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Comprehensive review on the feasibility of developing wave energy as a renewable energy resource in Australia

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ABSTRACT

The facts are that increasing energy demand, depletion of fossil fuel, and greenhouse gas emissions have increased the world's interest in renewable energy. Out of all RE options, Wave Energy (WE) is the least harnessed one despite the availability of WE Resource (WERs) in many countries and with the potential to cover a significant proportion of the world's energy needs. Australia, mainly in the southern part of the country, has plenty of this resource. Although recently, the Australian Government has started to focus on WERs as a Renewable Energy Source (RES) to cope with the energy crisis, research suggests that the country's progress in the WE generation to meet the energy demand is well below the potential generation capacity. However, insufficient research and studies address the issues and technologies in detail. This study examines the viability of further developing WE as a renewable energy source in Australia by evaluating the current constraints and challenges to achieving a satisfactory level of WE generation in the country. As a result, this study emphasizes the trustworthiness of WE in terms of several criteria. The availability of WERs within Australia and the status of producing WE are reviewed in this study. It also highlighted certain Australian technologies and devices that are now being tested or deployed in real-time. Moreover, this review is expanded by comparing the key developers in the WE sector to Australia to uncover some of the contributing elements in other countries that may have contributed to the growth of the WE generation in other nations. Finally, some of the barriers identified are lack of high-resolution data and social & environmental challenges. Some recommendations are given in the latter part of the review to accelerate WE production in Australia.

1. Introduction

The generation of energy through fossil- fuels has a negative influence on the environment. Despite the fact that these sources are used as principal Energy Sources (ES) for energy generation around the world, it has been proven that these are harmful to human health and contribute to global warming (Afrouzi et al., 2021). Factors such as the rapidly growing global energy demand, driving to low carbon economy, depletion of fossil fuels, and geopolitics in using fossil-based oil have strengthened the need for searching for RE sources (Mwasilu and Jung, 2019). Further, many off-shore remote areas use diesel generators (up to 1000 KVA) which create noise (~75 dB); with the aim of mitigating that noise and greenhouse gas emission, some countries have started using RE sources in the off-shore areas (Robertson et al., 2020). The exploitation of the RE sources was firstly started in a few countries, including Japan, Norway, and the UK, by conducting Government-sponsored programs aiming for the advancement in technology (Hayward and Osman, 2011b).

Wave Energy (WE) has not gained much of its due attention compared to other Renewable Energy Sources (RES), while it has the potential to cover a major proportion of energy consumption. According to Mwasilu and Jung (2019), Wave Energy Source (WES) are more reliable due to their accuracy in energy prediction and lower energy loss during generating. Further, WE are a very attractive alternative energy source

Abbreviations: WE, Wave Energy; WER, Wave Energy Resource; RE, Renewable Energy; RES, Renewable Energy Source; ES, Energy Source; WEC, Wave Energy Converter; OPT, Ocean Power Technology; OWC, Oscillating Wave Column; OWSC, Oscillating Wave Surge Converter; PTO, Power Take Off; LCOE, Levelized Cost of Energy; GDP, Gross Domestic Product; LNG, Liquified Natural Gas.

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in terms of availability and forecast ability. Also, it is more powerful as to the high density of sea water and intensity (2–3 kW/m^2) and when compared to solar (0.1 - 0.2 kW/m2) and wind (0.4 - 0.6 kW/m2), the power density for waves is 100 times greater than that of solar radiation and 10 times that of wind (Development, 2000).

Australia is well located at the right coastline orientation to enrich WE resource with the potential to generate one-third of the country's energy demand, while the success in generating power using hidden energy in a wave is far below even though wave as a RE source is the best option to energy crisis (Hong et al. 2020). This study is to review the feasibility of developing WE as a RES within Australia and further identify the solutions to enhance the same industry by identifying challenges.

WE is accumulated from solar energy. Earth surfaces get unevenly heated due to differential solar irradiation resulting in airflow. Some portion of the energy is transferred to seawater in the form of Waves when the wind blows, touching the sea surface (Jouanne, 2006). The kinetic energy is developed within the waves through this phenomenon which is called 'Wave Energy' and can be extracted by using WE devices/converters. Waves can be described in accordance with statistical parameters of height and period (Development, 2000). However, the energy stored in waves is not uniform all over, and as it differs due to various factors, some of them are listed below (Jouanne, 2006). First, the direction of waves in deep water varies with the change of the direction of the wind field, resulting in generating waves. Secondly, a friction force is created due to the movement of water particles and a seabed result in losing energy within the waves during the travel towards the shore. Third, the timescale and then the diffraction of waves, when approaching the shore.

2. Global distribution of WERs and production

WE is considerably available on some coasts with the potential of generating more than the annual average power density of 100 kW/m (Mwasilu and Jung, 2019). In accordance with the Ocean Energy System Technology programs, 58 facilities for Waves are available throughout the world. Respective of the latitude and the coastline orientation, some countries are properly situated to the WE conversion. Great Britain, Ireland, Norway, New Zealand, Northern Spain, Portugal, and North and South America coasts are some of them, and the Western coast of Europe has the best WERs as it is located at the end of a long fetch which is 'Atlantic Ocean' (Development, 2000)(Jouanne, 2006). In fact, the best WERs occur in areas having strong winds that travel over a long distance (Development, 2000). Also, it is noted that near the coastline, WE decrease due to the friction that is developed with the seabed.

The intensive research on WE generation began in the 1970s along with interest in REs (Development, 2000). Currently, most academic researchers and WE developers have shown their interest in exploiting these untapped powerful RESs for energy production applications. Subsequently, some of the pilot projects on Wave Resources Assessments and new WE Converter (WEC) technologies have been introduced to the industry (Mwasilu and Jung, 2019). It is noted that economically developed countries mostly lead the industry in terms of generating WE, and they have their own plans and targets that have been established based on their local marine characteristics (Felix et al. 2019). Countries like France and Spain and Companies like ABB group and Mitsubishi have already entered the WE market as well (Mwasilu and Jung, 2019). As Felix et al. (2019) stated that some WE projects could be found in the United Kingdom and the Norwegian Sea, having the capacity of 60–70 kW/m and 40–50 kW/m, respectively. Among the tropical Countries, Indonesia, India, and the Philippines have major places where a considerable number of WECs have been already installed. Besides that, the South China Sea (5.32 kW/m), North East Brazil (2–14 kW/m), Peninsulas of Malaysia (6.5 kW/m), Thailand (<10k W/m), etc. are feasible projects for generating WE (Felix et al. 2019).

2.1. WE conversion, mechanism and devices

WECs are designed to convert kinetic energy in waves to electrical energy. The Conversion process includes capturing and transmission of energy to a generator for the purpose of converting. The selection of WEC type is based on a few facts such as physical characteristics of the location, nature of local waves, etc. (Felix et al. 2019). There is no one classification approach to cover all types of WE conversion systems because WE conversion principles diverge, with over 1000 devices recorded. WEC systems can be categorized in general based on location, working principle, and how they operate (Guo and Ringwood, 2021).

2.1.1. Location

In terms of location, it can be categorized as shoreline, off-shore, and near-shore. The devices on the shoreline are installed at the coastline, where the maximum depth is 15 m. The devices that are installed at a depth of fewer than 25 m are named nature near-shore devices. In the case of off-shore, devices are placed at the sea bottom where the sea depth is within the range of 25m-200 m. In this type, the power generated is transmitted by underwater cables, and strong commercialization of this type is yet to be commenced (Satriawan et al. 2021).

Shoreline devices offer the advantages of being close to the utility network, being simple to maintain, and having a lower risk of being damaged in harsh weather because waves are attenuated as they travel over shallow water. This leads to one of the downsides of shore-based devices: lesser wave power due to shallow water, which can be partially countered by natural energy concentration places. Devices in nearshore are frequently affixed to the seabed, providing a stable base against which an oscillation body can operate. A downside, like shoreline devices, is that shallow water causes weaker waves, reducing harvesting capability. Most offshore devices are in deep water. Because deep ocean waves have a higher energy content, the location of a WEC in deep water has the advantage of allowing it to gather more energy (Alain et al. 2002). Off-shore devices, on the other hand, are more difficult to build and maintain and must be constructed to withstand more extreme circumstances because of the higher wave height and energy content in the waves, adding to the expense of construction (Korde, 2000). Despite the expensive nature, the safest system is the mooring system which is offshore as it is much safer from storm burns.

2.1.2. Type

Despite the wide range of designs and concepts, WECs can be divided into three types: attenuators, point absorbers, and terminators.

2.1.2.1. Attenuator. Attenuators ride the waves by lying parallel to the dominant wave direction. The McCabe Wave Pump and Pelamis are an example of attenuators.

