A Mini Review: Wave Energy Converters Technology, Potential Applications and Current Research in Indonesia

Muhammad Alfan Santoso
Integrated Port-Coastal Zone Planning and Management Research Group, Research Center for Hydrodynamic Technology, National Research and Innovation Agency (BRIN)

Wijayanti, Yureana
Civil Engineering Department, Faculty of Engineering, Bina Nusantara University

Ridwan Budi Prasetyo
Integrated Port-Coastal Zone Planning and Management Research Group, Research Center for Hydrodynamic Technology, National Research and Innovation Agency (BRIN)

Setyandito, Oki
Civil Engineering Department, Faculty of Engineering, Bina Nusantara University

他

https://doi.org/10.5109/7151712

出版情報：Evergreen. 10 (3), pp.1642-1650, 2023-09. 九州大学グリーンテクノロジー研究教育センター
バージョン：

A Mini Review: Wave Energy Converters Technology, Potential Applications and Current Research in Indonesia

Muhammad Alfan Santoso[1], Yureana Wijayanti[2,*], Ridwan Budi Prasetyo[1], Oki Setyandito[2], Nizam[3], Aprijanto[1], Andri Subandriya[4], Aries Taufiq Kurniawan[5], Agus Sudaryanto[6], and Bayu Sutejo[7]

[1]Integrated Port-Coastal Zone Planning and Management Research Group, Research Center for Hydrodynamic Technology, National Research and Innovation Agency (BRIN), Jakarta, Indonesia

[2]Civil Engineering Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

[3]Department of Civil and Environment Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia

[4]Research Center for Energy Conversion and Conservation, National Research and Innovation Agency (BRIN), Jakarta, Indonesia

[5]Master Program in System Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia

[6]Research Center for Environmental and Clean Technology, National Research and Innovation Agency (BRIN), Banten, Indonesia

[7]Geospatial for Disaster and Energy Potential, Geospatial Research Center, National Research and Innovation Agency (BRIN), Bogor, Indonesia 16911

*Author to whom correspondence should be addressed:
Email: yureana.wijayanti@binus.ac.id

(Received February 8, 2023; Revised August 15, 2023; accepted September 2, 2023).

Abstract: Wave energy is a promising renewable resource and is increasingly in demand in most countries, including Indonesia. The potential for the use of wave energy is quite large in Indonesia, especially in areas with coastlines that are directly exposed to open ocean waters. The use of this wave energy has the potential to be integrated with breakwater buildings in several locations as an alternative that can be considered. This is a significant solution, especially in areas where the implementation of network connections is not possible. However, wave energy technology among other renewable technologies is still considered in ongoing development. Another obstacle is the challenge of energy transfer where there is a requirement for a steady and uninterrupted energy supply, while the voltage generated from the surge can vary continuously. Therefore, this paper shows a general overview of wave energy converter (WEC) technology and power conversion. A solid perception concerning them is outlined. Furthermore, this paper describes research and projects for energy conversion and wave power as well as alternatives to WEC technology and suitable locations in Indonesia.

Keywords: wave energy; power take-off; renewable energy; ocean energy; power conversion

1. Introduction

Wave energy has emerged as a renewable energy source[1)], besides solar[2–5)], wind[6,7)], biomass[8–11)], and geothermal[12,13)], which already developed earlier, due to the energy crisis and environmental concerns[14,15)]. One of the many benefits of wave energy is the percentage of power generation. Wave energy power is up to 90% compared to wind or solar devices is 20-30%[1)]. Also, it has high applicability regarding the location where around 37% of the world's population lives in the coastal area[16)] and it has relatively low obstacles from the coastal environment[1)] and from social conflict[17,18)]. However, there are challenges in wave energy technology, such as wave energy implementation requires stages to convert the oscillatory motion of waves into electricity output to the grid[19,20)], the power level varies in accordance with wave height and period which inquire certain energy storage system types to ensure a regular power output[21,22)] and funding barrier as the wave energy converter plant needs large investment[23]. Important factors to evaluate wave energy resources are wave variability[24], wave climate availability[25], and power estimation[16]. A steady and moderate wave is more reliable than a strong but unsteady wave, hence the sites with a such steady wave are more appropriate for the implementation of wave energy[26]. Many researchers have conducted research and evaluation on wave energy resources of areas or countries, such as Swedish[27], Australia[28], Africa[29], China[30–33], and Indonesia[34,35].

