy is energy from limited sources that cannot be renewed and have a negative impact on the environment, while renewable energy comes from natural sources that can be produced continuously and are environmentally friendly [7]. One example of a non-renewable energy source is fossil fuel [8] .

Energy needs in Indonesia are increasing along with economic growth, population, and national industry [9]. Fulfillment of current energy needs is a crucial aspect in efforts to realize national resilience, disruptions in energy supply can have a direct impact on the rate of economic growth and the development process of a country [10]. Based on data from the National Energy General Plan (RUEN), the per capita electricity demand in Indonesia in 2025 is estimated to reach 2,030 kWh (BaU), 1,892 kWh (PB), and 1,834 kWh (RK). While in 2050, the per capita electricity demand is projected to be 6,723 kWh (BaU), 5,824 kWh (PB), and 4,935 kWh (RK) [11]. With the projection of strong Indonesian economic growth in 2050, the need for electricity is expected to increase rapidly to reach 6% per year, to meet these needs, it is necessary to switch energy sources by adopting renewable energy technology, in the National Energy General Plan, the target for renewable energy utilization is set at 23% in 2025 and increasing to 31% in 2031 [12].

The increase in electricity demand has encouraged the government to seek and develop alternative energy sources, one of which is through the use of New and Renewable Energy (EBT) to ensure the availability of electrical energy [13]. One type of renewable energy currently being developed is marine energy, which in a number of countries has been used as an alternative energy source to reduce the impact of climate change due to human activities and support energy security in the future [14]. As an archipelagic country with around 17,508 islands with a coastline of ± 81,290 km, Indonesia has great potential to utilize the sea as a new and renewable energy source that is efficient and environmentally friendly, one of which is through the use of ocean wave energy that can convert mechanical energy into electrical energy [15]. Ocean waves are one of the renewable energy sources that are free of carbon emissions, so they can be used as an alternative to replace non-renewable energy, the use of this alternative energy also supports the achievement of sustainable development goals by providing clean and renewable energy [16].

Ocean current energy is one of the energy resources that has great potential and is important in the development of renewable energy, this energy comes from the kinetic energy of ocean water flow, especially from stable ocean currents in straits or waterways, as well as from tidal currents that occur regularly, the utilization of ocean current energy can be done with principles that are theoretically similar to wind power plant technology[17]. This energy comes from the movement of the sea surface due to wind, and has the advantages of continuity and higher predictability compared to solar or wind energy [18]. According to data from the International Renewable Energy Agency (IRENA), the global ocean wave energy potential is estimated at more than 29,500 TWh per year, but its contribution to total energy generation is still very small due to challenges in terms of conversion efficiency, high initial investment costs, and the need for technology that is resistant to extreme sea conditions [19].

To convert wave energy into electricity, a device known as a Wave Energy Converter (WEC) is used. Wave Energy Converter (WEC) is a device used to utilize ocean wave energy to produce electric current. This tool is designed with the typeheaving devicewhich works based on the principle of vertical oscillation (up and down) of ocean waves to convert kinetic energy into electrical energy[20]. WEC technology itself is used to capture and convert ocean wave energy into electricity and WEC is also designed to utilize the kinetic and potential energy of waves to convert it into electrical energy through various mechanisms such as vertical movement, water pressure, or differences in water levels [21]. The main types of WEC include point absorbers, oscillating water columns (OWCs), and overtopping devices, each of which has different efficiencies and optimal operating conditions [19]. OWCs have a relatively simple working mechanism with minimal moving components, all of which are located above the water surface, this allows them to experience lighter mechanical loads and are able to absorb excess wave energy more efficiently than other types of WECs [22]. Therefore, this article aims to provide a comprehensive review of Wave Energy Converter (WEC) technologies, with a specific focus on the Oscillating Water Column (OWC) system, through an examination of recent literature that analyzes its efficiency, working principles, and implementation challenges within the context of Indonesian waters.

Materials and methods

The research design employed in this study is the literature review method. A literature review is a type of research conducted by collecting a number of articles or journals related to the research problem and objectives. This technique is used to identify and present various theories relevant to the issue being addressed, serving as a reference for the discussion and interpretation of the research findings [23].

Table 1. Literature Study Analysis

No.	Source	Research design	Research results
1	[24]	The results of the study show that oscillating body systems have the highest hydrodynamic efficiency compared to other types of WECs, especially when their characteristic width is small. In contrast, overtopping devices demonstrate the lowest efficiency. Additionally, the efficiency of the devices tends to increase as the wave energy potential at the location becomes higher. The article also concludes that improving efficiency at the initial stage, particularly hydrodynamic performance, is crucial for the commercial development of WEC technology.	The results of the study show that oscillating body systems have the highest hydrodynamic efficiency compared to other types of WECs, especially when their characteristic width is small. In contrast, overtopping devices demonstrate the lowest efficiency. Additionally, the efficiency of the devices tends to increase as the wave energy potential at the location becomes higher. The article also concludes that improving efficiency at the initial stage, particularly hydrodynamic performance, is crucial for the commercial development of WEC technology.
2	[25]	This study is a literature review that discusses the characterization of ocean wave energy resources, spectral numerical models such as SWAN, WW3, and WAM, wave energy conversion technologies, power take-off mechanisms, and economic assessment based on levelized cost of energy (LCOE).	The review findings show that the region between 40° and 60° latitude has the highest wave energy potential. Numerical models can provide accurate estimates when calibrated with satellite or buoy data. Wave energy converters are classified into three main types, namely oscillating water columns, overtopping devices, and oscillating bodies. The efficiency of PTOs varies widely. The success of a project is greatly influenced by the stability of ocean energy and economic factors such as capacity factors and levelized energy costs.
3	[26]	This literature review discusses the theoretical concepts, power harvesting technologies, types of wave energy converters, wave energy potential, installation challenges, and future prospects of	This study shows that wave energy converters have high potential but are still limited by technological, economic and policy barriers. Types of WECs such as Pelamis, Oyster and