McCabe Wave Pump device is designed with three narrow steel pontoons in front, back or center hinged together across the beam pointing to the incoming waves. The front and back rotate according to the center pontoon by rotating at the hinges. The hydraulic arms generate energy by extracting them during the rotation(Jouanne, 2006). A long prototype that has a length of 40 m has been installed along the coast of Kilbaha in Ireland, as in Fig. 1. Fig. 2 illustrates the schematic diagram of the components of McCabe WEC (Zhang et al. 2021).

Pelamis is a semi-submerged device, as shown in Fig. 3, and is designed with cylindrical sections where it is linked at the hinged joints. Like the McCabe Wave pump, this device is also pointed towards the incoming waves. The sections are functioned to move respective to each other. Through the installation of hydraulic rams, the movement has been restricted to pump the high-pressured oil for the function of Electrical generators. This device has been constructed and is operational in Scotland, where it has a capacity of 750 kW, dimensions of 150 m in length, and 3.5 m in diameter (Jouanne, 2006).

Overall, almost 200 different WE devices are either in the construction or testing stages (Hayward, 2011a), and around 50 companies em-

Fig. 1. McCabe Wave Pump (Jouanne, 2006).

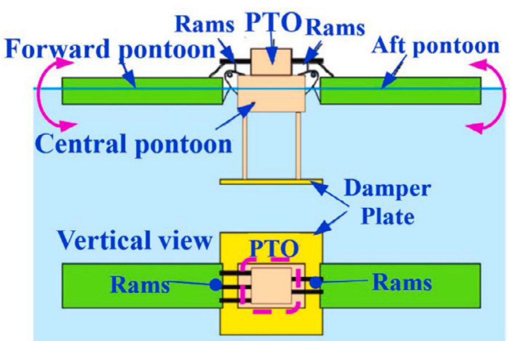


Fig. 2. Schematic diagram showing the parts of McCabe WEC (Zhang et al. 2021).

Fig. 3. Pelamis device (Drew et al. 2009).

ploy different technologies, as shown in Table 2. Fig. 4 shows the components of the oscillating body.

2.1.2.2. Point absorber. These devices have a tiny float in comparison to the swell wavelength. The float has complete freedom to follow the wave's path and take energy from any direction. It can be tethered and submerged, moving with the pressure of a passive wave, or it can float on the surface and track or heave with the movement of the sea surface (Hayward, 2011a). Ocean Power Technology's (OPT) PowerBuoy is one of the various examples of a point absorber. A wave farm using PowerBuoys is depicted in Fig. 5 below.

2.1.2.3. Terminator. These devices physically intercept waves by having their main axis parallel to the wave front (perpendicular to the primary wave direction). The Salter's Duck, produced at the University of Edinburgh, is an example of a terminator type WEC, as depicted in Fig. 6.

2.1.3. Mode of operation

2.1.3.4. Overtopping. These devices are terminators in which they face exactly the direction of the wave and then direct to a catchment tank. A mechanism is developed to concentrate the widely distributed WE to a narrow ramp, as shown in Fig. 7, to increase the height of the ramp. Ramps are designed to convert horizontally directed wave flux to a vertically directed WE by lifting and focusing on the incoming water (Knight et al. 2014). Fig. 8 depicts the basic principle of overtopping.

2.1.3.5. Oscillating water column (OWC). This is the most common shoreline design in which the chamber is partially submerged with a small exit at the top and a large opening below sea level. It is designed to change the level of water in the chamber, allowing it to rise and fall when the sea water flows in and out. To generate an alternative stream of air with a high velocity, the air above the sea water level of the chamber is continuously compressed or decompressed. Therefore, in this process, OWC treats as a pneumatic gearbox by turning slow waves to fast air flows in a way suitable to power the turbines. There are two main types of OWC designs that have been developed, namely Wavegen's Limpet and Energetech OWC (Jouanne, 2006).

Wavegen's Limpet - This device is comprised of a sloped OWC, allowing to maintain an annual power level within the range of 15 - 25 kW/m. Further, the water column is comprised of an area of 170 m^2 containing two well turbines of 250 kW each and generating a nameplate of 500 kW by each, typically. These turbines have a diameter of around 2.6 m, and they are mounted with aero foil blades at the right angle to the air flow, allowing them to rotate in the same direction without considering the variation of air flow direction (Jouanne, 2006). The first commercial size device with a capacity of 500 kW has been installed on the island of Islay (Scotland), as shown in Fig. 9. The installation of the same was done by carving a hollow behind the cliff edge and later deploying the OWC behind the rock band. Later, it was demolished to let the sea water into the OWC.

Energetech OWC- This device has been designed to address two challenges. First, by designing it with a 40 m wide parabolic reflector to reflect waves on the OWC chamber, which is 10 m wide, and focusing the parabola. Further, the parabolic walls in this design lead to enhance the output by approximately 300% and reduce the initial cost by 3%. Secondly, this design resulted in the innovation of another type of turbine that uses the mechanism of 'variable pitch' as shown in Fig. 10, to survive against the variations in air flow directions. It is proven that this process has a higher peak and average efficiency in comparison with good turbines in the Limpet device (Jouanne, 2006).

2.1.3.6. Oscillating wave surge converter (OWSC). An OWSC is made up of a hinged deflector (a terminator) that travels back and forth in response to the wave's horizontal particle velocity. The Aquamarine Power Oyster, a near-shore device with the top of the deflector above the water surface and hinged from the seabed, is one such example shown in Fig. 11 (Drew et al. 2009).

2.1.3.7. Submerged pressure differential. The submerged pressure differential device is a submerged point absorber that exploits the pressure difference between wave crests and troughs above the device to absorb waves. It is divided into two sections: a fixed air-filled cylindrical chamber on the seabed and a moving top cylinder. The water pressure above the device compresses the air within the cylinder when a crest passes over it, causing the upper cylinder to descend. The water pressure on the apparatus drops as a trough goes by, causing the upper cylinder to rise. Because it is completely submerged, this gadget is not subjected to the severe slamming pressures that floating devices are subjected to, and it has a lower esthetic impact. However, device maintenance could be an issue. Because a portion of the device is attached to the seabed, these devices are usually found close to shore. The Archimedes Wave Swing, depicted in an artist's concept in Fig. 12, is an example of this mechanism (Drew et al. 2009).

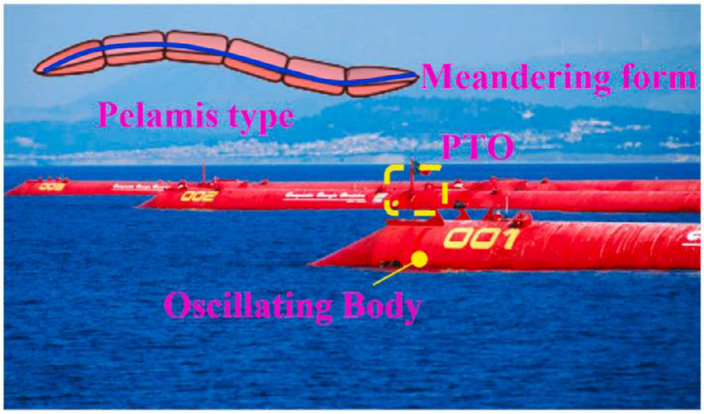


Fig. 4. The components of oscillating body WECs (Zhang et al. 2021).

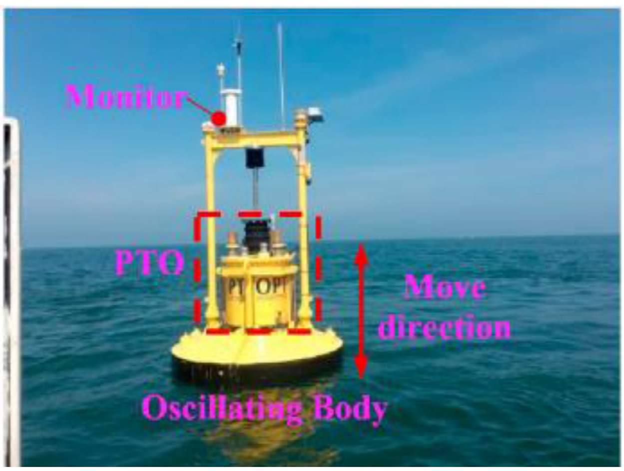


Fig. 5. OPT PoweBuoy: A Point Absorber Device (Zhang et al. 2021).

According to the Knight et al. (2014), Ocean Linx, Nautilus, PowerBuoy, Surge Drive, CETO, and BioWave are some of the main WE converters and devices that are being developed in Australia.

