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Unlimited Energy Source: A Review of Ocean Wave Energy Utilization and Its Impact on the Environment

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ABSTRACT

This paper aims to review the potential of wave energy in several countries, the wave energy converter technology that has been developed, and the impact of the installation of wave energy converter technology devices on the environment. In addition, it discusses the theoretical formulations and challenges in the development of energy converter technology in the future. Based on the detail analysis, the potential of ocean wave energy for alternative energy is very large but cannot be used optimally because the technology of wave energy converter that has been developed is still on a prototype scale. In addition, the impact of the use of ocean wave converters on the environment is insignificant compared with conventional energy. Finally, this study informs and recommends the government and the private sector to start investing in the ocean wave energy industry optimally in order to achieve a sustainable future.

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1. INTRODUCTION

Climate change and environmental pollutions are a global issue that is currently often talked about by the world community. The use of fossil fuels such as coal contributes greatly to environmental changes and environmental pollutions (Rahmat & Mutolib, 2016). Based on the global status report about energy renewables in 2018, 79.5% of the total share of energy consumption in 2016 is fossil fuel consumption, followed by modern renewable energy sources by 10.4% including wind energy, solar, biomass, geothermal, ocean power, biofuel and hydropower (Hales, 2018). Fossil fuels consumption in a large quantity will cause negative impacts on the environment and the health of living things (Andika & Valentina, 2016). This is because fossil fuels, such as a coal, natural gas and petroleum, contain carbon gas with a high percentage. Carbon gas is a colorless gas, which is a carbon compound with oxygen, doesn't burn and dissolve in water. If the carbon gas is thrown into the air, it will form compounds with oxygen and carbon dioxide gas, which increases radiation and contributes to global warming (Ekwurzel *et al.,* 2017).

The high population growth each year causes the world's energy needs to continue to increase while the fossil fuel reserves continue to thin out. Therefore, there is a need for a renewable energy source to meet the world's energy needs (Aziz, 2019). Wave energy is an energy source that has the potential to become a renewable energy source because 70% of the parts of the earth are covered by the ocean (Feng *et al.,* 2018). The other advantages are: (i) the wave energy is the energy that can be used at any time; (ii) it will never run out; (iii) it does not cause pollution because of no waste produced; (iv) it is easy to convert the electrical energy from the mechanical energy to waves; (v) it has greater kinetic energy intensity compared to the other renewable energy because of the seawater density 830 times of the air density in the same volume (Irhas & Suryaningsih, 2014), ocean current turbines will be smaller than wind turbines; and (vi) it does not require an excessive strength design of structures like that of wind turbines that is designed by taking into account hurricanes because the seawater situation at a particular depth tends to be quiet and predictable.

Basically, the energy in sea surface waves is caused by several things, namely the pressure from the atmosphere that causes wind so that friction occurs on the sea surface, the earth gravitational force with the moon and the sun, the movement of plates from within the earth, and surface tension (Bouws *et al.,* 1998). Ocean waves can be viewed as waveforms that have a maximum peak height and a minimum valley. At certain intervals, peak heights are achieved by a series of different ocean waves, even the height of these peaks varies for the same location if measured on different days. However, statistically significant elevations of ocean waves can be determined at one specific location point.

In this paper, the authors reviewed the availability of ocean wave energy sources in several countries with various wave energy conversion technologies that have been developed and analyze how the impact of wave energy converters on pollution of the ocean environment. However, in developing technology it is necessary to pay attention to environmental factors in order to become environmentally friendly technology.

2. POTENTIAL OF OCEAN WAVE ENERGY SOURCES

The potential of the worldwide wave power in the recent study ranged between 8000 - 80,000 TWh/y (Khan *et al.,* 2017). Based on the world energy council 2016 world energy resources report about the wave energy potential, the Asian and Australasian regions (Australia, New Zealand, Pacific Islands) have the greatest amount of wave power of 6200 TWh/y and 5600 TWh/y, respectively, and South and North America also has a quite large amount, which is 4600 TWh/y and 4000 TWh/y. However, not all countries directly adjacent to the ocean have the potential for the large wave energy. Some places that have an annual average of the offshore wave power flux of more than 10 kW are Hawaii, Rarotonga of the Cook Islands, Fiji, Majuro of Marshal Islands, Federated States of Micronesia, Nauru, Samoa, Tonga, Tuvalu, Vanuatu, South-Coastal India, Maldives, Sri Lanka, South Java of Indonesia, Luzon and Babyan Islands of Philippines (Mork *et al.,* 2010)