		using WECs in power generation systems.	Point Absorber show efficiency levels ranging from 25% to 90%.
4	[27]	This literature review study provides a comprehensive overview of ocean wave energy utilization since the 1970s, covering wave resource characterization, hydrodynamic theory, classification and development of various types of conversion devices, and evaluation of power take-off technologies and mooring systems.	Research shows that wave energy conversion technology has advanced significantly in terms of design variations and technical approaches. Several prototypes have been successfully tested at sea and have shown strong potential. However, major challenges remain related to conversion efficiency, device durability in extreme sea conditions, and high construction costs, highlighting the need for continued support through research, policy, and advanced technology development.
5	[28]	This comprehensive literature review maps out the direction of optimization research in wave energy converters, covering layout configurations, geometric parameters, power harvesting systems, and the application of metaheuristic, biologically inspired, and local search algorithms to improve efficiency and reduce costs.	This study found that the combination of biology-inspired algorithms and local search yielded the best results in layout optimization. The configuration of PTO parameters and geometric design significantly affect the absorbed power performance. Optimizing the interaction between WECs, improving efficiency at a specific frequency, and selecting the right algorithm play a major role in increasing the power output and reducing the levelized energy cost for large-scale
6	[29]	This in-depth literature review examines theoretical, numerical, and experimental studies on the hydrodynamic behavior of wave energy converter arrays, focusing on device interactions, numerical modeling approaches, and key design challenges.	Research shows that the interaction between WECs in an array significantly affects the power absorption efficiency and should be carefully considered in the design process. Various approaches such as linear wave theory, numerical models based on BEM and FEM, and laboratory-scale experiments have been applied. No single method is ideal for all scenarios, so complementary approaches that combine theoretical, numerical, and physical models are highly recommended.
7	[30]	Numerical simulation studies based on CFD using the Brinkman penalty method were conducted on a	Simulations show that proportional control of the PTO torque is required to maintain

		1:20 scale model to analyze the performance and dynamics of the ISWEC, including the PTO system, geometry, and hull behavior under regular and irregular wave conditions.	gyroscopic precession and enable power generation. The 2D model proved to be quite accurate compared to the 3D model. High efficiency was achieved when the hull length ranged from one third to one half of the wavelength. The energy transfer from the waves to the PTO was validated both analytically and numerically. The protection strategy of the device under extreme weather conditions was also successfully simulated.
8	[31]	This study uses a numerical model based on linear potential theory in MATLAB to simulate the performance of various layouts and spacing configurations of fully submerged buoy-type wave energy converters (WECs), arranged in formations of two to five units with varying orientations and spacings. The simulations are based on real wave data from four coastal locations in Australia, aiming to optimize the total annual power output and energy efficiency within realistic sea area constraints.	The results show that increasing the number of buoys and the spacing between WECs to the optimum point results in higher power output and annual energy output (AEO). The best performance was achieved by the 5-buoy configuration in Tasmania, which achieved an AEO of 2.98 MWh. In addition, a q-factor greater than 1 indicates constructive interaction in the optimal layout, which takes into account the angle relative to the wave direction.
9	[32]	This study is designed to develop and analyze the performance of a hexagonal wave energy converter with varying loads (empty, 10 kg, 20 kg, and 30 kg) as an alternative source of electricity generation in the Java Sea waters. The analysis was carried out using numerical modeling through software such as FreeCAD, Rhinoceros, Maxsurf, and Ansys Aqwa, focusing on the lift motion, frequency, amplitude, and wave spectrum based on the ITTC approach.	The results showed that the hexagonal converter with a load of 30 kg showed the best lifting motion performance, achieving the highest amplitude of 0.215818 meters at a wave height of 0.8 meters and a period of 1.675 seconds. This converter also produced a maximum excitation force of 908.5134 N, making it the optimal configuration among the tested load variations.

10	[33]	This study uses the hindcasting method based on wind speed and fetch length data to determine wave height, and calculates wave energy using a mechanical energy approach based on wave amplitude and seawater density.	The results of the study show that waves coming from the southeast, south, and southwest have the potential to generate electrical energy, with the highest potential from the southwest reaching 28,676.62 Joules/m², followed by the south reaching 8,042.63 Joules per square meter, and the southeast reaching 2,432.23 Joules/m².

Results and Discussion

Based on the analysis of the literature review of 10 journal articles that meet the criteria for ocean waves, the research article has the main topic of renewable energy. The results of the study of the research article are presented in the following explanation:

1. **Effectiveness of Electrical Energy Production from Ocean Waves Using the Oscillating Water Columb (OWC) System**

One method to utilize energy from ocean waves is through Wave Energy Converter (WEC) or ocean wave energy conversion tool, one type that is widely studied is Oscillating Water Column (OWC), the OWC system consists of four main components, namely chamber, air turbine, generator, and pontoon, the chamber functions as a space where oscillations occur between water and air, the air turbine captures energy from the air flow due to the oscillation, which is then used to rotate the generator so that it can generate electricity [34]. The efficiency of electricity production occurs when the up and down movement of the water column due to ocean waves causes changes in air pressure in the space, the trapped air will flow out through the turbine, rotate the turbine, and then produce electrical energy optimally [35].