The policy of Indonesian national energy stated that the renewable energy target is at least 23% of the total energy power must be met by 2025[36]. In the meantime, in 2022, the quantity of renewable energy power plants is around 11.6%, which is still below the target of national installed capacity[37]. Water for energy is one of the alternatives to the problem of an increase in energy demand[38,39]. Indonesia has a coastline of 54,716 km[40] and is located between two oceans that have enormous potential to be used as new renewable energy. Rizal and Ningsih[35] have conducted research on 20 locations of wave energy throughout Indonesia. A site can be selected for the placement of a wave power generation system if the annual mean wave energy is > 15 kW/m[41]. Furthermore, the southern location of Java also has the potential for wave energy[42,43], and even Bali and West Nusa Tenggara have wave energy available throughout the year[44]. This finding is in alignment with other research results and shows that south java[45] and the sea south of Kuta Bali are potential locations for the placement of a wave energy generation system[46]. Meanwhile, a study on Sumatra's west coast was conducted regarding evaluating the potential for wave energy[47]. Ribal et al.[48] have developed a map of wave energy flux in Indonesia using a satellite with a high resolution of about 5.5 km (Figure 1).

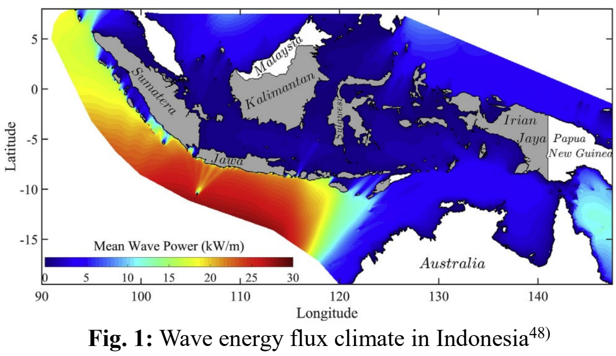


Fig. 1: Wave energy flux climate in Indonesia[48]

The mean wave power in Indonesia can reach up to 30 kW/m or potentially higher. Small islands located farther north and west of Sumatra can also tap into wave power as an alternative energy source, reducing their reliance on electricity from the mainland. The study also revealed that wave energy is consistently accessible year-round in certain areas, such as the southern part of Java Island, Bali Island, and West Nusa Tenggara. In the west Sumatera region, wave energy shows great potential specifically from March to November, offering a substantial resource during that period.

There have been many studies related to wave energy potential and studies related to technology[35,36], however, it is still rare to discuss the Power take-off (PTO) technology which is the core part of the wave energy converter (WEC) that has the potential to be applied in Indonesia. Likewise, when carrying out efficiency calculations and economic feasibility studies depend on the PTO system[49].

This paper aimed to review the wave energy converters and power conversions in Indonesia that can be used to understand their status and further research direction in energy conversion or PTO systems. This paper will briefly describe WEC and PTO, then proceed with looking at the research studies on WEC and PTO that have been carried out to understand the description of their applications in Indonesia.

2. Methods

The approach employed in this review relies on a scoping review protocol developed using the Preferred Reporting of Items for Systematic Reviews and Meta-Analysis (PRISMA). Figure 2 shows the PRISMA flow diagram.

