

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

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

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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 source¹, besides solar²⁻⁵, wind^{6,7}, biomass⁸⁻¹¹, 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 area¹⁶ and it has relatively low obstacles from the coastal environment¹ 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 investment²³). Important factors to evaluate wave energy resources are wave variability²⁴), wave climate availability²⁵), and power estimation¹⁶). 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 energy²⁶). Many researchers have conducted research and evaluation on wave energy resources of areas or countries, such as Swedish²⁷), Australia²⁸), Africa²⁹), China³⁰⁻³³), 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 2025³⁶). 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 capacity³⁷). 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 km⁴⁰) and is located between two oceans that have enormous potential to be used as new renewable energy. Rizal and Ningsih³⁵) 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/m⁴¹). 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 year⁴⁴). This finding is in alignment with other research results and shows that south java⁴⁵) and the sea south of Kuta Bali are potential locations for the placement of a wave energy generation system⁴⁶). Meanwhile, a study on Sumatra's west coast was conducted regarding evaluating the potential for wave energy⁴⁷). 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).

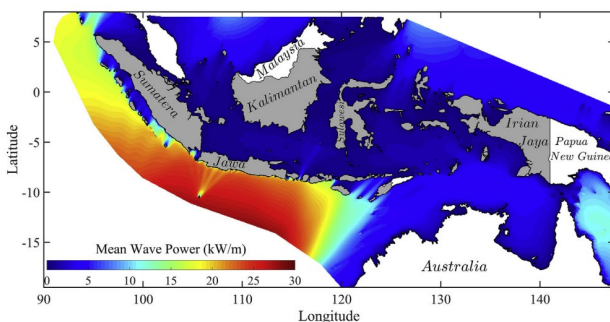


Fig. 1: Wave energy flux climate in Indonesia⁴⁸)

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 system⁴⁹).

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.

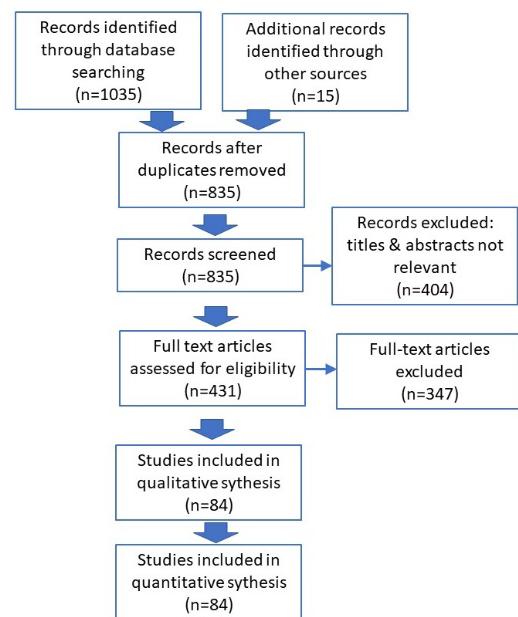


Fig. 2: PRISMA flow diagram for the study

It consists of several steps⁵⁰) 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 data⁵²⁻⁵³), 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).

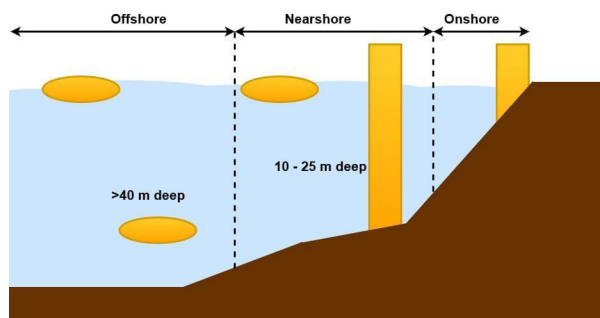


Fig. 3: A typical WEC location at the marine waters¹⁶

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 column¹⁹), while in OT, the water pressure is captured in the form of a reservoir wave energy extraction⁵⁷). The objective of these techniques is to increase the wave's pressure⁵⁸ or air pressure⁵⁹) to generate electricity.