The height of the sea waves has a major influence on the efficiency of electricity generation, the higher the waves, the greater the electrical energy produced, where during one year at Location A, the observed wave height and period showed that the greatest energy was produced when the significant wave height was in the range of 1-2 meters with a period of 15-16 seconds, which was 10,809 kWh/m. Overall, the total electrical energy that can be produced from all waves during one year reaches 45,969 kWh/m, while at Location B, during a period of one year, the greatest energy was produced when the significant wave height was in the range of 1-2 meters with a period of 15-16 seconds, which was 9,428 kWh/m. The total electrical energy that can be generated from all waves during one year reaches 45,042 kWh/m [36]. In determining the amount of total electrical energy produced, not only the height and period of the incoming waves, but also the width of the chamber have a significant contribution in determining the amount of electrical energy produced [37].

Overall, the Oscillating Water Column (OWC) System has proven to be one of the effective wave energy conversion technologies in generating electricity. The efficiency of this system is greatly influenced by the interaction between the movement of ocean waves, air pressure in the chamber, and system design, especially in components such as generators and turbines. Turbines used in OWC systems must have the ability to operate bi-directionally. Wells turbines show good efficiency at low speeds but tend to stall. Meanwhile, Impulse Turbines offer higher stability as well as better starting torque. In addition, other types of turbines such as radial turbines and special turbines are also applied to optimize performance according to system characteristics and needs.

2. Comparison of WEC Types between OWC and Overtopping Devices

2.1 Oscillating Water Column (OWC)

2.1.1 Working Principle

The oscillating water column (OWC) system consists of a concrete or steel structure that is partially submerged and open at the bottom, allowing air to be enclosed above the free surface of the water within it (Figure 1). The oscillating motion of the internal free surface produced by the incident waves makes the air to flow through a turbine that drives an electrical generator [27].

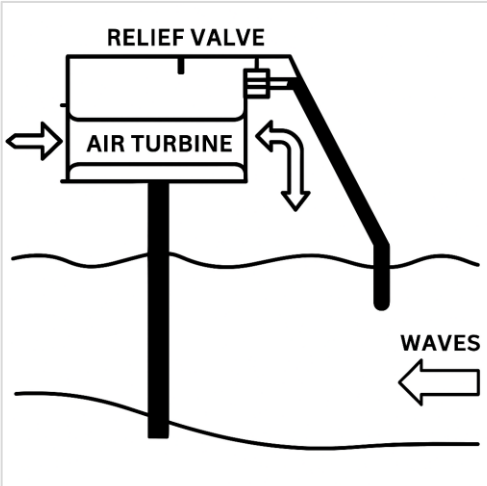

Figure 1. Cross-sectional view of a bottom-standing OWC (Pico plant) [28].

The OWC system harnesses wave energy to generate electricity. Incoming waves cause the water surface inside the column to rise and fall (oscillate), which compresses and decompresses the air in the enclosed chamber above. This bidirectional airflow passes through an air turbine connected to a generator, producing electricity. A relief valve is used to regulate the air pressure, ensuring the system operates safely and efficiently.

2.1.2 Hydrodynamic Efficiency

Tabel 2. Efficiencies of Selected OWCs based on Simulation and Numerical Analysis Results

ID	Scale of Wave Data	Efficiency	Comments
1	Laboratory [38 – 40]	Information not available	Simulation and numerical analysis done to verify lab tests
2	36 sea states at the Canadian Pacific site	11.6%	Annual, pre-design analysis including pneumatic, mechanical, and electrical efficiency
3	Real sea state at Monte Redondo in Chile		Rectangular cross-section
		(a) 40.87%	(6.0 m by 12 m)
		(b) 24.42%	(radius = 7.6 m)
		(c) 17.91%	(radius = 6.77 m)

4	14 sea states on the western coast of Portugal [41]	2%	Simulation + geometric optimization of OWC
5	Pico Wave site	(a)10% (b) 31%	Increase in efficiency by using control valves Average annual output vs. rated power of air turbine
6	Laboratory [42]	N/A	Geometry optimization. Maximum efficiency occurs when the ratio of the cross-sectional areas of the orifice and the air chamber = 0.66 (pneumatic efficiency)
7	Laboratory [43]	45%	Pneumatic efficiency
8	Laboratory [44]	71%	Geometry optimization: Bottom profile Instantaneous peak value at resonance for a circular bottom profile
9	(a) Sea states @ western coast of Portugal [45] (b) Sea states @ western coast of Portugal [46]	N/A	(a) Shape optimization. Almost sixfold increase in pneumatic efficiency claimed (b) Geometry optimization of device and turbine optimization 50% increase in electrical energy
10	Sea states from Italian coast	15%	Turbine optimization Increase in electrical efficiency

Table 3. Efficiencies of Wave Tanks and Sea Trials Performed on Selected OWCs.

ID	Type	Scale	Efficiency	Comments
11	Spar Buoy	1:7 (Wave Tank)	N/A	Aimed to use control strategy to increase turbine efficiency
12	Generic OWC	1:50 (Wave tank)	~30%	From pneumatic to mechanical stage
13	Generic OWC [47]	1:50 (Wave tank)	~30% ~7.5%	Mechanical efficiency Electrical efficiency

14	Mighty Whale	1:1 Sea trials	~5%	Mechanical efficiency
			~15%	Electrical efficiency
15	Swank DK3	N/A	20%	Pneumatic efficiency

2.1.3 Power Capacity

Table 4. Several major OWC devices and their power capacities [23].