Current researchers are still seeking for spots that have the potential for the wave power such as in Northwest Pacific with the wave power found of above 400 kW/m (Wan *et al.,* 2016), in Greek island of 2.88-2.99 kW/m (Ganea *et al.,* 2017), in Java and Bali southern coasts, Indonesia of 20 -40 kW/m (Ningsih *et al.,* 2019), in Terengganu and Sarawak, Malaysia of 2.8-8.6 kW/m (Nasir *et al.,* 2016), in the coasts of Turkey with the annual wave power of 3-17 kW/m (Ömeroğlu *et al.,* 2017), in Qeshm, Anzali and Chabahar Iran with an energy flux per unit of crest length of 500-600 W/m (Nezhad *et al.,* 2018), in Zhoushan Islands, China with the wave power density of 385.30 kW/m (Wan *et al.,* 2017), in the hotspots of Sardinia and Sicily, Italia of 11.4 kW/m and 9.1 kW/m (Vannucchi & Cappietti, 2016), and in the Rottnest Island, Australia with the wave power of more than 30 kW/m (Contestabile *et al.,* 2016).

This power plant has various advantages, such as the energy can be obtained for free; it does not require fuel; it does not produce waste; it can produce the energy in sufficient quantities; and it is environmentally friendly because it does not produce solid, liquid or gas waste. However, behind these advantages are several obstacles, namely the power plant is dependent on waves and sometimes it can also be energy, but sometimes not, meaning that this power plant cannot be used. Therefore, it is necessary to find a suitable location to install the wave energy technology, where the waves are strong and appear consistently. In addition, this power plant requires reliable conversion devices that are able to withstand the harsh conditions of the ocean environment caused by high levels of corrosion and strong ocean currents. The wave energy technology needs specific environmental conditions to be created. It is urgent to design structures that are able to efficiently harvest the energy transmitted by ocean waves and to survive from hurricanes where the wave power significantly increases (Rusu & Onea, 2018).

3. ENERGY AND FLUX IN OCEAN WAVE

Ocean waves are a series of sequential pulses that appear as the sea level changes, which is from the maximum elevation (peak) to the minimum elevation (valley). The wave arrangement in the ocean both in its form and type is very varied and complex, so it is very difficult to analyze. Therefore, the analysis of the ocean surface model used is based on some fairly simple assumptions: (i) the incompressibility of the seawater, which means that the seawater has constant density so that we can apply a fluid continuity equation; (ii) the in viscid nature of the water, which means that we suppose just only gravity and pressure are working because we do not know whether all of the forces are working and the friction is ignored; and (iii) the fluid current is not rotational, which means the individual particles will not rotate. They will move near each other and there are no turbulences (Bouws *et al.,* 1998).

The wave parameters consist of **a** for wave amplitude, **h** for wave height ($h = 2a$), **ω** for wave radian frequency, **f** for wave frequency ($f = 2\pi\omega$), **T** for wave period ($T = 1/f$),

λ for wavelength or distance between crests, **k** for wavenumber (k = 2π/λ), and **c** for phase speed (c = ω/k = λ/T). To describe the ocean wave's behavior, we use a Cartesian coordinate system by using the right hand, in which the upward thumb shows z-axis direction, the horizontal forefinger shows x-axis, and the horizontal middle finger shows y-axis. The ocean wave coincides with z = 0 when the ocean surface is in the rest state. When waves appear, the location of the surface is at z = η (x, y, t), where t is time. The location of the seabed at z = -h is flat, where h is a constant of the ocean depth as shown **Figure 1**.

Figure 1 describes a simple sinusoidal wave with number of wave parameter. We assume that a solution for the plane surface of the wave is with the amplitude moving in the positive x direction. Therefore, the solution for η (x, t) as

$$\eta = a \cos (kx - \omega t) \qquad (1)$$

describes the wave traveling in the x-axis, where a, ω and k are constants, and the relation between ω and k is

$$\omega = \sqrt{gk \tanh(kh)} \qquad (2)$$

where g is gravity constant and

$$\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \qquad (3)$$

is the tangent function of the hyperbolic.