The advantage of the onshore location is easy to maintain, has a lower cost (absence of mooring cable), and has fewer obstacles⁶⁰). 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)	<p>FLOATING</p> <p>FIXED</p>	<ul style="list-style-type: none"> Onshore : Limpet Nearshore : Oceanlix Offshore : OE Buoy
Oscillating Body or Water Activated Bodies (WAB)	<p>HEAVING</p> <p>OWSC</p> <p>ARTICULATED</p>	<ul style="list-style-type: none"> Nearshore : CETO III, Oyster, Seareaser, WaveStar Offshore : Archimedes Wave Swing AWS, PowerBuoy, Pelamis
Overtopping (OT)	<p>FLOATING</p> <p>FIXED</p>	<ul style="list-style-type: none"> 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 overtopping⁶⁰) (Table 2).

Table 2. WEC research locations from 2017-2021⁶⁰⁾

Author Affiliation	Oscillating Water Column					Oscillating Water Body					Overtopping (WEC)				
	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
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 grid⁶³⁾ (Figure 4).

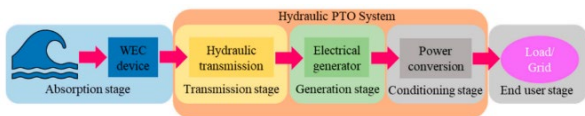


Fig. 4: Stages of wave energy conversion, modified from Jusoh et.al⁶³⁾

Primary conversion is the conversion of wave motion (in airflow, water flow, or body movement) through hydraulic, pneumatic, or mechanical systems¹⁾. 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 WEC⁴⁹⁾ (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.

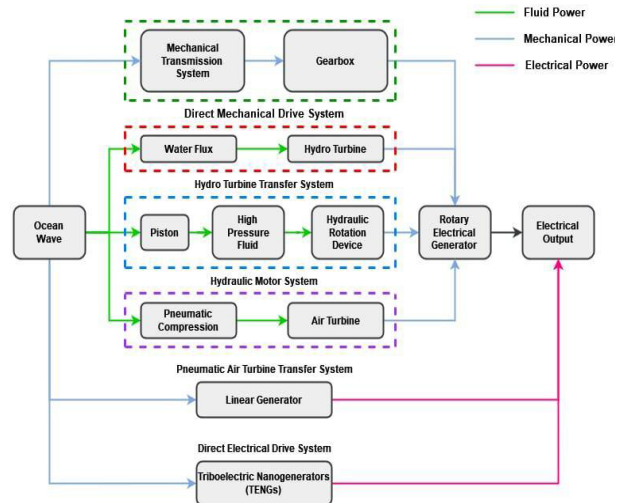


Fig. 5: The PTO system's working principles, modified from Ahmed et al.⁴⁹⁾

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 & Setiyawan⁶⁹⁾ 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 OWC⁶⁸⁾. 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 electricity⁷⁰⁾. 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 Husain⁷⁵⁾ 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 supply⁸⁴⁾. This integration could also benefit lowering the cost by using the established offshore wind turbines²⁰⁾ 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.