- PowerBuoy is a floating ocean power technology that is developed to extract kinetic energy from Waves. Different types of PowerBuoy models have been introduced to the market. The float moves along the spar according to the Waves and in a reduced response due to the heavy plate at the base. As the result of the developed relative motion between the float and spar, the push rod is driven into the spar. With the help of a mechanical actuator, the linear motion is converted to a rotary action that drives a vector-controlled generator. As the outcome, a three-phase voltage and a frequent AC power are generated. A power management and conditioning system converts the AC into DC power with higher quality. Conversion of voltage and frequent AC power varies according to the size and the PowerBuoy type (Edwards and Mekhiche, 2014).
- BioWAVE – is an Oscillating Wave Surge Converter. It is mainly based on the swaying motion of plants in the presence of waves. During an extreme condition, this converter system automatically identifies the hazard and ceases the operation. Then, it lies as a safety precaution against the seabed. However, this technology has been designed in the way of getting exposure to extreme forces and only allowing the lightweight designs (Zhang and Aggidis, 2018).
- OceanLinx- This is a near-shore OWC that is developed by the Company Energetech and is being used in Australia. This technology is built by using an Oceanlinx that is developed in-house and called 'Denniss-Auld Turbine' (Holmberg et al. 2011). It has been placed on the bottom sea near Kembla port in Eastern Australia (Development, 2000), as shown in Fig. 13.

Also, it has a capacity of generating 321 kW within a short duration of 7 s to 2 min. Normally, this converter is constructed to a length of 20 m having a width of 40 m. When compared to other technologies, the maintenance of this is quite low. Most of the components of the device are opened to the air, ensuring less contact with water. The turbine

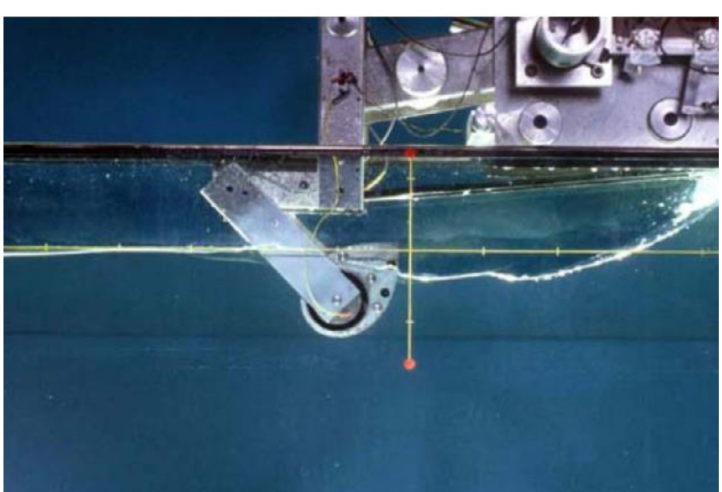


Fig. 6. Salter's Duck: Terminator Device (Drew et al. 2009).

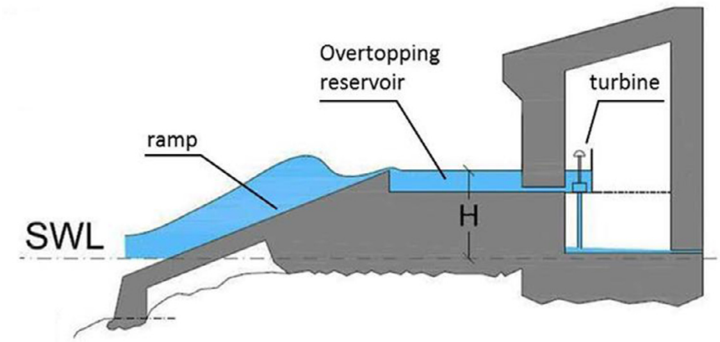


Fig. 7. Overtopping Ramp (Kralli et al. 2019).

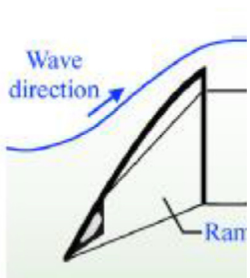


Fig. 8. Diagram showing the basic principle of overtopping (Zhang et al. 2021).

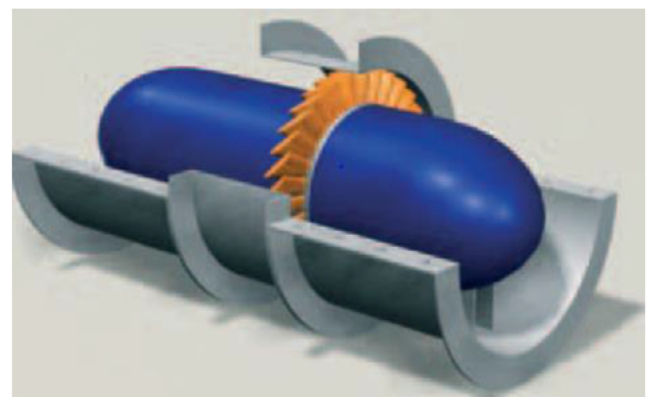


Fig. 10. Outline of the Energetech Variable-Pitch turbine (Jouanne, 2006).

and the structure, including the parabolic arm, are made of steel. The focal length is around 5 m. This system consists of a parabolic arm that is focused on the waves on a point. Also, there is a chamber, and that is designed above the parabola's focal point. The chamber of this system is filled with air, and it narrows to the top where the speed pitch blade air turbine is situated. The turbine is operated by using the oscillating air and tunes in to wave frequency to maintain the efficiency (Joubert et al. 2013).

- Nautilus-This is an attenuator type device, as shown in Fig. 14, and has been introduced to the industry by the Queensland Government in Australia. It has a capacity of 2MW and a standard size of 50 × 200 m per unit. However, the environmental impacts of this technology are low, and it requires higher maintenance as most of the components are moving and not fixed (Joubert et al. 2013).
- AquaGen Surge Drive -When the waves pass the Surge Drive wave farm, the system starts to move in oscillation, and then the system generates pure wave forces from the water by using the tension power of elements. Using 'off the shelf" components and an innovative mixture of designs, the energy conversion modules can generate electricity. This technology is comparatively simple, as most components are above the water, and those under water are minimized and simplified. The design of this system has been done in a way to reduce the capital expenditure significantly and reduce maintenance resulting in improving the flexibility of the system (Joubert et al. 2013).
- Energetech OWC – According to port Kembla, south of Sydney in Australia, the construction of the first commercial size of this device. It is 500 kW in capacity and hopefully will be able to make major achievements in the economics of OWC. Other than this, the countries like British Columbia and Spain are planning to construct these devices, which has a capacity of 2MW (Jouanne, 2006).
- CETO – This energy system is comparatively different from most other technologies. CETO is a technological concept that has been introduced to the world to extract the potential energy from waves for generating clean, renewable, zero-emission electricity (Ward, 2014). According to Ward (2014), Carnegie Wave Energy (CWE) company can be considered the inventor and developer and has the Ownership of CETO technology. As is stated in Holmberg et al. (2011), CETO technology has been developed to harness the WE in the produc-

Fig. 9. Wavegen Limpet at Islay (Zhang et al. 2021).

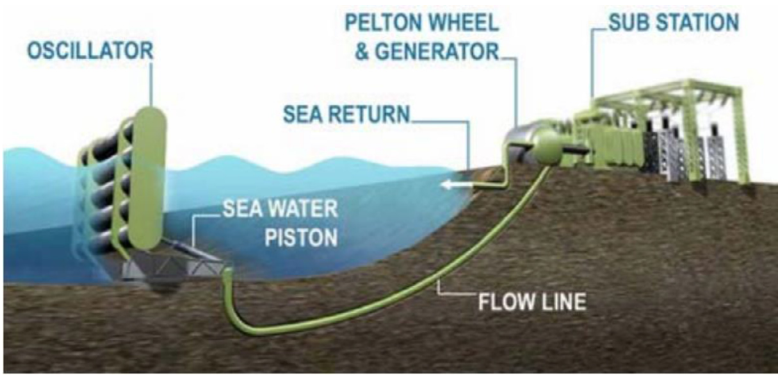


Fig. 11. Aquamarine Power Oyster: An example of OWSC (Drew et al. 2009).

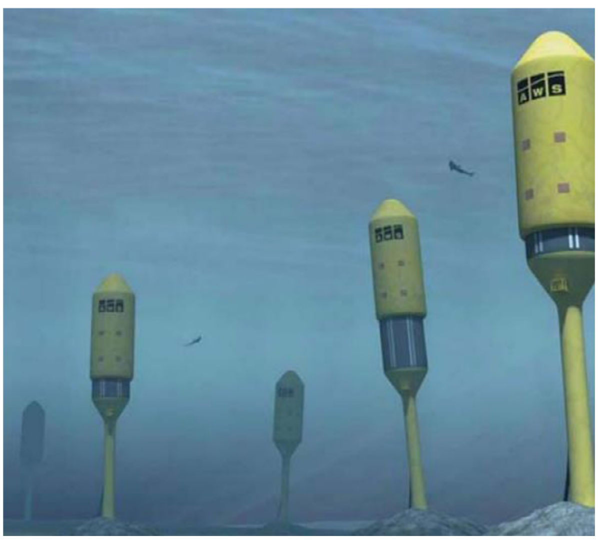


Fig. 12. The Archimedes Wave Swing: An Example of Submerged Pressure Differential (Drew et al. 2009).

tion of electricity as well as to produce fresh water and consists of submerged water pumps that pressurize the water to the land. CWE company has tested this CETO technology in the application of WE generation with the aim to improve the global market for this concept (Ramsay et al. 2016) 'Perth, WE project' (PWEP) and 'Albany WE' are two projects that were done using the CETO technology. Other than that, this system has been demonstrated at the Garden Island in Australia. As Holmberg Per stated, in the future, all of the CETO projects in the southern hemisphere will be operated by CWE, while the CETO projects in the North will be done jointly with Energies Nouvelles (Holmberg et al. 2011).