We can get the wave energy E by the sum of potential energy (PE) and kinetic energy (KE). In this case, the wave energy is the depth-integrated average energy of waves over a wave period. First, we determine the instantaneous of the potential energy with the following formula:

$$PE = \frac{1}{2}\rho g a^2 cos^2 \omega t \qquad (4)$$

Then, we calculate the average time in equation (4) during a wave period with that the following:

$$PE = \frac{1}{4}\rho g a^2 \qquad (5)$$

Before we calculate the Kinetic Energy (KE), we must determine how is the velocity of fluid that depends on location and time. The velocity of the fluid is a vector field that depends on x, y, z, and t. Thus, we can write it as (Salmon, 2008)

$$V(x, y, z, t) = (u(x, y, z, t); v(x, y, z, t); w(x, y, z, t)) \qquad (6)$$

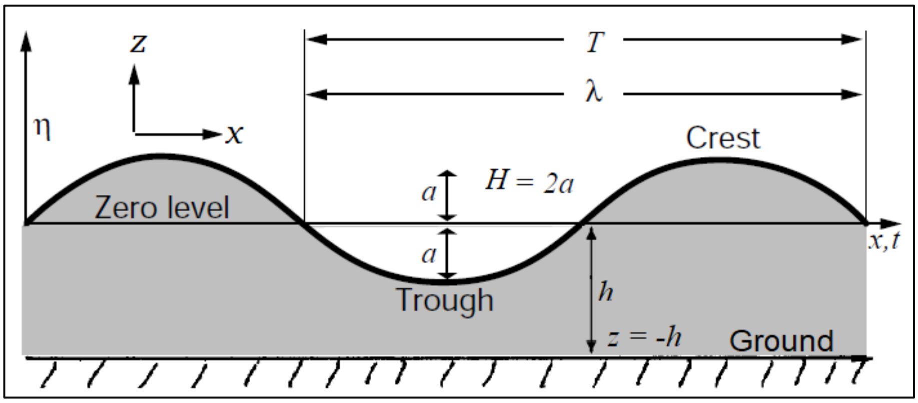

Figure 1. A simple sinusoidal wave

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For the wave described by in equations (1) and (2), the y-component of v is ignored, so v = 0. It means no velocity going out of the page. Therefore, we only use the x- and z-components, that is,

$$u = A\omega\frac{\cosh(k(h+Z))}{\sinh(kh)}\cos(kx-\omega t) \qquad (7)$$

$$w = A\omega\frac{\sinh(k(h+Z))}{\sinh(kh)}\sin(kx-\omega t) \qquad (8)$$

We suppose the wave is traveling to the right side although in fact it moves to the left too. This means that wavenumber k is positive. For the condition of the waves in the deep water, $kh \geq 1$. This means that the water depth h value is greater than a wavelength λ (Salmon, 2008). With the limit $kh \geq 1$, we get,

$$\tanh(kh) = 1 \qquad (9)$$

$$\frac{\cosh(k(h+z))}{\sinh(kh)} = e^{kz} \qquad (10)$$

$$\frac{\sinh(k(h+z))}{\sinh(kh)} = e^{kz} \qquad (11)$$

By using equations (9) (10) (11), we can determine some of the wave parameters in the deep water:

$$\eta = a\cos(kx-\omega t) \qquad (12)$$

$$\omega = \sqrt{gk} \qquad (13)$$

$$u = a\omega e^{kz}\cos(kx-\omega t) \qquad (14)$$

$$w = a\omega e^{kz}\sin(kx-\omega t) \qquad (15)$$

The next is calculating the kinetic energy, in which the local kinetic per unit volume is $\frac{1}{2}\rho|V|^2$, with the following integral formula:

$$KE = \frac{1}{2}\rho\int_{-h}^{0}|V|^2\,dz$$

$$KE = \frac{1}{2}\rho\int_{-h}^{0}(u^2+w^2)dz \qquad (16)$$

$$KE = \frac{1}{2}\rho\int_{-h}^{0}(a\omega e^{kz})^2\big(cos^2(kx-\omega t) + sin^2(kx-\omega t)\big)dz$$

$$KE = \frac{1}{2}\rho a^2\omega^2\int_{-h}^{0}e^{2kz}dz = \frac{1}{2}\rho a^2\omega^2\frac{1}{2k} \qquad (17)$$

with (13), we obtain *KE*,

$$KE = \frac{1}{4}\rho g a^2 \qquad (18)$$

From the equations (8) and (15), it can be explained that the potential energy is equal with the kinetic energy (PE = KE). This is consistent with the linear wave energy theory approach, known as equipartition of energy. Thus, the total energy per unit horizontal area (*E*) is,

$$E = PE + KE = \frac{1}{2}\rho g a^2 \qquad (19)$$

Next, we determine the total energy flux (P_{wave}),

$$P_{wave} = Ec_g \qquad (20)$$

c_g is called the *group velocity* and we can find it with

$$c_g = \frac{1}{2}c\left(1+\frac{2kh}{sinh2kh}\right)$$

$$c_g = \frac{g}{2\omega}\left[\left(1-\left(\frac{\omega^2}{gk}\right)^2\right)kh + \frac{\omega^2}{gk}\right] \qquad (21)$$

This result is valid for the wave in the deep-water.