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References

- 1) B. Drew, A.R. Plummer, and M.N. Sahinkaya, "A review of wave energy converter technology," *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, **223** (8) 887–902 (2009). doi:10.1243/09576509JPE782.
- 2) I. Roihan, K. Tjandaputra A., E.A. Setiawan, and R.A. Koestoer, "Installing and testing the grashof portable incubator powered using the solar box 'be-care' for remote areas without electricity," *Evergreen*, **7**(4) 621–628 (2020). doi:10.5109/4150516.
- 3) K. Marzia, M.F. Hasan, T. Miyazaki, B.B. Saha, and S. Koyama, "Key factors of solar energy progress in bangladesh until 2017," *Evergreen*, **5**(2) 78–85 (2018). doi:10.5109/1936220.
- 4) P. Byrne, N. Putra, T. Maré, N. Abdallah, P. Lalanne, I. Alhamid, P. Estelle, A. Yatim, and A.L. Tiffonnet, "Design of a solar ac system including a pcm storage for sustainable resorts in tropical region," *Evergreen*, **6**(2) 143–148 (2019). doi:10.5109/2321009.
- 5) H.A. Jaffar, A.A. Ismaeel, and A.L. Shurajji, "Review of hybrid photovoltaic- air updraft solar application: present and proposed state models," *Evergreen*, **9**(4) 1181–1202 (2022). doi:10.5109/6625729.
- 6) A.M.M. Ismaiel, and S. Yoshida, "Study of turbulence intensity effect on the fatigue lifetime of wind turbines," *Evergreen*, **5**(1) 25–32 (2018). doi:10.5109/1929727.
- 7) R.A. Jessam, "Experimental study of wind turbine power generation utilizing discharged air of air conditioner blower," *Evergreen*, **9**(4) 1103–1109 (2022). doi:10.5109/6625722.
- 8) Z.F. Zahara, "Economic assessment of the sugarcane-based bio-refinery in indonesia," *Evergreen*, **5**(2) 67–77 (2018). doi:10.5109/1936219.
- 9) N.B. Prihantini, N. Rakhmayanti, S. Handayani, W. Sjamsuridzal, W. Wardhana, and Nasruddin, "Biomass production of indonesian indigenous leptolyngbya strain on npk fertilizer medium and its potential as a source of biofuel," *Evergreen*, **7**(4) 593–601 (2020). doi:10.5109/4150512.
- 10) A. Rahman, N.B. Prihantini, and Nasruddin, "Biomass production and synthesis of biodiesel from microalgae synechococcus hs-9 (cyanobacteria) cultivated using bubble column photobioreactors," *Evergreen*, **7**(4) 564–570 (2020). doi:10.5109/4150507.
- 11) Y. Furutani, K. Norinaga, S. Kudo, J.I. Hayashi, and T. Watanabe, "Current situation and future scope of biomass gasification in japan," *Evergreen*, **4**(4) 24–29 (2017). doi:10.5109/1929681.
- 12) Y. Gunawan, N. Putra, E. Kusri, I.I. Hakim, and M.D.H. Setiawan, "Study of heat pipe utilizing low-temperature geothermal energy and zeolite-a for tea leaves withering process," *Evergreen*, **7**(2) 221–227 (2020). doi:10.5109/4055223.