Name/Location	Capacity	Comments
KVAENER/Norway	500 kW (Operation)	N/A
Japan	60 kW	Prototype
LIMPET/Scotland	75 kW prototype, * 500 kW operated	* Downgraded to 250 kW later
India	150 kW	N/A
Pico/Portugal [48]	400 kW	N/A
Australia	450 kW	N/A
Mutriku Spain	296 kW	16 units with 18.5 kW each
Mighty Whale	110 kW	N/A
KRISO/South Korea	500 kW	N/A

2.1.4 Prototype Example

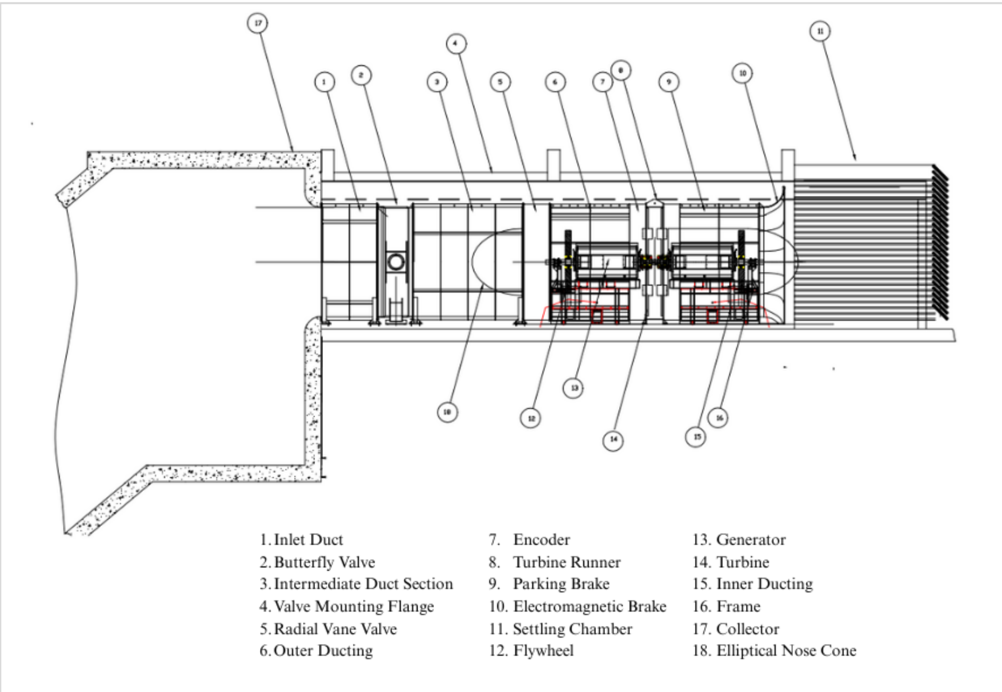

Figure 2. LIMPET Instrumentation Coverage [49]

Figure 3. Concept of Oscillating Water Column [50]

Figure 4. Prototype of LIMPET Constructed In 2000 on the West Coast Of The Scottish Island Of Islay [51]

LIMPET serves as a full-scale prototype to demonstrate that OWC technology can operate effectively, safely, and efficiently in real-world conditions, while also providing a platform for research, optimization, and technology validation prior to further commercial deployment [52].

2.2 Overtopping Devices

2.2.1 Working Principle

Overtopping Devices work by utilizing the overflow of sea wave water into a reservoir or reservoir 2 at a higher level than sea level and driving a water pump to generate electricity [53]. The Overtopping system consists of a ramp, reservoir, and turbine to convert ocean wave energy into electrical energy, the waves propagate, rise to the ramp, and fill the reservoir thus creating a high water column; this water is directed to the turbine which produces electricity [54]. Figure 4 illustrates the operating principle of this device.

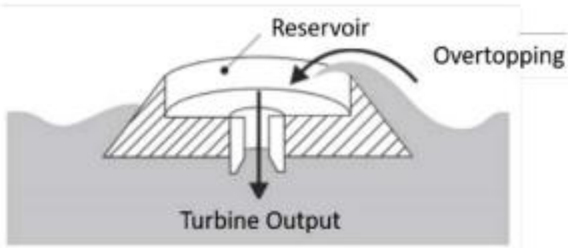

Figure 4. Operating principle of the Overtopping device [39]

2.2.2 Hydrodynamic Efficiency

Table 5. Hydrodynamic Efficiency of Overtopping Devices based on Simulation and Numerical Analysis

ID	Scale of Wave Data	Efficiency	Comments
1	Full-scale simulation (Brazil), Regular wave, H = 1 m, T = 7.5 s	100% ($H_3/L_3 = 0.33$)	Best case with trapezoidal obstacle (L_1/L_2 = 0.67), improved 30% over baseline.
2	Full-scale simulation (Brazil), Same wave config	90% ($H_3/L_3 = 0.34$)	Still high performance.
3	Full-scale simulation (Brazil), Same wave config	25% ($H_3/L_3 = 0.37$)	Worst geometry.
4	Laboratory-scale (Brazil, validated)	90%	Good agreement; error ~1.8% vs numerical.
5	Gulf of Naples, Italy (OBREC), Real sea, wave + wind	65–90%	OBREC tested with trapezoidal design, improved energy + coastal defense.
6	Western Portugal (OBREC), 14 real sea states [55]	70–95%	Field-tested overtopping device performance under site-specific sea states.

Table 6. Efficiencies of Wave Tanks and Sea Trials Performed on Overtopping Devices.