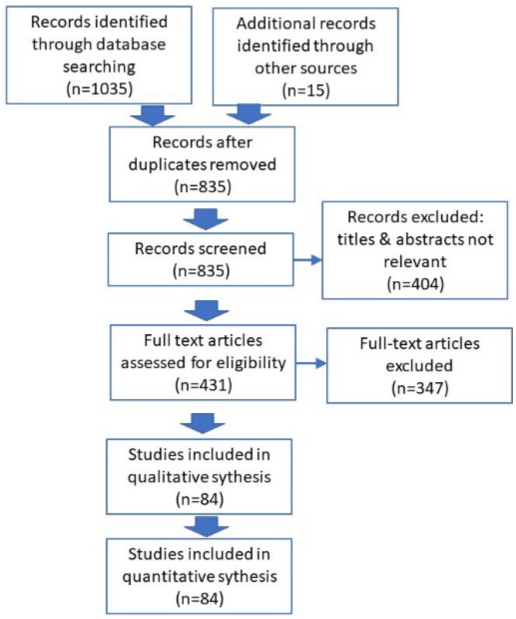


Fig. 2: PRISMA flow diagram for the study

It consists of several steps[50] such as defining eligibility criteria, defining information sources, study selection, data collection process, data item selection, and eligibility criteria. A systematic search was conducted to find all articles published in English and other languages related to the subject of the current review from 2000 to 2022 in Scopus, Science Direct, Web of Science, Taylor and Francis as well as Google Scholar databases[51,52]. Scopus, being widely recognized for its extensive range of bibliometric data[52-53], is the preferred choice. Previous authors[54,55] who conducted systematic literature reviews on construction materials also utilized the Scopus database, thus validating its selection as the data retrieval tool for this review. To ensure the relevance of journal articles to the current investigation, an inclusion/exclusion criterion was established. The search strings or keywords used for the search are "wave energy, wave energy converter, power technology in coastal and marine areas, site for wave energy converter, tidal energy, marine renewable energy, and ocean current power generation". The articles found were then selected according to the scope of the subject of this current review.

3. Result and discussion

3.1. Variety of wave energy converters

WEC devices are designed and developed according to their location of harvest. It can be located offshore, nearshore, or onshore, which is defined by the gap between the beach line and the sea water level of the WEC location[16,56] (Figure 3).

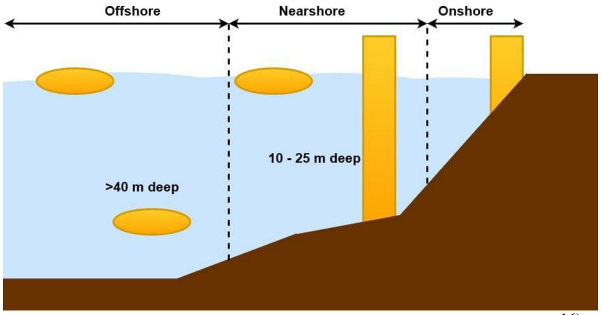
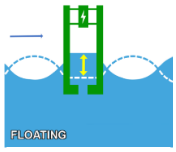
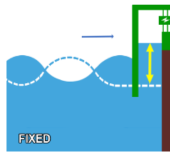
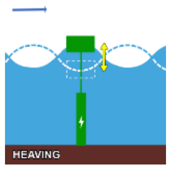
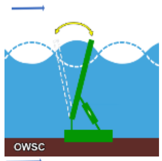
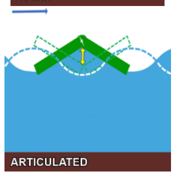
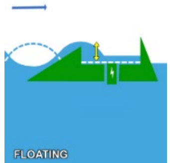
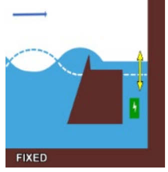


Fig. 3: A typical WEC location at the marine waters[16]

WEC devices located onshore are either attached to a breakwater or placed on the coastline area. The working principles that are suitable for this location are oscillating water column (OWC) or overtopping (OT) devices. In OWC, the water pressure is directed across a chamber column[19], while in OT, the water pressure is captured in the form of a reservoir wave energy extraction[57]. The objective of these techniques is to increase the wave's pressure[58] or air pressure[59] to generate electricity.