- 13) B. Prasetyo, Suyanto, M.A.M. Oktaufik, and S. Himawan, "Design, construction and preliminary test operation of bppt-3mw condensing turbine geothermal power plant," *Evergreen*, **6**(2) 162–167 (2019). doi:10.5109/2321012.
- 14) N. Bhasin, R.N. Kar, and N. Arora, "Green disclosure practices in india: a study of select companies," *Evergreen*, **2**(2) 5–13 (2015). doi:10.5109/1544075.
- 15) M.K. Barai, and B.B. Saha, "Energy security and sustainability in japan," *Evergreen*, **2**(1) 49–56 (2015). doi:10.5109/1500427.
- 16) I. López, J. Andreu, S. Ceballos, I. Martínez De Alegría, and I. Kortabarria, "Review of wave energy technologies and the necessary power-equipment," *Renewable and Sustainable Energy Reviews*, **27** 413–434 (2013). doi:10.1016/j.rser.2013.07.009.
- 17) N.A. Pambudi, V.S. Pramudita, M.K. Biddinika, and S. Jalilinasrabad, "So close yet so far - how people in the vicinity of potential sites respond to geothermal energy power generation: an evidence from indonesia," *Evergreen*, **9**(1) 1–9 (2022). doi:10.5109/4774210.
- 18) M. Muslihudin, W.R. Adawiyah, E. Hendarto, R.D. Megasari, and M.F. Ramadhan, "Environmental constraints in building process a sustainable geothermal power plant on the slopes of slamet mount, central java, indonesia," *Evergreen*, **9**(2) 300–309 (2022). doi:10.5109/4793669.
- 19) N. Delmonte, D. Barater, F. Giuliani, P. Cova, and G. Buticchi, "Review of oscillating water column converters," *IEEE Trans Ind Appl*, **52** (2) 1698–1710 (2016). doi:10.1109/TIA.2015.2490629.
- 20) E. Rusu, and F. Onea, "A review of the technologies for wave energy extraction," *Clean Energy*, **2** (1) 10–19 (2018). doi:10.1093/ce/zky003.
- 21) A. Babarit, "A database of capture width ratio of wave energy converters," *Renew Energy*, **80** 610–628 (2015). doi:10.1016/j.renene.2015.02.049.
- 22) D. Clemente, P. Rosa-Santos, and F. Taveira-Pinto, "On the potential synergies and applications of wave energy converters: a review," *Renewable and Sustainable Energy Reviews*, **135** (2021). doi:10.1016/j.rser.2020.110162.
- 23) D. Wang, D. Conley, M. Hann, K. Collins, S. Jin, and D. Greaves, "Power output estimation of a rm3 wec with hf radar measured complex representative sea states," *International Marine Energy Journal*, **5** (1) 1–10 (2022). doi:10.36688/imej.5.1-10.
- 24) N. Khan, A. Kalair, N. Abas, and A. Haider, "Review of ocean tidal, wave and thermal energy technologies," *Renewable and Sustainable Energy Reviews*, **72** 590–604 (2017). doi:10.1016/j.rser.2017.01.079.
- 25) A. Roberts, B. Thomas, P. Sewell, Z. Khan, S. Balmain, and J. Gillman, "Current tidal power technologies and their suitability for applications in coastal and marine areas," *J Ocean Eng Mar Energy*, **2** (2) 227–245 (2016). doi:10.1007/s40722-016-0044-8.
- 26) C. Iuppa, L. Cavallaro, D. Vicinanza, and E. Foti, "Investigation of suitable sites for wave energy