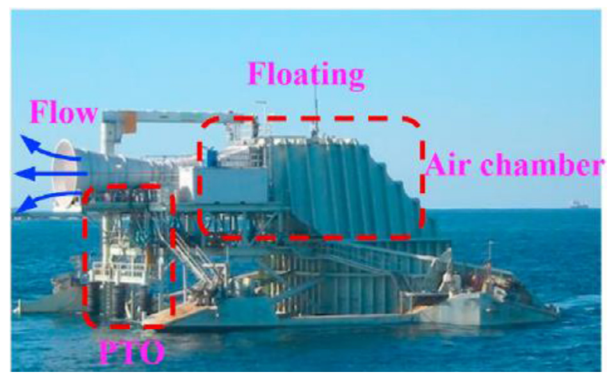


Fig. 13. OceanLinx device near Kembla port in Eastern Australia (Zhang et al. 2021).

Table 1 summarizes the updated status of WEC development in a few major countries along with their capacities. However, it is to be noted that most of these WE technologies are still at the prototype scale. On the other hand, table 2 compares all WECs along with their efficiency, location, type, and their status. Fig. 15 shows a different kind of WEC.

2.2. Factors affect the evaluation of the WEC performance

As Zhang et al. (2021) states, there are considerable differences in the technical principles, structural designs, and the PTO method of each WEC. There are very few commercially viable devices as the development of WE is still at the initial stage. Capturing capacity, technological cost, reliability of the technology, and environmental friendliness are some of the parameters by which the performance of WECs can be determined.

2.2.1. Energy capturing capacity

The coefficient of energy conversion is a result of three mechanisms when it is considered a WEC and they are namely capturing, transmis-

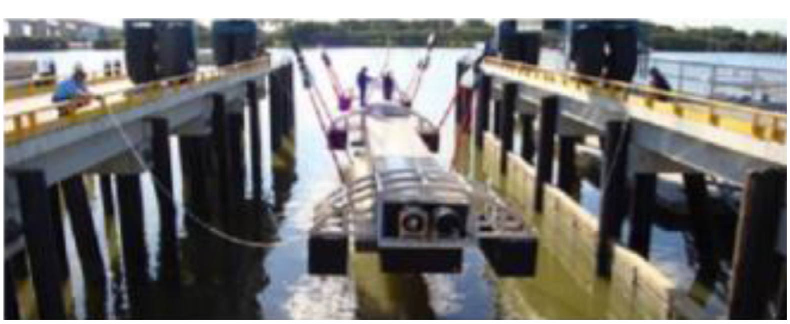
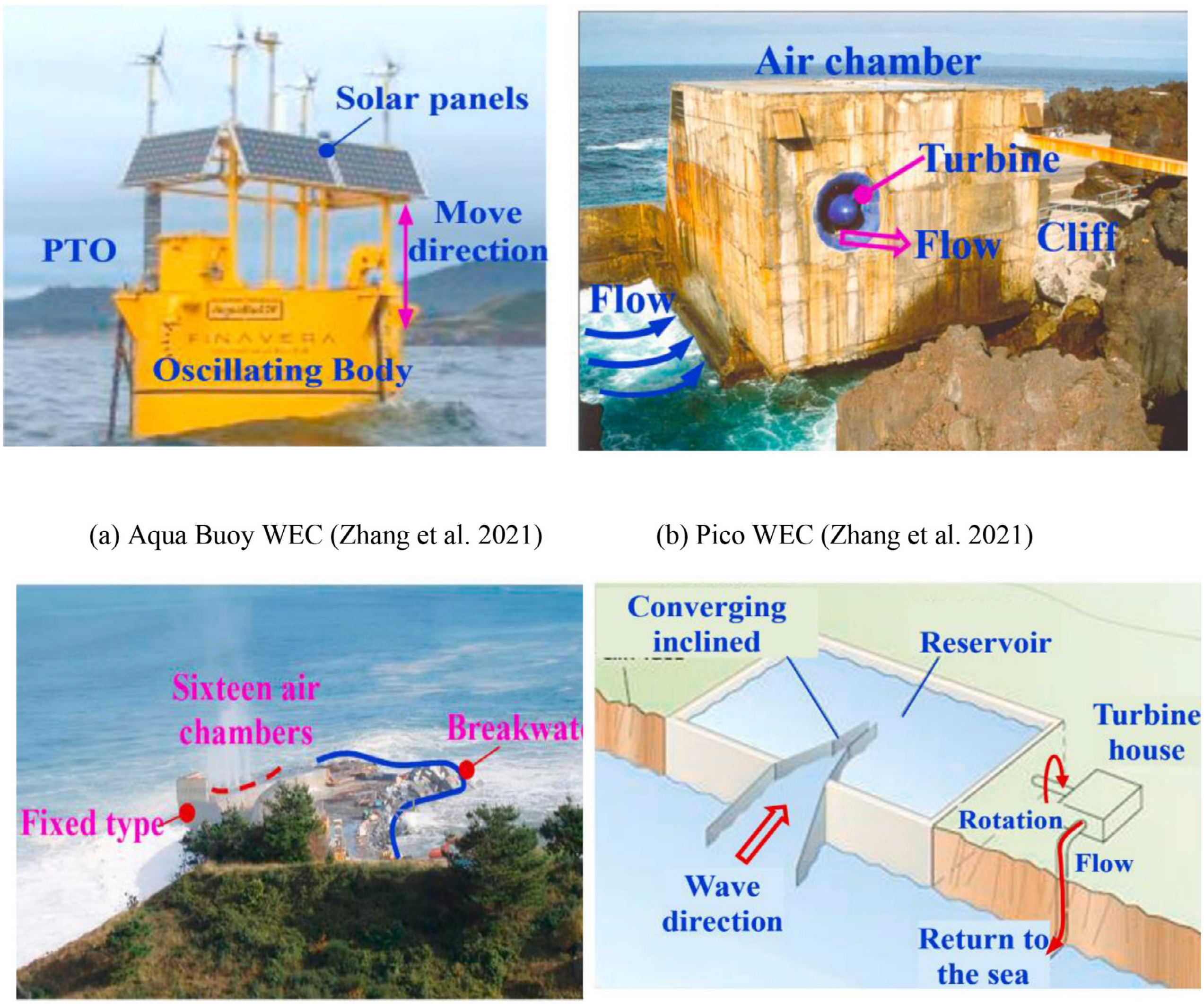


Fig. 14. The Nautilus Device That Had Been Introduced by The Queensland Government (Joubert et al. 2013).

Table 1
Few WEC Technology Types Along With The Countries That Have Been Developed Those (Satriawan et al. 2021).

Country	Technology Name	Technology Type	Status	Project Capacity
Belgium	Laminaria WE 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-1MW
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	1MW
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



(a) Aqua Buoy WEC (Zhang et al. 2021)

(b) Pico WEC (Zhang et al. 2021)

(c) Mutriku WEC (Zhang et al. 2021)

(d) TAPCHAN WEC(Zhang et al. 2021)

Fig. 15. Various Types of WEC In Few Countries.

sion, and generation mechanisms. It is identified that the highest coefficient is accounted for by Multi Degree freedom WEC while the lowest is accounted for by attenuator (Zhang et al. 2021).

2.2.2. Technological cost

When addressing technological cost, due to the lack of standardized cost details of processes (manufacture, operation, and installation), it is considerably difficult to evaluate. However, in the case of technological cost, it can be noted that MDWEC accounts for the highest. Then it is followed by the point absorber, terminator, and the over topping type, respectively (Zhang et al. 2021).

Due to the competitive nature among the RES, the cost of generating WE takes an important role in making it more reliable for the users. As it is explained in Hayward and Osman (2011b), it is possible to identify the current and future economics of placing WE devices around the country as meant by the resource data of Australia. A study has been done to calculate the Levelized Cost of Electricity (LCOE) using capital, operational, and maintenance costs. It was noticed that the southern and west coastlines of Tasmania have the lowest LCOE as more WE is available in these areas. Due to the low LCOE of WE in southern Australia, it becomes comparable with other already existing REs such as solar and wind (Morim, 2014). As the same article describes, LCOE can be reduced

Table 2
Different Types of WE Converters Classified from Least Developed to Most Frequently Utilized.