4. WAVE ENERGY CONVERTER (WEC)

Wave energy converter is a device or machine that works by utilizing the kinetic energy and potential energy possessed by ocean waves to drive the rotor in the generator to produce the electrical power, which is then channeled to the transmission system (load). Wave energy converters are the right answer to harness the ocean's energy potential. At present, several countries have operated wave energy converters to utilize the energy potentials of ocean waves as electricity suppliers as shown in **Table 1**.

Table 1 shows that current status wave energy technology in several countries. Based on the data in **Table 1** that the wave conversion technology that has been developed is still prototype scale with various design.

Table 1. Several countries that have developed and operated wave energy converters

Country	Technology name	Technology type	Status	Project Capacity
Belgium	Laminaria Wave Energy Converter	Surge and pitch-based point absorber	Under development	200 kW
Denmark	Smart Ocean Buoy	Point Absorber	Completed	0.3 kW
Ireland	OE35 Buoy	Floating Oscillating Water Column device	Development; device under construction	500 kW - 1 MW
Portugal	WaveRoller	Oscillating wave surge converter (OWSC)	Under construction	350 kW
Spain	MARMOK A-5	Floating Oscillating water column (OWC)	Operational; under testing	30 kW
Sweden	Seabased L12	Point absorber	Operational; under testing	1 MW
USA	StingRAY PTO system	Permanent magnet generator	Operational; under testing	500 kW
India	Wave-powered navigational buoy	Floating Oscillating Water Column (OWC)	Operational; under testing	100 W

WEC designs can be classified according to the location and the method of energy extraction. Based on the location, WEC is classified into three types: shoreline, nearshore, and offshore (Ghasemi *et al.,* 2017). WEC devices on the shoreline location may be installed on the coastline or integrated into structures like breakwaters. The location is called shoreline if the depth is about less than 15 m. WEC devices on the nearshore work by utilizing buoys up and down to capture the energy, which is then converted to electricity. The location is called nearshore if the depth is about less than 25 m. Meanwhile WEC devices on the offshore are moored to the bottom of the sea and then move the electricity produced using submarine cables placed on the bottom of the sea. The location is called offshore if the depth is about more than 25 m but less than 200 m. Wave energy converters using offshore buoys are the latest wave energy projects and are still being developed (Güney, 2015). Using a mooring system at a greater depth is a challenge and is expensive, but tends to be safer from the brunt of a storm. However, if viewed from the locations, various WEC types may be more efficient in harvesting of energy. WEC whose working principle utilizes horizontal waves can be installed on nearshore locations because they are more effective in harvesting the horizontal force of the wave, while the WEC whose working principle utilizes vertical waves can be installed on the offshore locations because they are more effective in harvesting the vertical force of the wave. Therefore, the lower hinged flap devices and the mooring buoy system are more efficient to be installed on the offshore than near shore (Anbarsooz *et al.,* 2014).

4.1 Oscillating water columns (OWC)

OWC is a device that can convert the ocean wave energy into the electricity using oscillation columns. In general, the OWC consists of an air-filled chamber, which functions to drive turbines, wind turbines, and generators. The working principle is to capture the wave energy that hits the OWC door hole, which causes fluctuation or oscillation of the movement of water in the isolation space, which then produces air pressure differences inside and outside the isolation space. This difference in the air pressure causes air to flow and move the turbine propellers connected to the generator to produce electricity. For security, a device that functions to convert the mechanical energy into electricity is placed above the sea surface in a special water-resistant space so that it is certainly not in contact with sea water. To be more efficient, the turbine is designed to be able to work on a generator with a two-way rotation. In addition, with the right design, the power plant can utilize the optimal efficiency of the wave energy by minimizing extreme waves. Optimal efficiency can be obtained when waves are in normal conditions. This can be obtained by using a special valve that prevents the turbine from over speed (Jeffcoate *et al.,* 2015).