- converters around sicily (italy)," *Ocean Science*, **11** (4) 543–557 (2015). doi:10.5194/os-11-543-2015.
- 27) V. Castellucci, and E. Strömstedt, "Sea level variability in the swedish exclusive economic zone and adjacent seawaters: influence on a point absorbing wave energy converter," *Ocean Science*, **15** (6) 1517–1529 (2019). doi:10.5194/os-15-1517-2019.
 - 28) P. Marsh, I. Penesis, J.R. Nader, and R. Cossu, "Multi-criteria evaluation of potential australian tidal energy sites," *Renew Energy*, **175** 453–469 (2021). doi:10.1016/j.renene.2021.04.093.
 - 29) H. Bouhrim, and A. El Marjani, "Wave energy assessment along the moroccan atlantic coast," *Journal of Marine Science and Application*, **18** (2) 142–152 (2019). doi:10.1007/s11804-018-00060-8.
 - 30) Y.C. Chang, P.C. Chu, and R.S. Tseng, "Site selection of ocean current power generation from drifter measurements," *Renew Energy*, **80** 737–745 (2015). doi:10.1016/j.renene.2015.03.003.
 - 31) Y. Li, N. Ren, X. Li, and J. Ou, "Hydrodynamic analysis of a novel modular floating structure system integrated with floating artificial reefs and wave energy converters," *J Mar Sci Eng*, **10** (8) (2022). doi:10.3390/jmse10081091.
 - 32) H. Shi, X. Zhang, W. Du, Q. Li, H. Qu, and Z. You, "Assessment of wave energy resources in china," *J Mar Sci Eng*, **10** (11) (2022). doi:10.3390/jmse10111771.
 - 33) Y. Wan, C. Fan, J. Zhang, J. Meng, Y. Dai, L. Li, W. Sun, P. Zhou, J. Wang, and X. Zhang, "Wave energy resource assessment off the coast of china around the zhoushan islands," *Energies (Basel)*, **10** (9) (2017). doi:10.3390/en10091320.
 - 34) I. Alifdini, D.N. Sugianto, Y.O. Andrawina, and A.B. Widodo, "Identification of wave energy potential with floating oscillating water column technology in Pulau Baai Beach, Bengkulu," in: IOP Conf Ser Earth Environ Sci, Institute of Physics Publishing, 2017. doi:10.1088/1755-1315/55/1/012040.
 - 35) A.M. Rizal, and N.S. Ningsih, "Description and variation of ocean wave energy in indonesian seas and adjacent waters," *Ocean Engineering*, **251** 111086 (2022). doi:10.1016/j.oceaneng.2022.111086.
 - 36) PT PLN, "Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero) 2021-2030," 2021. <https://web.pln.co.id/statics/uploads/2021/10/ruptl-2021-2030.pdf> (accessed June 6, 2023).
 - 37) IESR Institute for Essential Services Reform, "Indonesia Energy Transition Outlook 2022," 2022. www.iesr.or.id.
 - 38) H.Y.S.H. Nugroho, D.R. Indrawati, N. Wahyuningrum, R.N. Adi, A.B. Supangat, Y. Indrajaya, P.B. Putra, S.A. Cahyono, A.W. Nugroho, T.M. Basuki, E. Savitri, T.W. Yuwati, B.H. Narendra, M.K. Sallata, M.K. Allo, A.R. Bisjoe, N. Muin, W. Isnani, F. Ansari, A. Sudomo, and A. Hani, "Toward water, energy, and food security in rural indonesia: a review," *Water (Switzerland)*, **14** (10) (2022). doi:10.3390/w14101645.