Type	Working Principle	Device	Location	Efficiency (%)	Capacity (MH)	Project Status	Comment
Terminators	• The location is near the water's surface • A device that extends in a direction that is perpendicular to the most likely moving wave front direction. • The device generates forces that will be transformed into electricity because of the collision	Salter's Duck	Off-shore	< 90	0.01	Decommissioned	Installed in China
		Wave Star	Offshore	16–30	2.71	Decommissioned (2016)	Prototype launched in 2006
Pressure Differential	• Devices that are semisubmersible or attached to the ground. • Activated by pressure changes caused by surface waves.	mWave	Near-shore	–	–	Operating	Pembroke Dock, Wales, since 2017
Oscillating Wave Surge Converters (OWSC)	• In shallow waters, pitching flaps anchored to the floor move due to currents. • KE is transformed into hydraulic energy. • The high-pressure water is piped onto the shoreline. • Harvesting energy in hydroelectric plants.	• Oyster full scale	Near-shore	–	2.5	Not Commercialized	Prototypes were tested
		• Wave Roller	Near-shore	25–50	0.35	Decommissioned (Finland) Project approved (Portugal) Project waiting for approval (Mexico)	–
		• BioWAVE	Offshore	~ 60	–	Completed	Unique technology with specific cost, performance, and environmental benefits
Overtopping	• Devices with one or two reservoirs that are long. • Water is collected in the top reservoir, and at the bottom, a low-head hydro turbine is built. • Water will flow from the top reservoir to the bottom reservoir, spinning the turbine and generating power.	• Wave Dragon	Off-shore	18	4–11	Decommissioned	Installed in Denmark (2003 – 2007)
		• TAPCHAN	Onshore	25–35	0.35	Decommissioned (1991)	–
		• Sea Wave Sat-Cone Generator (SSG)	Onshore	–	~ 12	Decommissioned	–

(*continued on next page*)

Table 2 (*continued*)

Type	Working Principle	Device	Location	Efficiency (%)	Capacity (MH)	Project Status	Comment
Attenuators	Connect long floating devices in a line parallel to the primary wave direction to generate power from relative pitch shifts between them	• The Mighty Whale	Off-shore	–	0.11	Decommissioned	(1998–2000)
		• Pelamis	Offshore	< 90	2.25	Decommissioned (2016)	–
		• Floating Raft	Offshore	< 26	0.01	Decommissioned (2007)	Pump break down (USA)
		• McCabe Wave Pump	Off-shore	~ 60	1.49	Decommissioned (1996)	One year in operation, Hydraulic fault
		• OWEL	Offshore	30–80	12	–	Launched in 2016
Oscillating Wave Column (OWC)	• A chamber opens below the water's surface, allowing water to enter and form a water column. • Because air is trapped in the chamber, the air acts like a piston due to the change in the height of the water column caused by wave motions. • Air is drawn toward a turbine that generates power	• Nautilus	Off-shore	30	2	–	High maintenance
		• SPAR Type OWC	Off-shore	–	0.5–5	Decommissioned (Spain)	Installed in Portugal and Spain
		• Energetech	Offshore	0–20	0.5–2	–	A first commercial device by Australia
		• OceanLinx	Nearshore	20–40	0.32	–	Low maintenance
Point Absorbers	• Two connected devices, one stationary at a point and the other floating can create electricity due to a difference in position caused by random wave motion. • In some circumstances, the link is magnetic rather than physical.	• Laminaria WE Converter	Shoreline	–	0.2	Under development	–
		• Smart Ocean Buoy	Shoreline	–	0.03	Completed	–
		• Sea-based L12	Off-shore	–	1	Operational, under testing	Successfully
		• WaveBob	Offshore	~ 40	1	Decommissioned (2005)	–
		• AquaBuoy	Off-shore	–	0.25	–	Installed in Ireland
		• Archimedes Wave Swing	Near-shore	–	2.30	Decommissioned (1998)	2MW connected in Portugal

by controlling the capital, operation, and maintenance costs as they contribute majorly to the LCOE. However, as described by Morim (2014), based on the currently available data on WECs and WERs in Australia, the LCOE of Australian WE have been estimated as $100/MWh for the southern area with a capacity factor of 54%.

As Morim (2014) states, there are significant effects on LCOE by the amount of energy production from the technology used for WE generation. Further, it is reported to have an LCOE of $78.2–261 MWh for WECs, including point absorber and attenuator along the southern while a lower value of 100$/MWh for the west coast. However, according to an economic study on WE in Western Australia, policy mechanisms such as feed-in-tariff have already been designed to motivate the developers to invest in WE generation (Contestabile et al. 2017). According to statics, 40 cent/KW/h of the net Tariff has been reserved for the RE buyback scheme in Southwest Australia (Contestabile et al. 2017).

2.2.3. Reliability

The reliability of WEC is noted to vary depending on the material and structural design. Materials used have a major effect on the performance of converters due to the high possibility of getting corroded in the marine environment. Therefore, the utilization of anticorrosion materials and high-strength materials is significant. In terms of structural designs, the reliability of converters can be largely reduced due to complex transmission mechanisms and depending on the number of parts in seawater, etc. (Zhang et al. 2021). OWC and overtopping devices have higher reliability due to the low number of parts that is in the seawater. On the other hand, as a consequence of the complex nature of the MDWEC structure, it accounts for low reliability (Zhang et al. 2021).

2.2.4. Environmentally friendly

The most important driving factor related to this energy type is the nature of environmental friendliness. When comparing the environmental impacts caused due to the utilization of fossil fuels against this technology, it later has a minimum impact on the environment. Some considerable effects on the ecology, waterways, and fish can be expected (Zhang et al. 2021). MDWEC can be identified as the most environmentally friendly device, and then it is followed by a point absorber and terminator, respectively (Zhang et al. 2021).

With the concerns on climate change, the attention was driven to clean energy and WE. WEC is considered the wet RE device due to the low contribution to climate change compared to the fossil fuel-based electricity generation as already described. Regarding the positive effects of WE generation and WECs, there are positive effects on tourism by installing WECs off-shore as it will lead to the rapid, sustainable development attempting to maintain the environment with high quality (Satriawan et al. 2021).

Even though WE is a clean and green RE, it has some environmental effects associated with it (Khan et al. 2017). The main drawback of WE harness on the environment is the threat to marine life. The underground noise and the electromagnetic field formed at the bottom sea create life threats for marine organisms, including fishes, corals, etc. Marine organisms can get injured when the fishes swim near or through the blades of WE turbines (Khan et al. 2017). Further, the massive sound of ships, generators, and turbines disturb the life of underwater creatures. Also, the installation of generators and blades disturbs the navigation system of these underwater organisms. Further, the reproduction process of marine organisms has the risk of getting affected by the electromagnetic field and the noise created in the water. To protect from these hazards, marine organisms tend to swim/migrate from these areas, which have loud noise and a lot of disturbances, and subsequently, it leads to environmental crises (Khan et al. 2017). Even though there are no significant effects of WECs on climate change, there are on marine organisms. Australian sea is abundant in various marine organisms, including fishes, turtles, etc., and therefore, the harnessing of WE vastly affect the underwater world, as discussed earlier. On the other hand, the installation of these WE extraction devices creates disturbances in the shipping industry, affecting even human lives (Satriawan et al. 2021). Despite that, some of WECs, such as Pelamis, perform poorly but do major environmental effects accelerating the photochemical oxidizer formation and acid rains, etc. (Satriawan et al. 2021). Therefore, it is noted that even the clean energy that waves energy causes considerable harm to the local ecosystem. The described environmental impacts that are possible to occur in any country can be expected even in Australia.

As Flocard et al. (2016) states, when selecting a suitable site for the WEC, difficulty in quantifying the potential conflicts and the importance of the site section is two of the main challenges. For the selection of a suitable site for WEC, the assessment can be performed in terms of seabed nature, climatology of the wave, environmental factors, quality of WES, and in terms of conflicts with other marine users such as shipping fisheries, etc. High-resolution data such as data on wave and current, information on benthic habitat, and typology of seafloor too are important for selecting an optimal site (Flocard et al. 2016). Table 3 shows the various types of converters and their parameters.