ID	Type	Scale	Efficiency	Comments
7	Single-level Overtopping Device	Model Scale (Wave Tank)	~4–5%	Lower hydrodynamic efficiency; consists of only one reservoir level, resulting in more wave energy loss.
8	Multi-level Overtopping Device	Model Scale (Wave Tank)	~6–10%	About 6% improvement compared to single-level; more effective at capturing overtopped water with two-level reservoirs.

9	Multi-level Overtopping Device [56]	Full Scale (Simulated)	~6% (extrapolated)	Based on East China Sea conditions (Hs 1–1.5 m, T 4–7 s); used as reference for real-sea scenarios in simulation setup.

2.2.3 Power Capacity

Table 7. Several major Overtopping Devices and their power capacities [57].

Name/Location	Capacity	Comments
OBREC (Naples, Italy)	~2.5 kW (pilot)	Full-scale prototype at San Vincenzo breakwater; tested in real sea.
SSG (Norway, WaveEnergy AS)	Up to 320 kW/module	Multi-reservoir system; high potential but complex and costly structure.
Pico Plant (Azores, Portugal)	~40 kW average	Uses Oscillating Water Column, but relevant as a hybrid overtopping/OWC.
Mutriku OWC (Spain)	~296 kW total	Not a pure overtopping device but referenced in overtopping-WEC contexts.
Proposed OBREC (San Antonio, Chile)	~1.62 kW/m → ~2.5 GWh/year (est.)	Potential from 500 m breakwater integration, not yet realized.

2.2.4 Prototype Example

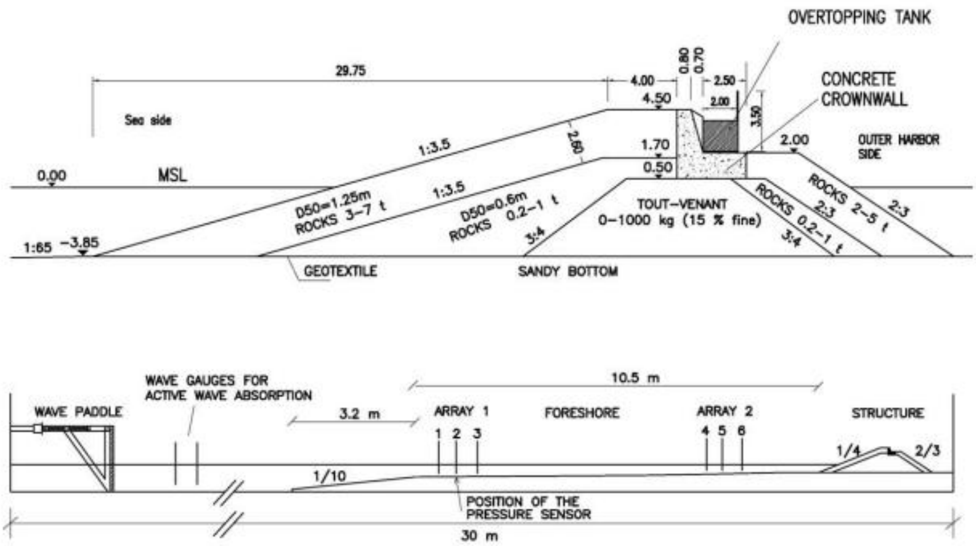

Figure 5. Upper panel: Design cross-section of the west breakwater at the overtopping wave tank [58]

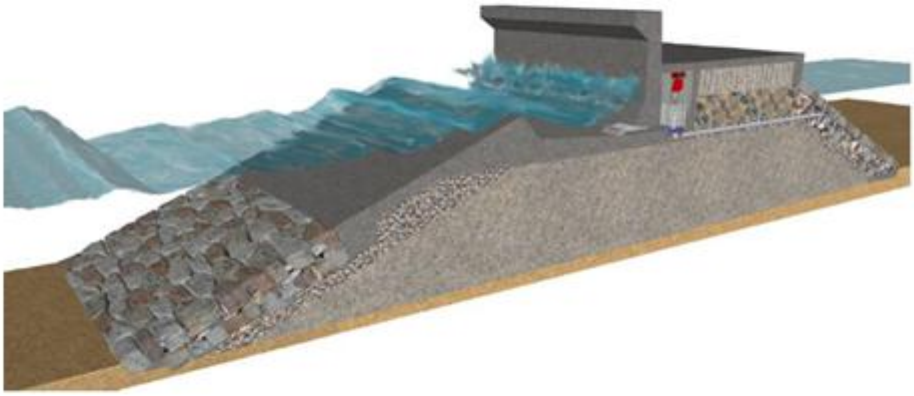

Figure 6. Conceptual design of the Overtopping Breakwater for Energy Conversion (OBREC) [44]

Overtopping Breakwater for Energy Conversion (OBREC) can capture part of the energy from incident waves that overtop the frontal ramp, the potential energy of the water stored in the reservoir is then converted into kinetic energy, flowing through low-head turbines located in a machine room behind the reservoir, the energy is thus converted into electrical energy by means generators coupled to the turbines [59].