 - 39) Y. Wijayanti, M. Anda, L. Safitri, S. Tarmadja, Juliastuti, and O. Setyandito, "Water-energy nexus development for sustainable water management in Indonesia," in: IOP Conf Ser Earth Environ Sci, Institute of Physics Publishing, 2020. doi:10.1088/1755-1315/426/1/012058.
 - 40) CIA Coastline, "The world factbook," <https://www.cia.gov/the-world-factbook/Countries/Indonesia/>, (n.d.).
 - 41) A. Pecher, and J.P. Kofoed, "Handbook of Ocean Wave Energy," Springer International Publishing, Cham, 2017. doi:10.1007/978-3-319-39889-1.
 - 42) Irhas, and R. Suryaningsih, "Study on wave energy into electricity in the south coast of yogyakarta, Indonesia," in: Energy Procedia, Elsevier Ltd, 2014: pp. 149–155. doi:10.1016/j.egypro.2014.01.208.
 - 43) A.T. Kurniawan, R. Budiarto, R.B. Prasetyo, and A. Budiman, "Selecting an Ideal Site for Oscillating-Water-Column (OWC) Wave Energy Converter for Hydrogen Production in the Southern Coast of Yogyakarta, Indonesia," in: Proceeding - 1st International Conference on Information Technology, Advanced Mechanical and Electrical Engineering, ICITAMEE 2020, Institute of Electrical and Electronics Engineers Inc., 2020: pp. 35–40. doi:10.1109/ICITAMEE50454.2020.9398402.
 - 44) M.N. Habibie, M.A. Marfai, H. Harsa, and U.A. Linarka, "Spatial temporal analysis for potential wave energy resources in Indonesia," in: IOP Conf Ser Earth Environ Sci, IOP Publishing Ltd, 2021. doi:10.1088/1755-1315/893/1/012050.
 - 45) N.P. Purba, J. Kelvin, R. Sandro, S. Gibran, R.A.I. Permata, F. Maulida, and M.K. Martasuganda, "Suitable Locations of Ocean Renewable Energy (ORE) in Indonesia Region-GIS Approached," in: Energy Procedia, Elsevier Ltd, 2015: pp. 230–238. doi:10.1016/j.egypro.2015.01.035.
 - 46) I. Alifdini, N.A.P. Iskandar, A.W. Nugraha, D.N. Sugianto, A. Wirasatriya, and A.B. Widodo, "Analysis of ocean waves in 3 sites potential areas for renewable energy development in indonesia," *Ocean Engineering*, **165** 34–42 (2018). doi:10.1016/j.oceaneng.2018.07.013.
 - 47) A.M. Rizal, and N.S. Ningsih, "Ocean wave energy potential along the west coast of the sumatra island, indonesia," *J Ocean Eng Mar Energy*, **6** (2) 137–154 (2020). doi:10.1007/s40722-020-00164-w.
 - 48) A. Ribal, A. V. Babanin, S. Zieger, and Q. Liu, "A high-resolution wave energy resource assessment of indonesia," *Renew Energy*, **160** 1349–1363 (2020). doi:10.1016/j.renene.2020.06.017.
 - 49) R. Ahamed, K. McKee, and I. Howard, "Advancements of wave energy converters based on power take off (pto) systems: a review," *Ocean Engineering*, **204** (2020). doi:10.1016/j.oceaneng.2020.107248.
 - 50) J. Matsimbe, M. Dinka, D. Olukanni, and I. Musonda, "Geopolymer: A Systematic Review of