3. Energy status in Australia

3.1. Australian energy statistics

3.1.1. Energy consumption (2019–20)

As explained in Australian statics, energy consumption is the amount of energy that is used in the economy of Australia. In 2019–20, the Australian Gross Domestic Product (GDP) shrank by 0.3% to $1.9 trillion. The population increased by 1.3% to 22.5 million. Australia's energy consumption dropped by 2.9% to 6014 petajoules. This reduction in usage was 182 petajoules, or the energy equivalent of filling a 55-liter petrol tank 97 million times. This compared to an average annual growth rate of 0.7% over the previous ten years to 2018–19 (Hayward, 2011a). Energy productivity (GDP divided by energy consumption) increased by 2.7% and by 21% during the previous ten years. For every petajoule of energy consumed, Australia now generates $324 million in GDP, almost $56 million more than a decade ago. Moreover, oil consumption declined by 7% because of reduced transportation and refinery crude usage. With 37% of total primary energy consumption, oil remained Australia's most important source. On the other hand, natural gas now accounts for 27% of the total primary energy mix. Gas use increased by approximately 4%, with increases in LNG production, electricity generation, and industrial and residential use (Australian Energy Update, 2021). Table 4 represents the average annual growth of population, GDP, and energy consumption in Australia for 2019–20 and the past 10 years. In addition, Fig. 16 represents the energy consumption in Australia by type of fuel used.

From the Fig. 16, it can be observed that coal, which accounted for 28% of total energy consumption in 2019–20, remained the second most popular fuel. Coal consumption declined 5%, double the ten-year average. Lower brown and black coal-fired electricity output, which was supplanted by renewables and gas, was a major contributor to the reduction.

3.1.2. Energy production (2019–20)

The total amount of primary energy produced in the Australian economy, measured before consumption or transformation into secondary energy products, is referred to as energy production. Primary energy sources include wind, hydro, and solar PV, as well as other renewable energy sources that produce electricity without a heat component. Because the coal is previously accounted for when mined, coal-fired electricity generation is considered secondary production and is not included (Australian Energy Update, 2021).

Moving forward, according to Australian Energy Update (2021), natural gas and oil production both increased by 2%, bringing total energy production to 20,055 petajoules. While natural gas production climbed by 8%, owing to higher output in the northwest for Liquified Natural Gas

Table 3
Few Types of Converters and The Parameters.

Name	Category	Location	Data	HDE (%)	Scale(m)	Capacity (kW)
AquaBuoy	Point absorber	Canada	2000	20	6	250
Wavebob	Point absorber	Ireland	2007	40	15	1000
Pelamis	Attenuator	UK	2007	15	150	750
DEXA	Attenuator	Denmark	2011	8	22	160
Biowave	Terminator	Australia	2008	45	16	250
Oyster	Terminator	UK	2005	40	18	315
Mutriku	OWC	Norway	2011	7	180	300
Pico	OWC	Portugal	2000	20	48	400
Wave Dragon	OWEC	Denmark	2009	26	300	1200
SSG	OWEC	Norway	2008	23	54	350
Three-DOF WEC	MDWEC	NA	NA	80	10	152
Six-DOF WEC	MDWEC	NA	NA	54	10	831

Table 4
Summarized Table Containing the Statics of Energy Consumption with Australian Population.

–			Average Annual Growth (%)	
	2010–11	2019–20	2019–20 (%)	10 Years (%)
Population(millions)	22.3	25.7	1.3	1.6
GDP ($ billion)	1580.9	1947.1	−0.3	2.3
Energy Consumption (PJ)	5902.5	6013.8	−2.9	0.2
Energy Consumption per person (GJ)	264.2	234.0	−4.2	−1.3
Energy Intensity (GJ/$ million)	3733.6	3088.6	−2.7	−2.1
Energy productivity ($ million/PJ)	267.3	323.8	2.7	2.1

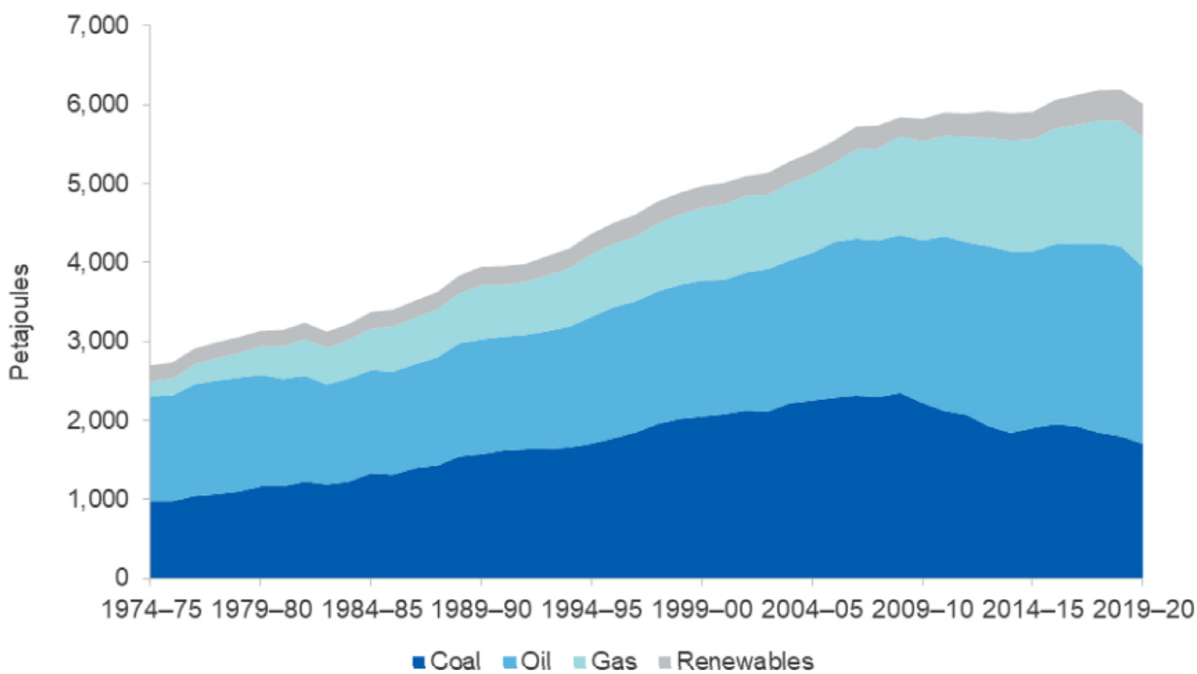


Fig. 16. Energy Consumption in Australia by Fuel Type During 2019–20.

(LNG) export. Moreover, black coal production declined by 2%. Brown coal production decreased by 4%, indicating a longer-term trend away from brown coal-fired power generation. Besides, renewable energy output increased by 5% to 419 petajoules and accounted for 2% of total energy production. The amount of naturally occurring LPG produced increased by 48% to 151 petajoules (6 billion liters). The main sources of growth were wind and solar. Fig. 17 will show the energy production in Australia based on the type of fuel.

3.1.3. Energy generation (2019–20)

Total power generation in Australia remained stable at 265 terawatt-hours (955 petajoules). Industrial, rooftop solar PV and off-grid generation are all included. Industry and households generated about 16% of Australia's electricity outside of the electricity sector. At the same time, black and brown coal-fired energy generation decreased by 7% and 2%, respectively. Further, coal accounted for 55% of total power, down to 54% in the calendar year 2020. Natural gas-fired generation increased by 5% in 2019–20, to 21% of total generation, before dropping to 20% in the calendar year 2020.

Renewable generation climbed by 15.2%, accounting for 22.6% of total generation. This was mostly due to a 42% rise in solar generation and a 15.2% increase in wind generation, with solar and wind each accounting for 8% of total generation. Renewable production increased to 24% of total generation in the calendar year 2020. The last