The advantage of the onshore location is easy to maintain, has a lower cost (absence of mooring cable), and has fewer obstacles[60]. On the other hand, waves onshore are weakened, hence the energy is low. Examples of WEC onshore devices are Limpet and SSG, for OWC and OT, respectively[56,61] (Table 1).

Table 1. WEC technology categories based on their working principles and locations[16,56].

WEC categories	Working principles	Location and example of device
Oscillating Water Column (OWC)	 	• Onshore : Limpet • Nearshore : Oceanlix • Offshore : OE Buoy
Oscillating Body or Water Activated Bodies (WAB)	  	• Nearshore : CETO III, Oyster, Seareaser, WaveStar • Offshore : Archimides Wave Swing AWS, PowerBuoy, Pelamis
Overtopping (OT)	 	• Onshore : SSG • Nearshore : Waveplane • Offshore : Wave dragon

The working principle suitable for nearshore WEC devices is OWC, OT, or water-activated bodies (WAB). The points that should be taken into consideration in applying these devices are mooring cost, sea cable placement, and the possibility of medium wave energy (located before the wave-breaking zone). Some examples of nearshore WEC devices which has been implemented are CETO and Oyster in the UK and WaveStar in Denmark.

Research on WEC around the world in 2017-2021 shows that the oscillating body type is the most studied type, followed by OWC and WEC overtopping[60] (Table 2).

Table 2. WEC research locations from 2017-2021[60]

Author Affiliation	Oscillating Water Column					Oscillating Water Body					Overtopping (WEC)				
Year 2017-2021	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
China	256	353	471	620	754	504	680	856	1038	1382	9	16	18	17	33
Indonesia	NA	3	2	2	4	5	4	4	12	8	NA	NA	NA	NA	NA
South Korea	28	27	33	32	47	74	77	88	71	91	6	NA	2	1	2
Japan	30	40	44	61	57	78	100	115	119	118	2	2	1	2	2
Malaysia	11	5	11	13	10	19	16	24	23	31	3	NA	NA	NA	1
Singapore	9	24	18	23	17	36	52	38	43	39	1	1	1	2	NA
Thailand	2	3	6	8	3	3	6	6	9	15	NA	NA	NA	NA	NA
Vietnam	2	3	4	4	2	4	10	9	18	6	1	NA	NA	1	NA
Canada	48	65	65	78	77	96	96	115	121	180	NA	5	1	NA	3
Germany	110	88	108	112	126	223	222	232	245	267	NA	NA	NA	NA	1
France	95	105	99	110	121	165	158	169	218	218	3	1	1	NA	1
Italy	81	95	92	82	102	163	177	200	173	184	3	2	8	8	3
Netherlands	27	32	28	41	31	62	70	60	79	54	1	1	NA	3	2
Spain	121	96	116	114	127	131	131	169	159	170	9	9	14	8	1
UK	78	90	99	143	121	170	214	196	219	246	5	9	14	4	11
USA	211	230	219	278	280	410	393	443	458	518	5	5	7	4	3

There are 3 (three) ways to harness wave power: hydraulically, pneumatically, and mechanically. These forms of gaining energy are called Take-Off systems or Power take-off (PTO)[62], and they consist of several phases depending on the types of conversions that occur (primary, secondary, and tertiary conversion) until gaining the correct signal for input to the grid[63] (Figure 4).

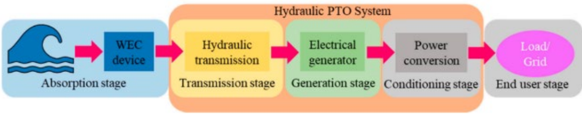


Fig. 4: Stages of wave energy conversion, modified from Jusoh et.al[63]

Primary conversion is the conversion of wave motion (in airflow, water flow, or body movement) through hydraulic, pneumatic, or mechanical systems[1]. The objective of this conversion is to transform the waves' low frequency (1 Hz) into a quick movement by pneumatic and mechanical systems, to enhance the velocity of the flow. Secondary conversion includes the energy conversion from the generated workflow in the previous stage, into electricity. The components employed for this are hydraulic turbines and pneumatic turbines and electrical generators. Tertiary conversion delivers the correct power signal for grid input.