- Methodologies,” *Materials*, **15** (9) (2022). Doi: 10.3390/ma15196852
- 51) A. A. Chadegani, H. Salehi, M. M. Yunus, H. Farhadi, M. Fooladi, M. Farhadi, N. A. Ebrahim, “A Comparison between Two Main Academic Literature Collections: Web of Science and Scopus Databases,” *Asian Social Science*, **9** (5) (2013). Doi:10.5539/ass.v9n5p18
 - 52) E. M. L. Bergman, “Finding Citations to Social Work Literature: The Relative Benefits of Using Web of Science, Scopus, or Google Scholar,” *The Journal of Academic Librarianship*, **38** (6) (2012). Doi: 10.1016/j.acalib.2012.08.002
 - 53) L. I. Meho, “Using Scopus’s CiteScore for assessing the quality of computer science conferences,” *Journal of Informetrics* **13** (1) (2019). Doi: 10.1016/j.joi.2019.02.006
 - 54) W. Ahmad, A. Ahmad, K. A. Ostrowski, F. Aslam, P. Joyklad, “A scientometric review of waste material utilization in concrete for sustainable construction,” *Case Studies in Construction Materials* **15** (2021). Doi: 10.1016/j.cscm.2021.e00683
 - 55) B. Zhang, H. Zhu, P. Feng, P. Zhang, “A review on shrinkage-reducing methods and mechanisms of alkali-activated/geopolymer systems: Effects of chemical additives,” *Journal of Building Engineering* **15** (2022). Doi:10.1016/j.job.2022.104056
 - 56) S. Jin, S. Zheng, and D. Greaves, “On the scalability of wave energy converters,” *Ocean Engineering*, **243** 110212 (2022). doi:10.1016/j.oceaneng.2021.110212.
 - 57) L. Rusu, and F. Onea, “The performance of some state-of-the-art wave energy converters in locations with the worldwide highest wave power,” *Renewable and Sustainable Energy Reviews*, **75** 1348–1362 (2017). doi:10.1016/j.rser.2016.11.123.
 - 58) S. Kushwah, “An oscillating water column (owc): the wave energy converter,” *Journal of The Institution of Engineers (India): Series C*, **102** (5) 1311–1317 (2021). doi:10.1007/s40032-021-00730-7.
 - 59) A.F.O. Falcão, and J.C.C. Henriques, “Oscillating-water-column wave energy converters and air turbines: a review,” *Renew Energy*, **85** 1391–1424 (2016). doi:10.1016/j.renene.2015.07.086.
 - 60) M. Li, H. Luo, S. Zhou, G.M. Senthil Kumar, X. Guo, T.C. Law, and S. Cao, “State-of-the-art review of the flexibility and feasibility of emerging offshore and coastal ocean energy technologies in east and southeast asia,” *Renewable and Sustainable Energy Reviews*, **162** 112404 (2022). doi:10.1016/j.rser.2022.112404.
 - 61) H.M. Ramos, C. Teyssier, and P.A. López-Jiménez, “Optimization of retention ponds to improve the drainage system elasticity for water-energy nexus,” *Water Resources Management*, **27** (8) 2889–2901 (2013). doi:10.1007/s11269-013-0322-3.
 - 62) D. Gallutia, M. Tahmasbi Fard, M. Gutierrez Soto, and J. He, “Recent advances in wave energy conversion systems: from wave theory to devices and control strategies,” *Ocean Engineering*, **252** 111105 (2022). doi:10.1016/j.oceaneng.2022.111105.
 - 63) M.A. Jusoh, M.Z. Ibrahim, M.Z. Daud, A. Albani, and Z.M. Yusop, “Hydraulic power take-off concepts for wave energy conversion system: a review,” *Energies (Basel)*, **12** (23) (2019). doi:10.3390/en12234510.
 - 64) A. Tetu, J. F. Chozas, “A Proposed Guidance for the Economic Assessment of Wave Energy Converters at Early Development Stages,” *Energies* **14** (15) (2021). Doi: 10.3390/en14154699
 - 65) D. Magagna, R. Monfardini, A. Uihlein, “JRC Ocean Energy Status Report 2016th Edition,” Joint Research Centre, Directorate for Energy, Ed.; Technical , Report; Publication Office of the European Union: Luxembourg (2016). Available online:https://publications.jrc.ec.europa.eu/repository/bitstream/JRC104799/kj1a28407enn.pdf (accessed on 8 June 2023)
 - 66) J. F. Chozas, A. MacGillivray, A. A. Raventos, H. Jeffrey, K. Nielsen, D. Aderibigbe, “International Levelised Cost of Energy for Ocean Energy Technologies; Technical Report; Ocean Energy Systems (OES): Lisbon, Portugal (2015)
 - 67) Pecher, A.; Kofoed, J.P. Handbook of Ocean Wave Energy; Springer, Ocean Engineering & Oceanography: Cham, Switzerland (2017)
 - 68) J.U. Jasron, S. Soeparman, L. Yuliati, and D.B. Darmadi, “Experimental Study on the Effect of Ocean Wave Characteristics on Air Pressure in Oscillating Water Column Device,” in: IOP Conf Ser Mater Sci Eng, Institute of Physics Publishing, 2019. doi:10.1088/1757-899X/494/1/012019.
 - 69) Y.A. Rahman, and Setiyawan, “The Potential of Conversion of Sea Wave Energy to Electric Energy: The Performance of Central Sulawesi West Sea using Oscillating Water Column Technology,” in: IOP Conf Ser Earth Environ Sci, IOP Publishing Ltd, 2021. doi:10.1088/1755-1315/926/1/012073.
 - 70) A.T. Kurniawan, A. Budiman, R. Budiarto, and R.B. Prasetyo, “Wave energy potential using owc (oscillating water column) system at pantai baron, gunung kidul, di yogyakarta, indonesia,” *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, **92** (2) 191–201 (2022). doi:10.37934/arfmts.92.2.191201.
 - 71) R. Priyoko Prayitnoadi, F. Rosa, M. Hudatwi, M. Ubed Nurhadi, A. Febrianto, and N. Roliana, “Analysis of sea wave power plant design in Bangka Island Indonesia,” in: IOP Conf Ser Mater Sci Eng, Institute of Physics Publishing, 2019. doi:10.1088/1757-899X/694/1/012021.
 - 72) R. Walujo Prastianto, I. Syarif Arief, H. Laksana Guntur, and H. Setiyawan, “Performance modeling of a wave energy converter: pembangkit listrik tenaga gelombang laut sistem bandulan (‘Pltgl-sb’),” **11** (4) (2016). www.arpnjournals.com.
 - 73) F. Husain, “Effect of Wave Power Device