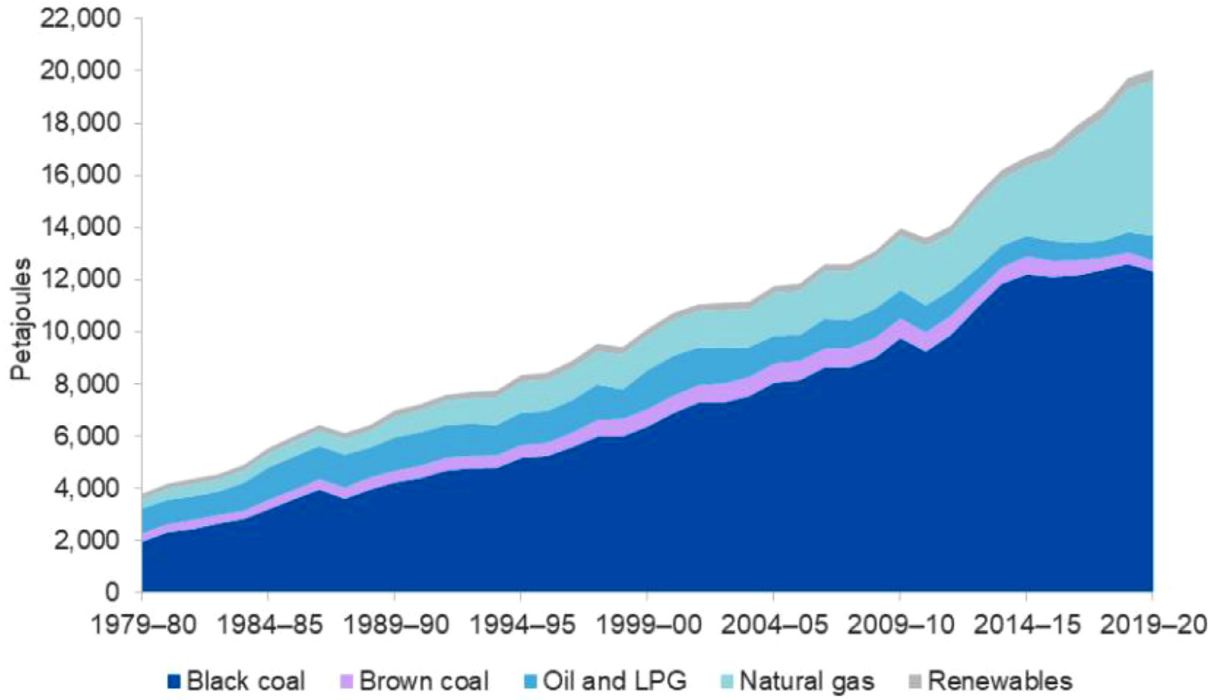


Fig. 17. Australia's energy production by fuel type during 2019–20.

Table 5
A Summarized Table Containing the Statics of Energy Consumption with Fuel Type.

–	2019–20		Average Annual Growth (%)	
	GWh	Share (%)	2019–20 (%)	10 Years (%)
Fossil Fuels	205,248	77.4	−3.2	−1.1
Black Coal	111,873	42.2	−6.7	−0.5
Brown Coal	33,649	12.7	−2.4	−5.4
Gas	55,216	20.8	4.6	1.3
Oil	4509	1.7	−8.4	4.3
Renewables	59,930	22.6	15.2	9.5
Hydro	15,150	5.7	−5.1	−1.1
Wind	20,396	7.7	15.2	14.4
Bioenergy	3352	1.3	−4.1	5.3
Solar PV	21,033	7.9	41.7	33.8
Total	**265,178**	**100.0**	**0.4**	**0.5**

time renewables made up such a large percentage of overall power in Australia was in the mid-1960s, when the Snowy Mountains hydroelectric plant gradually came online. In both 2019 and 2020, the fastest increasing generation type was solar PV and particularly large-scale solar PV (Australian Energy Update, 2021). Table 5 represents the data on energy generation by fuel type in Australia, while Fig. 18 shows the electricity generation from fossil fuels based on fuel type in Australia.

In the Australian economy, lower energy intensity & high productivity can be noted as the consequence of economic growth is more than consumption. Therefore, it is able to experience a shift in the Australian energy industry from high to low energy industries with the improvements in energy efficiency (Australian Energy Update, 2021).

3.1.4. Australian energy status for calendar year 2021

According to Australian Energy Statistics (2022), which are official estimates of Australia's overall electricity generation. These estimates are based on a variety of data sources. First clean energy regulator, which includes data collected under the national greenhouse and energy reporting scheme and the renewable energy target. Second is the Australian energy market operator, which covers the national electricity market and the western Australian wholesale electricity market. At the time of writing this manuscript, the Australian energy statistics have been updated to incorporate projections for 2020–21 and the calendar year 2021, based on the most recent data on total power generation in Australia.

By looking into this data, it is perceived that in the calendar year 2021, total energy generation in Australia is expected to be 267,452 gigawatt-hours (GWh), up slightly from 2020. Renewable energy sources supplied a projected 77,716 GWh, accounting for 29% of total electricity generation in Australia, up 5% from 2020. Additionally, solar-generated the most renewable energy (12% of total), followed by wind (10%) and hydro (6%). On the other hand, fossil fuels generated 189,737 GWh (71%) of total energy output, down 5% from 2020. Coal generated most of the electricity, accounting for 51% of total generation in 2021.

These statistics demonstrate total energy generation in Australia, including electricity generated by power plants as well as electricity generated by businesses and homes for their own consumption (Australian Energy Statistics, 2022). Table 6 depicts Australia's electricity generation by fuel type, physical units, and calendar year. Table 7 shows the energy generation in Australia in 2020–21 by fuel type and physical units in each state.

The main source of electricity generation in Australia in 2021 was black coal, but by looking into past data, it is understandable that the use of non-renewable fuels is gradually declined. Furthermore, the use of geothermal is not used in Australia nowadays. Among the renewable energy sources, wind and solar have marked a fast growth during the past decade in the country. However, it is believed to have a greater influence on the consumption of renewables towards the productivity of the energy industry.

From table 6, it is recognized that Queensland is a top state which uses non-renewable fuels for energy production, while on the other hand, New South Whales is the top state using renewable fuels as a source of energy production.

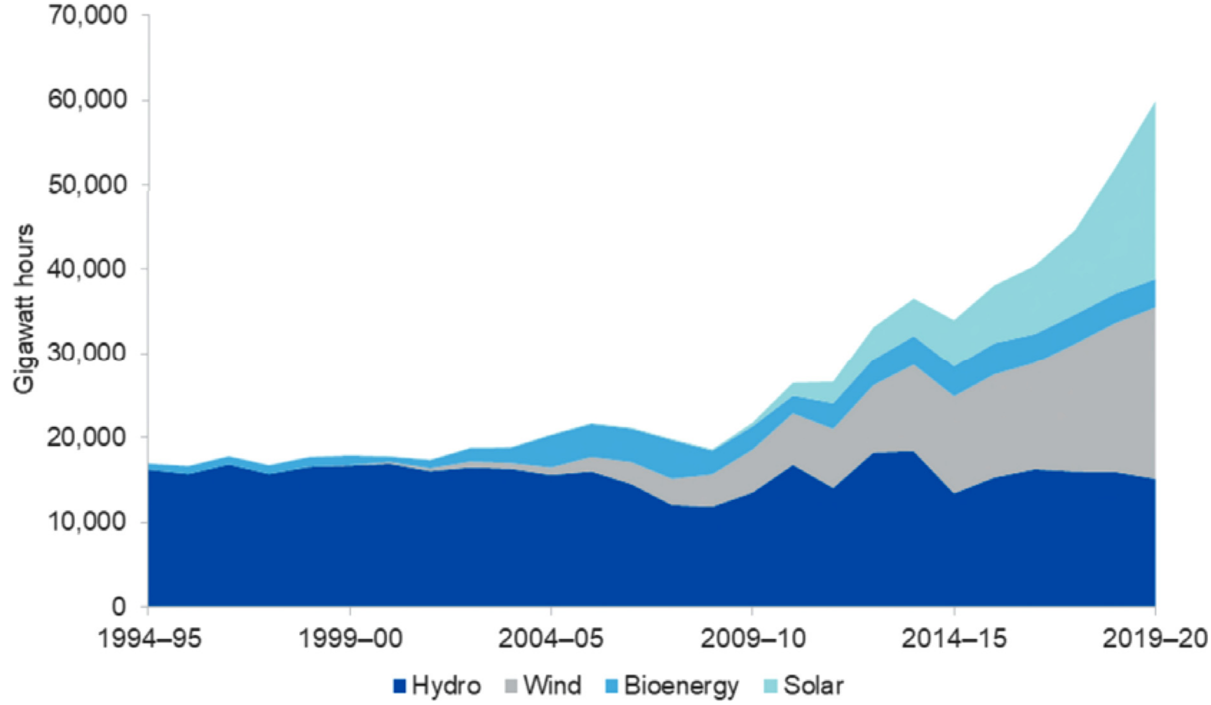


Fig. 18. Australia's Energy Generation from Fossil Fuels and Based on Fuel Type.

Table 6
Electricity Generation in Australia, Broke Down by Fuel Type, Physical Units, and Calendar Year.