PTO systems are a very important element of WEC. The feasibility of the WEC relies on its PTO system. Many various concepts have been conducted to design the PTO system of the WEC[49] (Figure 5). The PTO system's working methods most used methods are the hydraulic motor, turbine transfer, and direct mechanical and direct electrical drive. Yet, there are some new methods such as hybrid systems, triboelectric nanogenerators, and others.

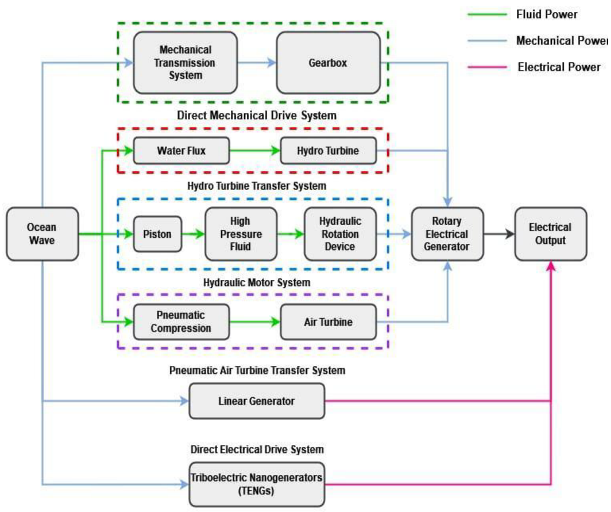


Fig. 5: The PTO system's working principles, modified from Ahmed et al.[49]

Estimating the economic value of a newly developed wave energy converter during its journey from conceptualization to commercialization poses a challenge. The widely accepted metric for assessing the economic potential of energy technologies is the levelized cost of energy (LCoE)[64]. Nevertheless, estimating the LCoE for wave energy technologies is complicated by the absence of dominant technology and uncertainties related to untested PTO system[65,66,59,67].

3.2. Discussion

WEC system research and projects are developed into simulation and experimental. The experimentation consists of laboratory and small-scale prototypes. Several simulation models, laboratory-sized experiments, and small-scale prototypes are included in this paper. In Indonesia, several researchers have also studied the potential application of WEC technology in electrical energy such as OWC, oscillating body, and overtopping. A summary of the WEC research in Indonesia is presented in Table 3.

Table 3. Types of WEC Research in Indonesia

WEC	PTO	Reference
Oscillating water column (OWC)	Pneumatic	68,69,70,71,72)
	N/A	73,74,75,76)
Oscillating body (water activated bodies) using Pelamis, AquaBuoy & Wavebob located offshore	Hydraulic	77)
Oscillating body, Floating WEC using RM3	Hydraulic	78)
Oscillating body, Floating WEC using WaveStar, located onshore	N/A	74,79)
Hybrid, Floating WEC with solar & wind energy	Hydraulic	80)

Rahman & Setiyawan[69] simulate the OWC devices that the electricity generated is enough for Alindau Village demand. Other researchers conducted a laboratory experiment on the ocean wave characteristics' effect on air pressure in OWC[68]. The potential of electrical energy generation by the OWC located at 3 locations on the nearshore of Baron Beach was simulated, and one OWC device can produce 4.7 MWh/year of electricity[70]. OWC was also studied by integrating simulation and prototype approach to determine the potential rotation of electric motor drive shaft in the design of the ocean wave power plant buoy system, located in Bangka Island, Sumatera[71,72]. A laboratory experiment was also conducted by Husain[75] on OWC modification using a double-water-chamber type seawall, which was designed to enhance the effective wavelength to increase the efficiency rate and decrease the reflection wave.