Conclusions

Ocean wave energy has great potential as a renewable energy source, especially in archipelagic countries such as Indonesia. This review shows that Wave Energy Converter (WEC) technology, particularly the Oscillating Water Column (OWC) system, offers high energy conversion efficiency, good operational stability, and adaptability to various sea conditions. OWC performance is influenced by chamber geometry, turbine configuration, and local wave characteristics.The application of this technology can support energy security, reduce carbon emissions, and strengthen coastal infrastructure. Case studies such as LIMPET and OBREC prove that this technology can be commercially developed with the right design and policy support. However, challenges such as high initial costs, material corrosion, and infrastructure limitations remain key barriers. Successful implementation also depends on local institutional support and community acceptance. Public education and community engagement are essential to build understanding, increase social acceptance, and maintain project sustainability. With an integrated approach that includes technological innovation, adaptive policies and community empowerment, OWC systems have the potential to be an important part of the clean energy transition and sustainable coastal development. Further research is needed to evaluate the economic, environmental, institutional aspects, and integration with other renewable energy sources.

Acknowledgements

We the authors, would like to express our gratitude to the Department of Chemical Engineering, Faculty of Engineering, Universitas Negeri Semarang for the facilities and guidance provided during the writing of this paper.

References

[1] N. Jelley, *Energi Terbarukan: Pengantar Singkat*. Oxford University Press. doi: 10.1093/actrade/9780198825401.001.0001.

[2] Jalaluddin and S. Fadly, “Intensifikasi Penggunaan Energi Terbarukan Dalam Pembangunan Ekonomi Berkelanjutan Di Indonesia,” pp. 1–8, 2023.

[3] A. A. Solikah and B. Bramastia, “Systematic Literature Review : Kajian Potensi dan Pemanfaatan Sumber Daya Energi Baru dan Terbarukan Di Indonesia,” *J. Energi Baru dan Terbarukan*, vol. 5, no. 1, pp. 27–43, 2024, doi: 10.14710/jebt.2024.21742.

[4] A. J. Adellea, “Rangka Ketahanan Energi Nasional,” *Indones. State Law Rev.*, vol. 05, no. 1, pp. 43–51, 2022.

[5] A. Y. Nasution *et al.*, “Jurnal Dinamis TEMPURUNG KELAPA MENGGUNAKAN ANSYS,” vol. 10, no. 1, pp. 22–29, 2022.

[6] E. Dunia, “No Title.”

[7] V. Dwisari, S. Sudarti, and Y. Yushardi, “Pemanfaatan Energi Matahari: Masa Depan Energi Terbarukan,” *Opt. J. Pendidik. Fis.*, vol. 7, no. 2, pp. 376–384, 2023, doi: 10.37478/optika.v7i2.3322.

[8] N. Hasna, P. Senapati Bagus Handoko, F. Wahyuningtyas Destantri, A. Bintang Syahputra, and Z. Ash Shiddieqy Bahlawan, “Bioethanol Production from Rice Straw through Utilization of Agrobiomass Waste in Central Java Towards Clean Energy: a Review,” *J. Clean Technol.*, vol. 1, no. 1, pp. 1–8, 2024, [Online]. Available: https://doi.org/

[9] Z. A. S. Bahlawan *et al.*, “The Potential Bioethanol Production from the Starch of Breadfruit Peel-A Review Case in Indonesia,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1203, no. 1, 2023, doi: 10.1088/1755-1315/1203/1/012038.

[10] A. Vidura, R. L. W, and Mukhtasor, “Potensi Pemanfaatan Pembangkit Listrik Tenaga Gelombang Laut Di Perairan Selatan Pulau Jawa Dalam Mendukung Ketahanan Energi,” *J. Ketahanan Energi*, vol. 8, no. 1, pp. 32–48, 2022.

[11] D. J. E. B. T. da. K. E. EBTKE), “KESDM – Danish Energy Agency Luncurkan Laporan Renewable EnergyPipeline.https://ebtke.esdm.go.id/post/2021/09/13/2960/kesdm.danish.energy.agency.luncurkan.laporan.renewable.energy.pipeline?lang=en.”

[12] J. Langer, J. Quist, and K. Blok, “Review of Renewable Energy Potentials in Indonesia and Their.pdf,” *Energies*, vol. 14, no. 21, p. 14, 2021.

[13] E. B. Setiawan and N. Upara, “Perancangan Konverter Energi Gelombang Laut Untuk Pembangkit Listrik Menggunakan Sistem Floating,” pp. 1–9, 2019.

[14] I. H. Suherman and P. Raharjo, “Potensi Energi Gelombang Laut Di Perairan Mentawai,” *J. Geol. Kelaut.*, vol. 18, no. 2, pp. 97–110, 2020, doi: 10.32693/jgk.18.2.2020.564.

[15] M. Sidik and N. Sinaga, “Potensi Pemanfaatan Gelombang Laut Menjadi Tenaga Listrik Dengan Metoda Oscillating Water Column di Pulau Bawean Gresik,” *J. Energi Baru dan Terbarukan*, vol. 4, no. 2, pp. 132–144, 2023, doi: 10.14710/jebt.2023.17306.

[16] E. S. Siahaan, I. B. Prasetyawan, and A. Ismanto, “Pemetaan Potensi Daya Listrik yang Dibangkitkan Gelombang Laut di Perairan Selatan Bali Tahun 2018-2023,” vol. 07, no. 02, pp. 140–149, 2025, doi: 10.14710/ijoce.v7i2.26252.

[17] A. Alamsah, A. Wahjudi, P. J. Moon, N. Hamidi, and D. Widhiyanuriyawan, “Potensi Energi Arus dan Tinggi Gelombang Laut Indonesia Berdasarkan Data Penginderaan Jauh,” vol. 18, no. April, pp. 49–59, 2025, doi: 10.32897/techno.2025.18.1.4087.

[18] Hl. lain-lain, “Teknologi konversi energi gelombang canggih untuk laut yang berkelanjutan dan cerdas: Tinjauan komprehensif,”Perbarui,” *Energi*, vol. 238, p. 121980, doi: 10.1016/j.renene.2024.121980.