OWC is the old concept for the wave energy conversion that has been developed and is still the favorite technology conversion of the wave energy in several countries such as Spain, Portugal, Korea, Italy, and China (Weiss *et al.,* 2018). An important step in the development of OWC is testing the model, usually in a wave tank or wave flume. The effects of compressibility of air in the air space and air turbine simulation pose special problems in testing models which, in many cases, fail to be adequately handled. OWC consists of two types, namely fix structure (Anbarsooz *et al.,* 2016; Falcao & Henriques, 2016) and floating structure (Crespo *et al.,* 2017; Falcão & Henriques, 2016; Stanham *et al.,* 2018). Some OWC fix structure models that have been developed and tested are linear PICO generators (Azhari *et al.,* 2017), LIMPET (Boake *et al.,* 2007; Folley *et al.,* 2006), and Mutriku wave power plant (Ibarra-berastegi *et al.,* 2018), whereas the OWC floating models developed include a mighty whale model (Osawa *et al.,* 2002; Osawa *et al.,* 2013), Spar-Buoy model (Bayoumi *et al.,* 2015; da Fonseca *et al.,* 2016), Oe-Buoy (Babarit *et al.,* 2012; Delmonte *et al.,* 2014), and Oceanlinx floating OWC as shown in **Figure 2** (Gareev, 2011; Falcao & Henriques, 2016).

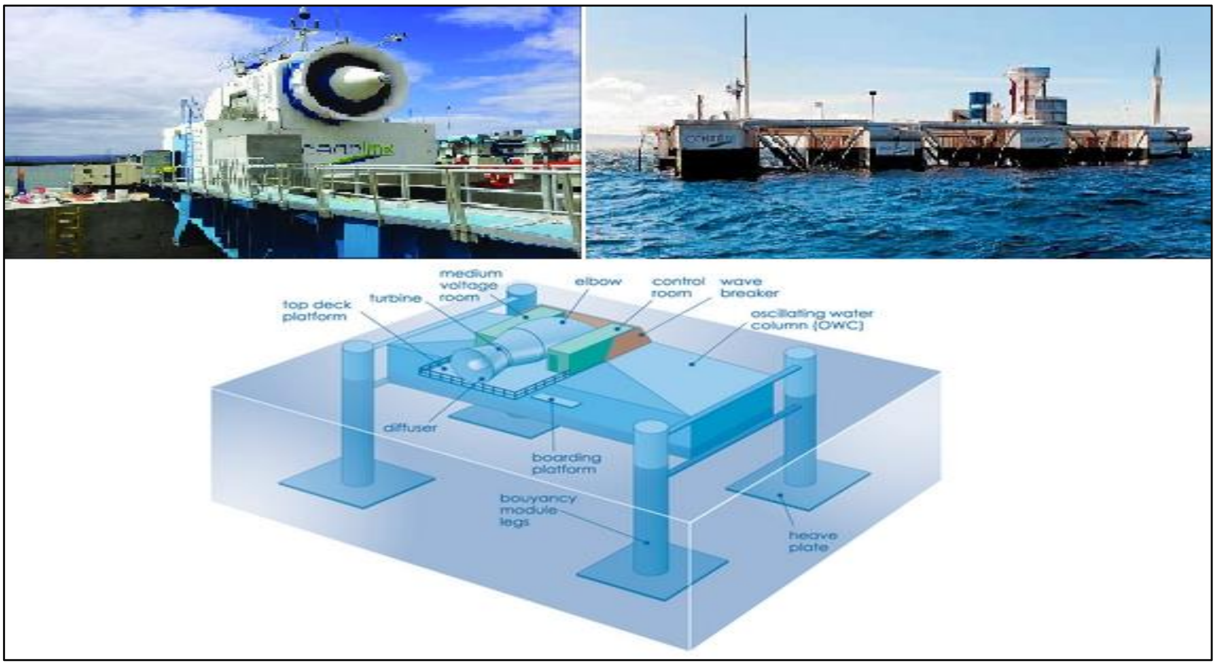

Figure 2. Oceanlinx floating OWC (Falcão & Henriques, 2016)