Floating WEC located onshore was studied by Madi et al.[79], where a laboratory scale experiment was performed in a 1:20 scale model of a flap-float horizontal WEC to study the effect of its arm design. Further study should be conducted using irregular waves. Aji et al.[78] conducted a simulation of a floating-point absorber buoy, using the RM3 device on the Sumatras' west coast (south Pagai Island II, Enggano Island), southern coast of Java (Cilacap and Jember area), and south coast of Bali. Another simulation on floating WEC was performed by Jufri et al.[64]

Haryuda et al.[80] proposed hybrid wind energy, photovoltaic (PV), and floating WEC system with a hydraulic system to rotate a 1 KW power 3 phase power generator. The result of this experiment shows that solar PV systems hybrid with WEC produce electricity higher than a hybrid with wind turbines. Setyandito et al.[83] conducted a laboratory experiment of overtopping WEC, where this device was intended to be attached to the breakwater structure. However, this study is still preliminary and should continue to determine the PTO system that is suitable for this type of WEC. Wahyudie et al.[77] was determining the most suitable locations for the WEC installation on the south coast of Yogyakarta and Central Java province. After that, the performance of 3 (three) floating WEC devices of the Pelamis (offshore semi-submerged slack-moored WEC), the AquaBuoy (offshore semi-submerged heaving WEC), and the Wavebob (offshore two-body heaving WEC), was examined in two sites off the coast of Penyu Bay and Yogyakarta. For these sites, the Pelamis produced the highest average annual energy yield of 1.35 GWh, and 1.11 GWh, for the Yogyakarta site and Penyu Bay site, respectively. It is because regarding wave-to-wire efficiency, the Pelamis has higher efficiency of wave power in low intensities. The electrical energy yielded by solar photovoltaic and floating WEC is 3,574 KW.

The electrical energy produced by wind turbines and floating WEC is 3,397 KW. The hybrid WEC incorporates other renewable energy sources to ensure a continuous power supply[84]. This integration could also benefit lowering the cost by using the established offshore wind turbines[20] or/and solar photovoltaic.

4. Conclusion

The effective utilization of renewable resources holds great promise in Indonesia due to its extensive coastline and abundant wave resources. One of the challenges, however, lies in refining the method of harnessing wave power. Across the globe, there has been substantial research and implementation of Wave Energy converter (WEC) devices. This brief review aims to shed light on the existing WEC technology, encompassing its power conversion systems, as well as the ongoing WEC research landscape in Indonesia. Additionally, this review unveils select studies pinpointing optimal wave energy harvesting locations. These locations are situated in south Java, Bali, and west Sumatra. The southern location of Java, even Bali, and West Nusa Tenggara have wave energy available throughout the year reaching 30 kW/m. Several researchers have also studied the potential application of WEC to electrical energy such as OWC, oscillating body, and overtopping. The potential locations for the WEC installation are on the Indian Ocean, on the south coast of Yogyakarta, and in Central Java province. The Pelamis produced the highest average annual energy yield of 1.35 GWh. Regarding wave-to-wire efficiency, the Pelamis has higher efficiency of wave power in low intensities. This is an interesting finding that the Pelamis device shows high energy production The potential for this wave energy market niche is developed in small and remote islands in Indonesia which are far from the reach of integrated electricity such as the coastal areas of North Maluku, West Papua and Papua, NTT or the WEC system installed in this location can be an alternative energy source for electrical energy has increased. Hence, the WEC system installed in this location could be an alternative energy source for this area. The integration of WCE and other established offshore renewable energy source (e.g wind turbine or/and solar PV) not only stabilize power output fluctuations but also could reduce the cost. Hence, it will increase competitiveness in its implementation.

The research on WEC is mainly focused on developing WEC extraction devices, optimizing WEC devices, and/or oceanography study. The research on PTO system development in Indonesia is still at an early phase, therefore further research in energy conversion or PTO system is encouraged to understand the efficiency, reliability, and cost factor of the overall WEC system.

Acknowledgments

We would like to thank our institutions of National Research and Innovation Agency, Bina Nusantara University, and Gadjah Mada University which facilitate us in conducting collaboration work.

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