[19] “IRENA,Prospek inovasi: Teknologi energi laut.”

[20] W. N. Mustikojati, E. S. Hadi, and ..., “Desain Konverter Gelombang Bentuk Segienam Sebagai Sumber Pembangkit Listrik Di Perairan Laut Jawa,” *J. Tek. Perkapalan*, vol. 4, no. 2, pp. 466–475, 2016.

[21] D. Gallutia, M. T. Fard, M. G. Soto, and J. B. He, “Kemajuan terbaru dalam sistem konversi energi gelombang: Dari teori gelombang hingga perangkat dan strategi kontrol,”Ocean.” doi: 10.1016/j.oceaneng.2022.111105.

[22] M. Rosati, J. C. C. Henriques, and J. V. Ringwood, “Oscillating-water-column wave energy converters: A critical review of numerical modelling and control,” *Energy Convers. Manag. X*, vol. 16, no. November, p. 100322, 2022, doi: 10.1016/j.ecmx.2022.100322.

[23] S. Budi Raharjo and Masahere, “Komitmen organisasi sebagai strategi peningkatan kinerja dan loyalitas karyawan: studi tinjauan literatur,” *J. Entrep. Bisnis Manaj. Akunt.*, vol. 4, no. 1, pp. 143–156, 2020.

[24] T. Aderinto and H. Li, "Review on power performance and efficiency of wave energy converters," *Energies*, vol. 12, no. 22, pp. 1–24, 2019, doi: 10.3390/en12224329.

[25] M. H. Jahangir and A. R. Mahmoudi, "Ocean Wave Energy Conversion Technologies : a Review," pp. 1–25, 2024.

[26] M. A. U. Amir, R. M. Sharip, M. A. Muzanni, and H. A. Anuar, "Wave energy convertors (WEC): A review of the technology and power generation," *AIP Conf. Proc.*, vol. 1775, no. November 2019, 2016, doi: 10.1063/1.4965220.

[27] A. F. d. O. Falcão, "Wave energy utilization: A review of the technologies," *Renew. Sustain. Energy Rev.*, vol. 14, no. 3, pp. 899–918, 2010, doi: 10.1016/j.rser.2009.11.003.

[28] D. Golbaz *et al.*, "Ocean Wave Energy Converters Optimization: A Comprehensive Review on Research Directions," 2021.

[29] S. De Chowdhury *et al.*, "A review of hydrodynamic investigations into arrays of ocean wave energy converters," 2015.

[30] K. Khedkar, N. Nangia, R. Thirumalaisamy, and A. P. S. Bhalla, "The inertial sea wave energy converter (ISWEC) technology: Device-physics, multiphase modeling and simulations," *Ocean Eng.*, vol. 229, 2021, doi: 10.1016/j.oceaneng.2021.108879.

[31] E. Amini, D. Golbaz, and F. Amini, "Performance investigation on the different wave energy converters layouts in real wave scenarios," pp. 1–22.

[32] R. Yudanto, E. S. Hadi, and Kiryanto, "Desain Konverter Gelombang Bentuk Tabung Sebagai Sumber Pembangkit Listrik Di Perairan Laut Jawa," *J. Tek. Perkapalan*, vol. 4, no. 2, pp. 476–484, 2017.

[33] I. Irwan and S. Suaib, "Studi potensi pemanfaatan energi gelombang laut menjadi energi listrik di Kelurahan Sapolohe Kabupaten Bulukumba," *Pros. Semin. Nas. Politek. Pertan. Negeri Pangkajene Kepul.*, vol. 3, no. September, pp. 74–83, 2022, doi: 10.51978/proppnp.v3i1.284.

[34] , R. and J. Arifin, "Prototip Oscillating Water Columb (Owc)," *Al Jazari J. Ilm. Tek. Mesin*, vol. 5, no. 1, pp. 14–17, 2020, doi: 10.31602/al-jazari.v5i1.3042.

[35] A. Rendra, P. Abduh, A. M. F. Sulfa, D. T. Kelautan, and U. Hasanuddin, "MASA DEPAN ENERGI TERBARUKAN DI LAUT : PERAN TEKNOLOGI TENAGA LAUT DALAM MITIGASI PERUBAHAN IKLIM," pp. 11–18.

[36] T. Elektro, U. Kristen, and P. Surabaya, "LAUT SAWU NUSA TENGGARA TIMUR," vol. 17, no. 1, pp. 51–54, 2024.

[37] M. Sidik and N. Sinaga, "Potensi Pemanfaatan Gelombang Laut Menjadi Tenaga Listrik Dengan Metoda Oscillating Water Column di Pulau Bawean Gresik," *J. Energi Baru dan Terbarukan, jilid*, vol. 4, tidak., pp. 132–144,, doi: 10.14710/jebt.2023.17306.

[38] E. Septyaningrum, D. T. Fisika, F. Teknologi, I. Dan, and R. Sistem, "Model Trimaran Pada Pembangkit Listrik Tenaga Gelombang Laut Sistem Bandul (Pltg-Sb)," 2020.

[39] R. G. Hübner *et al.*, "Numerical Study Comparing the Incidence Influence Between Realistic Wave and Regular Wave Over an Overtopping Device," *Rev. Eng. Térmica*, vol. 18, no. 1, p. 46, 2019, doi: 10.5380/reterm.v18i1.67047.