4.2 Oscillating bodies

Oscillating body is one of the devices that can convert the ocean wave energy into the electrical energy. The electrical energy is generated from generators, which are driven by interactions between the oscillating body and ocean waves. The device of the oscillating body can be a single rigid body or a body system that can move by respect to the other with the constraint that allows relatively or relative translation. The large and small bodies can produce equally large waves with the condition that the small body oscillates have greater amplitude. An oscillating body device is good if it can move the seawater by oscillating and by the right phase. Therefore, there must be the wave cancellation and reduction through the device of the energy converter or the reflection. The cancellation and reduction of waves can be applied by the oscillating device providing that it produces waves that oppose with the passing or reflected waves. This means that the resulting wave must interfere destructively with the others (Evans, 1976). The power take-off (PTO) system in the oscillating body converter of the wave energy can be executed using high-pressure hydraulic PTO (Gaspar *et al.,* 2016) or hydraulic turbine (Garcia-Rosa *et al.,* 2012). However, these two PTO systems have their advantages and disadvantages, where high pressure hydraulic PTO is able to absorb a large amount of energy but is not good at fluid containment, wear of seals, maintenance and efficiency. Meanwhile, the turbine hydraulic PTO system has no impact on the environment since the working fluid is sea water, but the disadvantage is that the seawater is so abrasive that it can damage the system components. Besides, the use of hose pumps does not allow a high-pressure water supply and turbines can be more suitable for low head applications (Erselcan & Kükner, 2014). Several types of oscillating bodies of wave energy converters that have been developed and tested are eco wave power (power wing and wave clapper) as shown **Figure 3** (Cascajo *et al.,* 2019; López *et al.,* 2013), Aquabuoy (Wacher & Nielsen, 2010), IPS buoy (Falcão *et al.,* 2012), Wavebob (Weber *et al.,* 2010; Weber *et al.,* 2009), Powerbuoy (Hart *et al.,* 2012), Pelamis (Gobato *et al.,* 2016; Thomson *et al.,* 2019), PS Frog (McCabe *et al.,* 2006), SEAREV (Josset *et al.,* 2007), Archimedes Wave Swing/AWS (Marei *et al.,* 2015), WaveRoller (Chehaze *et al.,* 2016), Oyster (Renzi *et al.,* 2014; Whittaker & Folley, 2012).

4.3 Overtopping

An Overtopping converter is one of the wave energy converters that utilizes the wave energy by directing the overtopping water to one or more reservoirs placed at a higher position than the mean water level. This condition will produce potential energy in the overtopping water and then convert it into the electrical energy by directing water from the reservoir back to the sea with a low head hydraulic turbine as a power take-off system connected to a generator (Buccino *et al.,* 2015). The overtopping device can be constructed very largely because the WEC technology performance is not dependent on resonance with the waves. The most important thing to note is floating overtopping WEC's issue, which is how to stabilize and control the floating structure to optimize the power output (Bevilacqua & Zanuttigh, 2011).