- Arrangement in Double-Water-Chamber Type Seawall towards Wave Power Extraction Rate and Wave Dissipation,” in: IOP Conf Ser Mater Sci Eng, Institute of Physics Publishing, 2020. doi:10.1088/1757-899X/875/1/012084.
- 74) Jufri, D. Paroka, Jalaluddin, and R. Tarakka, “The simulation buoy shape bullet of sea wave energy absorption based on diameter variations,” in: IOP Conf Ser Mater Sci Eng, Institute of Physics Publishing, 2020. doi:10.1088/1757-899X/885/1/012021.
- 75) F. Husain, M.R. Alwi, and Ashury, “Efficacy of Water Chamber Type Seawall to Dissipate Incident Wave and Its Performance to Extract Wave Power,” in: IOP Conf Ser Earth Environ Sci, Institute of Physics Publishing, 2018. doi:10.1088/1755-1315/135/1/012002.
- 76) F. Husain, M.Z.M. Alie, and T. Rahman, “Parameter Governing of Wave Resonance in Water Chamber and Its Application,” in: IOP Conf Ser Earth Environ Sci, Institute of Physics Publishing, 2018. doi:10.1088/1755-1315/140/1/012031.
- 77) A. Wahyudie, T.B. Susilo, F. Alaryani, C.S.A. Nandar, M.A. Jama, A. Daher, and H. Shareef, “Wave power assessment in the middle part of the southern coast of java island,” *Energies (Basel)*, **13** (10) (2020). doi:10.3390/en13102633.
- 78) N. Aji, E. Ekawati, and I.N. Haq, “The Simulation of Wave Energy Conversion by Floating Point Absorber Buoy in Indonesian Sea Waves,” in: 2021 International Conference on Instrumentation, Control, and Automation (ICA), IEEE, 2021: pp. 112–117. doi:10.1109/ICA52848.2021.9625671.
- 79) M. Madi, Mukhtasor, R.W. Prastianto, T. Tuswan, and A. Ismail, “Experimental study on the effect of arm design on the performance of a flap-float horizontal ocean wave energy converter,” *Nase More*, **69** (2) 77–83 (2022). doi:10.17818/NM/2022/2.1.
- 80) S.I. Haryuda, I.W. Susila, I.H. Siregar, and A. Aris, “Power Control of Grid-Connected Photovoltaic-Wind Turbin-Bouy Conversion Energy Wave Hybrid System,” in: IOP Conf Ser Mater Sci Eng, Institute of Physics Publishing, 2019. doi:10.1088/1757-899X/494/1/012074.
- 81) H.A. Imran, M.A. Thaha, M.P. Hatta, and B. Bakri, “Preliminary design of wave energy utilization model simulation for buoy type seawater pumps,” in: IOP Conf Ser Earth Environ Sci, IOP Publishing Ltd, 2021. doi:10.1088/1755-1315/841/1/012027.
- 82) B. Triasdian, Y.S. Indartono, N.S. Ningsih, and D. Novitasari, “Device Selection of the Potential Wave Energy Site in Indonesian Seas,” in: IOP Conf Ser Earth Environ Sci, Institute of Physics Publishing, 2019. doi:10.1088/1755-1315/291/1/012040.
- 83) O. Setyandito, N. Nizam, A.J. Pierre, G.D. Suputra, Y. Wijayanti, and M. Anda, “Numerical analysis of velocity magnitude on wave energy converter system in perforated breakwater,” *International Journal of Renewable Energy Development*, **11** (1) 27–33 (2022). doi:10.14710/ijred.2022.38535.
- 84) J. Burhanudin, A.S.A. Hasim, A.M. Ishak, J. Burhanudin, and S.M.F.B.S.M. Dardin, “A review of power electronics for nearshore wave energy converter applications,” *IEEE Access*, **10** 16670–16680 (2022). doi:10.1109/ACCESS.2022.3148319.