[40] A. S. de Barros *et al.*, "Numerical Study and Geometrical Investigation of an Onshore Overtopping Device Wave Energy Converter with a Seabed Coupled Structure," *J. Mar. Sci. Eng.*, vol. 11, no. 2, 2023, doi: 10.3390/jmse11020412.

[41] Z. Wan, Z. Yao, T. Song, and J. Chen, "Hydrodynamic characteristics of the multi-level overtopping wave power device," *J. Low Freq. Noise Vib. Act. Control*, vol. 38, no. 3–4, pp. 1314–1326, 2019, doi: 10.1177/1461348418813745.

[42] P. Contestabile, G. Crispino, E. Di Lauro, V. Ferrante, C. Gisonni, and D. Vicinanza, "Overtopping breakwater for wave Energy Conversion: Review of state of art, recent advancements and what lies ahead," *Renew. Energy*, vol. 147, pp. 705–718, 2020, doi: 10.1016/j.renene.2019.08.115.

[43] L. Franco, J. Geeraerts, R. Briganti, M. Willems, G. Bellotti, and J. De Rouck, "Prototype measurements and small-scale model tests of wave overtopping at shallow rubble-mound breakwaters: the Ostia-Rome yacht harbour case," *Coast. Eng.*, vol. 56, no. 2, pp. 154–165, 2009, doi: 10.1016/j.coastaleng.2008.03.009.

[44] P. Contestabile, F. Vincenzo, E. Di Lauro, and D. Vicinanza, "Full-Scale Prototype of an Overtopping Breakwater for Wave Energy Conversion," *Coast. Eng. Proc.*, no. 35, p. 12, 2017, doi: 10.9753/icce.v35.structures.12.

[45] K. R. Lee, W. Koo, and M. H. Kim, "Fully nonlinear time-domain simulation of a backward bent duct buoy floating wave energy converter using an acceleration potential method," *International Journal of Naval Architecture and Ocean Engineering*, vol. 5, no. 4, pp. 513–528, 2013, doi:

10.2478/IJNAOE-2013-0150.
[46] H. Bailey, B. R. D. Robertson, and B. J. Buckham, "Wave-to-wire simulation of a floating oscillating water column wave energy converter," *Ocean Engineering*, vol. 125, pp. 248–260, Oct. 2016, doi: 10.1016/j.oceaneng.2016.08.017.
[47] C. I. M. Rivera and R. A. R. Berroeta, "STOCHASTIC MODELLING OF OWC DEVICE AND POWER PRODUCTION," 2017.
[48] J. C. C. Henriques, J. C. C. Portillo, L. M. C. Gato, R. P. F. Gomes, D. N. Ferreira, and A.F. O. Falcão, "Design of oscillating-water-column wave energy converters with an application to self-powered sensor buoys," *Energy*, vol. 112, pp. 852–867, Oct. 2016, doi: 10.1016/j.energy.2016.06.054.
[49] The Queen's University of Belfast, "ISLAY LIMPET WAVE POWER PLANT," 1998
[50] European Marine Energy Centre (EMEC) Ltd., Internet: http://www.emec.org.uk/marine-energy/wave-devices/, (20 Dec 2013).
[51] SEED, Internet: http://learning.media.mit.edu/seed/wave%20energy.html, (20 Dec 2013).
[52] D. Z. Ning, R. Q. Wang, Q. P. Zou, and B. Teng, "An experimental investigation of hydrodynamics of a fixed OWC Wave Energy Converter," *Appl Energy*, vol. 168, pp. 636–648, Apr. 2016, doi: 10.1016/j.apenergy.2016.01.107.
[53] M. Iino, T. Miyazaki, H. Segawa, and M. Iida, "Effect of inclination on oscillation characteristics of an oscillating water column wave energy converter," *Ocean Engineering*, vol. 116, pp. 226–235, Apr. 2016, doi: 10.1016/j.oceaneng.2016.03.014.
[54] S. John Ashlin, V. Sundar, and S. A. Sannasiraj, "Effects of bottom profile of an oscillating water column device on its hydrodynamic characteristics," *Renew Energy*, vol. 96, pp. 341–353, Oct. 2016, doi: 10.1016/j.renene.2016.04.091.
[55] S. Ribeiro E Silva, R. P. F. Gomes, and A. F. O. Falcaõ, "Hydrodynamic optimization of the UGEN: Wave energy converter with U-shaped interior oscillating water column," *International Journal of Marine Energy*, vol. 15, pp. 112–126, Sep. 2016, doi: 10.1016/j.ijome.2016.04.013.
[56] J. C. C. Henriques, L. M. C. Gato, J. M. Lemos, R. P. F. Gomes, and A. F. O. Falcão, "Peak-power control of a grid-integrated oscillating water column wave energy converter," *Energy*, vol. 109, pp. 378–390, Aug. 2016, doi: 10.1016/j.energy.2016.04.098.
[57] S. Ceballos, J. Rea, E. Robles, I. Lopez, J. Pou, and D. O'Sullivan, "Control strategies for combining local energy storage with wells turbine oscillating water column devices," *Renew Energy*, vol. 83, pp. 1097–1109, Nov. 2015, doi: 10.1016/j.renene.2015.05.030.
[58] A. Falcao, A. F. De, and O. Falcão, "The shoreline OWC wave power plant at the Azores," 2000. [Online]. Available: https://www.researchgate.net/publication/306204136
[59] C. B. Boake, T. Whittaker, M. Folley, T. J. T. Whittaker, and H. Ellen, "Overview and Initial Operational Experience of the LIMPET Wave Energy Plant," 2002. [Online]. Available: https://www.researchgate.net/publication/266579487