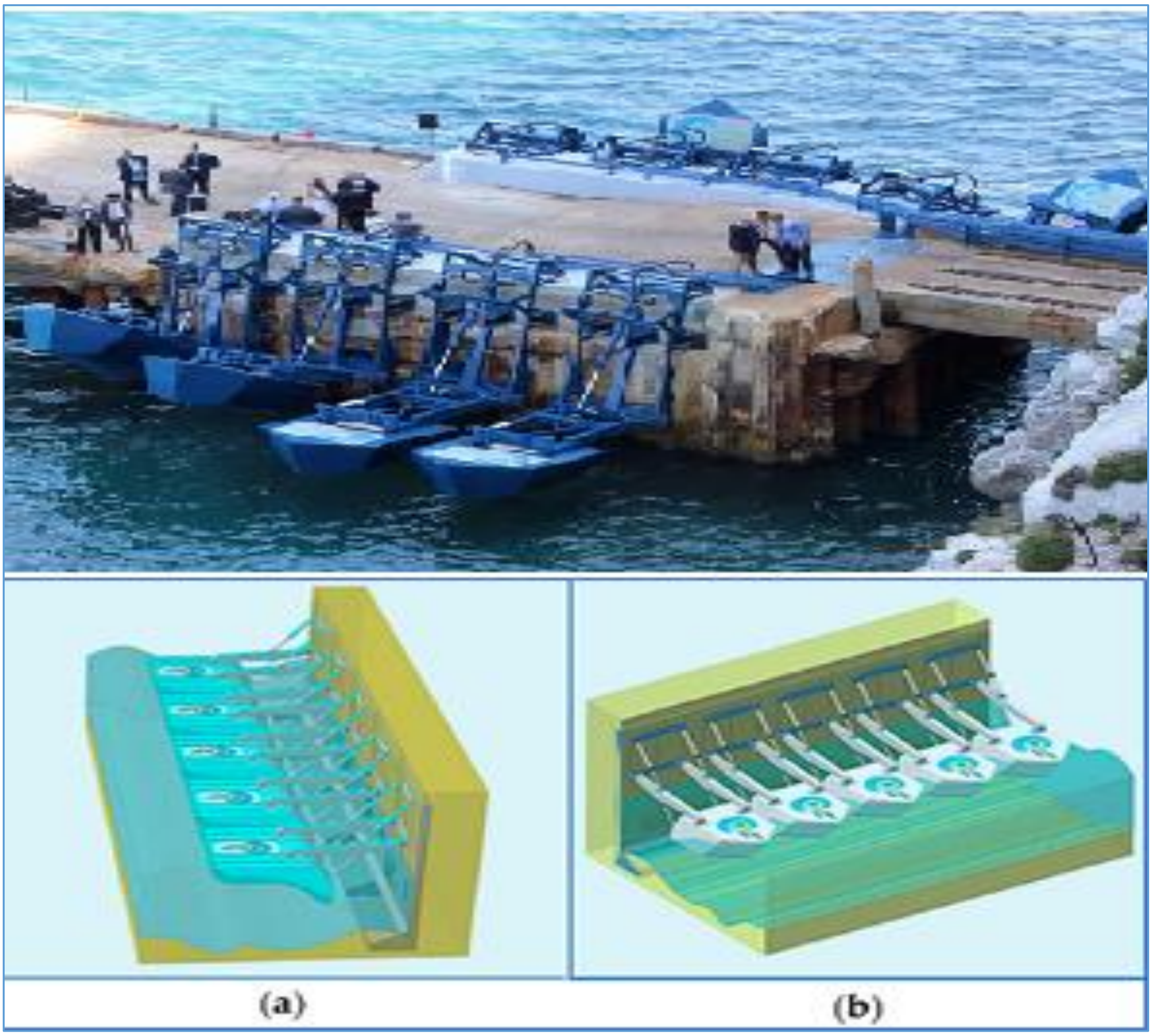

Figure 3. Oscillating Body WEC Type Eco Wave Power (a) Power Wing (b) Wave Clapper (Cascajo *et al.,* 2019)

In general, the overtopping converter has advantages that distinguish from other wave energy converters; (i) the energy fluctuations produced are relatively small due to the conversion process in quiet conditions in a reservoir where water is temporary stored; (ii) the condition on the back of the devices is so calm that it is possible to be used as recreational activities; and (iii) after electricity is produced, the water moved through the turbine can be reprocessed to improve its quality. However, because the device is usually installed offshore, it needs an appropriate anchoring system. On the other hand, because of this offshore installation, this device requires an appropriate anchoring system. Several overtopping converters that have been developed and tested are Tapered channel converter (Güney, 2015; Mehlum, 1986), Seawave Slotcone Generators Converter (Buccino *et al.,* 2018; Khalifehei *et al.,* 2018; Oliveira *et al.,* 2016), Wave Dragon Converter as shown **Figure 4** (Beels *et al.,* 2010; Kofoed *et al.,* 2006), and WaveCat converter (Fernandez *et al.,* 2012; Fernandez *et al.,* 2012).

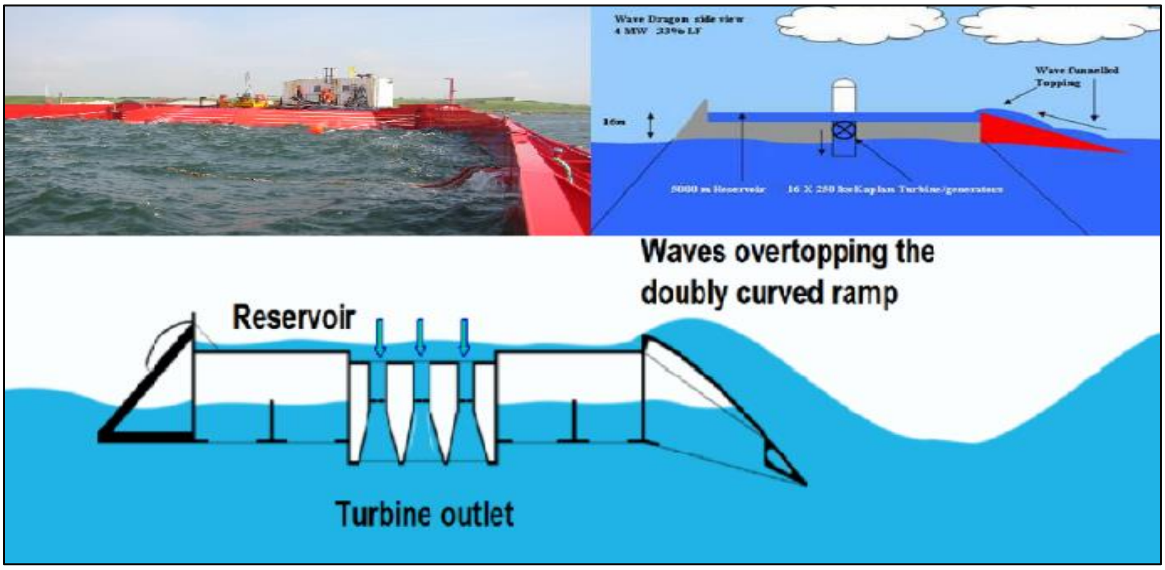

Figure 4. Overtoping WEC Type Wave Dragon (Parmeggiani *et al.,* 2013; Poullikkas, 2014)

5. WAVE ENERGY CONVERTER IMPACT ON ENVIRONMENT

In recent years, due to the increasing emphasis on global climate change, the government has tended to reduce greenhouse gas emissions. Thus, the government began to choose renewable energy sources. Wave energy has enormous potential to replace traditional fossil fuel power plants because it is unlimited, clean, and environmentally friendly (Akar & Akdogan, 2018). Wave energy is considered a renewable and non-polluting energy source, especially about hazardous compounds like nitrogen oxide and carbon dioxide when producing electricity. All wet renewable energy devices have the potential to produce low-carbon energy (Frid *et al.,* 2012). One of the wet renewable energy devices is a wave energy converter. A wave energy converter has lower impacts on climate change, radiation of ionizing, a transformation of natural land, depletion of water, and the cumulative fossil energy demand when compared to the conventional fossil-fueled power generation (Thomson *et al.,* 2019). However, almost all forms of either renewable or conventional power plants will have an impact on the environment. The spread and use of wave energy devices can also have an impact on the environment, in terms of local shipping and fishery industries, as well as on the local environment. However, the small number of wave energy converter distributions that are mostly still in the prototype testing stage results in the negative impact of the installation of the wave energy converter in the sea environment to be very low. Conversely, the application of the wave energy on offshore islands will have a positive impact on tourism because, on these islands, there will be sustainable development that works and maintains a high-quality environment (Fadaeenejad *et al.,* 2014).

The complete LCA results in **Table 2** confirm that the wave energy converter has lower impacts of climate change, ionizing radiation, transformation of natural land, water depletion when compared to conventional fossil fuel power plants. In addition, not all impact categories can be considered equally important; for example, thinning metals can be considered less alarming than climate change. Pelamis performance, which is relatively poor in many categories, can trigger the formation of photochemical oxidizers (325 mg NMVOC/kWh) and acidification, which has become a significant environmental problem in recent decades. This confirms that it is important not only to assess climate change impact but also to consider the impact of the overall environmental change.

6. CONCLUSION

The potential to generate electricity from the wave energy is very large. The ocean is a very large resource and utilizing the energy from ocean waves is an important step to meet the target of renewable energy. This review introduces the wave energy converter technology current status. Various types of devices of wave energy converters have been made and tested in several countries. Until now, the research and development about wave energy converters are still conducted to obtain reliable, cost-effective, flexible, manageable, measurable, durable, and efficient devices that do not have a negative impact on marine ecosystems. The wave energy converter has lower climate change, ionizing radiation, water depletion, natural land transformation, and demand for fossil energy impacts compared to the conventional energy like fossil-fuel power. Although the wave energy converter does not have a significant impact on climate change, the installed wave energy converter device has a significant impact on the marine life. Therefore, in the development of energy converters, we must consider the negative effects on organisms in the sea.

7. ACKNOWLEDGMENTS

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8. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

Table 2. Results of life cycle assessment (LCA) and cumulative energy demand calculation on Pelamis Converter Device (Thomson *et al.,* 2019)

Impact category	
Climate change (CC)	35 g CO_2 eq/kWh
Ozone depletion (OD)	3.7 µg CFC-11 eq/kWh
Photochemical oxidant formation (POF)	325 mg NMVOC/kWh
Ionizing radiation (IR)	2.4 Bq 235U eq/kWh
Urban land occupation (ULO)	393 mm^2a/kWh
Natural land transformation (NLT)	8.5 mm^2/kWh
Metal depletion (MD)	26 g Fe eq/kWh
Water depletion (WD)	241 cm^3/kWh

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