–	2015 GWh	2016 GWh	2017 GWh	2018 GWh	2019 GWh	2020 GWh	2021 GWh
Non-renewable fuels							
Black Coal	111,654.6	115,365.7	120,892.0	120,594.1	116,618.7	108,740.9	103,922.1
Brown Coal	50,547.9	46,990.9	38,276.7	35,961.4	33,221.9	34,194.1	33,476.1
Natural Gas	49,705.6	48,110.5	55,087.8	51,464.7	55,710.6	53,124.3	47,631.0
Oil Products	6162.2	5718.2	5272.8	4901.2	4727.2	4506.4	4707.5
Total non-renewable	**218,070.2**	**216,185.2**	**219,529.3**	**212,921.5**	**210,278.4**	**200,565.6**	**189,736.7**
Renewable Fuels							
Bioenergy	3677.6	3627.2	3561.4	3588.1	3467.7	3410.4	3344.0
Wind	11,833.0	13,039.7	13,210.8	16,262.0	19,471.7	22,606.9	26,795.9
Hydro	14,207.6	17,926.4	13,747.7	17,528.3	14,385.8	14,806.6	16,381.8
Large-Scale Solar PV	283.5	593.9	838.9	2402.6	5965.0	8123.4	10,970.7
Small-Scale Solar PV	5912.0	6845.9	8078.6	9929.9	12,332.0	15,719.3	20,223.1
Geothermal	0.4	0.4	0.3	NA	NA	NA	NA
Total Renewable	**35,914.2**	**42,033.4**	**39,437.8**	**49,711.0**	**55,622.2**	**64,666.6**	**77,715.6**
Total	**253,984.4**	**258,218.7**	**258,967.1**	**262,632.5**	**265,900.6**	**265,232.2**	**267,452.3**

3.2. WER availability in Australia

It was stated by Cuttler et al. (2020) that Australia had been recognized as a major region abundant with sufficient WERs as a result of the Austrian South coast's proximity and exposure to storms from the Southern Ocean Well. As described by Morim (2014), WERs in coastal and near-shore areas of southern Australia are consistent throughout the year, with the highest WE recorded in the spring and winter. The Australian Southern Ocean is an ideal place to WE generation as it has a latitude between 60- 70°, and generally, the waves in the southern area propagate from west to east. Therefore, it is rather obvious that the climate in Southern Australia is a perfect climate for wave generation (Curran, 2012). However, the wave in southern Australia can be categorized into two waves varying within the height of 1–4 m and period of 6–11 s (Morim, 2014). As it is further explained, the height of swell-off waves in southwest and southeast are identified as 2–2.5 m and 1–2 m, respectively, while wave period of 8 s and 7 s was identified for again southern, west, and east, respectively (Morim, 2014). As again stated by Hemer et al. (2017)," WERs are rich between Geraldton and the Southern tip of Tasmania, having huge potential to WE totaling over 1300 TWh/yr, which is almost five times of Australian Annual Energy requirement (Hayward, 2011a). Despite that, the areas like Victoria and Western Australia are reported with a high level of WE, approximately 30 kW/m collectively (Morim, 2014). Queensland, New South Wales, and mid-Southern & Western Australia are also identified as the coastal area which has the potential for harvesting WE with moderate WE power level. As Simon P. Neill correctly outlined, Australia is comprised of the largest tidal resources as well as semidiurnal & diurnal waves (Neill et al. 2021). However, there is some seasonal variability and small variation in the magnitude of Queensland and South Wales Waves in respective to the mean of southern coastal (Morim, 2014).

A comparison between wave and wind revealed that the prediction of a wave for 36 h is mostly as accurate as 12 h of wind forecast, proving the high prediction of waves. According to Hemer and Griffin (2010), the potential of generating WE by using the WERs prevailing along Australia's Southern Margin is almost around 140 GW which is three times

Table 7
Energy Generation in Each State of Australia in 2020–21, Broke Down by Fuel Type and Physical Units.

–	NSW GWh	VIC GWh	QLD GWh	WA GWh	SA GWh	TAS GWh	NT GWh	AUS GWh
Non-renewable fuels								
Black Coal	50,790.8	0.0	46,248.2	9212.4				106,251.4
Brown Coal	0.0	34,060.0	0.0	0.0				34,060.0
Natural Gas	1903.2	1956.9	10,324.4	25,680.3	5589.0	186.1	4143.0	49,782.9
Oil Products	340.6	179.1	1034.9	2458.3	126.7	19.8	502.5	4661.9
Total non-renewable	**53,034.6**	**36,196.0**	**57,607.5**	**37,351.0**	**5715.7**	**206.0**	**4645.5**	**194,756.3**
Renewable Fuels								
Bagasse, wood	686.1	229.7	1076.4	0.0	0.0	0.0	0.0	1992.2
Biogas	411.0	499.3	198.5	110.8	94.6	31.8	8.0	1354.0
Wind	4805.9	7080.6	1826.0	3140.5	5867.1	1815.3	0.0	24,535.4
Hydro	2964.2	2852.0	950.2	128.0	3.5	8301.9	0.0	15,199.7
Large-Scale Solar PV	3368.0	1455.5	3395.8	486.6	884.3	3.0	44.6	9637.9
Small-Scale Solar PV	4892.9	3176.4	5160.9	2298.5	2128.2	218.6	203.6	18,079.1
Geothermal	NA	NA	NA	NA	NA	NA	NA	NA
Total Renewable	**17,128.2**	**15,293.5**	**12,607.9**	**6164.3**	**8977.6**	**10,370.6**	**256.1**	**70,798.2**
Of Which ACT	341.2							
Total	**70,162.8**	**51,489.5**	**70,215.4**	**43,515.3**	**14,693.3**	**10,576.5**	**4901.6**	**265,554.5**
Renewable Generation (%)	24%	30%	18%	14%	61%	98%	5%	27%

Table 8
Electricity Generation Capacity by different renewable technologies (Dunn et al. 2008).

RE Technology	2015(In GW)	2020(In GW)	2030(In GW)	2040(In GW)
Hydro	8	8	7	7
Biomass	0	1	1	1
Wind	4	11	15	15
PV	3	3	4	4
Wave	0	0	3	6

Australia's total capacity. Further, it is explained that, by converting 10% of WE to Electricity, Australia can satisfy one-half of its present-day energy demand (Hemer and Griffin, 2010).

As Australia's Energy Assessment states, the greatest, WE (25–35 kW/m) is reported from the southern half, while the WE in the northern shelf is even lower than 10 kW/m, making it not suitable for harvesting purposes (Australian Energy Resource Assessment, 2014). Considering the availability of WERs within Australia, it is quite promising that the WE can be utilized to modify the Australian electricity industry by moving to a sustainable alternative like WE (Morim, 2014). However, based on the local features and climate conditions, the WE resource change. Therefore, the uniformly distributed nature of WERs cannot be predicted (Morim, 2014). Therefore, in order to determine the extracted site for harvesting of WE, it is required to do an investigation of near-shore WERs as suggested by Morim (2014). Fig. 19 shows Australia's WE atlas.

3.3. WE generation in Australia

Australis's focus has been driven to unconventional energy sources with the requirement to change from fossil fuels (Knight et al. 2014). Table 8 shows the Renewable Electricity generation in Australia according to forecasts by the Australian Government.

It is able to note that Australia comprises various RESs, including Wind, Solar, Wave, tidal, etc. There has been a significant increase in utilizing solar and wind energy sources since 2010. However, in terms of utilization, waves are still at the primary stage (Australian Energy Resource Assessment, 2014). As stated by another study, there is a 50% increase in solar and a 17% rise in wind consumption leading to an overall increment of 5% in using renewables in 2018–19 (Australian Energy Update, 2021).

As summarized in table 4, the wind is the main renewable power source. It shows 0 productions of wave in 2015 regardless of WERs availability within the country. However, according to Australian Preliminary Energy estimates, 10% of energy requirements in the 2050 year can be generated from WERs. It is suggested that even though the WE near tropical counties does not exceed 40 kW/m power, the West coasts of Australia are capable of harvesting in the range of 40–25 kW/m (Felix et al. 2019). In Australia, WERs are mainly available in Southwest, South, and Southeast coastal area, as discussed earlier. Commonwealth Scientific and Industrial Research Organization of Australia is responsible for making the maps showing the Waves, Tidal, and Non-tidal flow distributions around the country's coastal area. These distribution maps are constructed using the available up-to-date information in order to provide evidence of available and extractable WERs (Knight et al. 2014) for the developers. Further, when generating WE for commercial purposes, it is required to install the wave devices in 'Wave Farm,' which is a specific area filled with a collection of WEC. The largest ORE project in the country was the construction of a wave farm on the coast of Victoria by the company called 'Ocean Power Technologies Australasia Pty Ltd' (Hayward and Osman, 2011b). Even though the WE are widely available, a few numbers of commercial-size devices exist to exploit the WE. With the long-term targets to reduce greenhouse gas emissions by 60% in 2050, it is planned to 20% energy by the year 2020 from RES. To achieve a long-term target of a 60% reduction in gas emission, it has been estimated that an additional RE generation of 45 000GW h/yr is required to be generated by 2020 (Hemer and Griffin, 2010). The Australian Government has already taken some necessary actions by investing in pre-commercial WE developments convincing its potential to contribute to Australia's future target of a low carbon energy mix (Hemer et al. 2017).

It was identified that the near-shore WERs available in Australia are the potential to contribute to energy generation significantly, and that was proved by an evaluation that was done on identified hypothetical Wave farms at 25 m depth from South Australia to Queensland (Morim, 2014).

3.4. Role of Carnegie company in the Australian WE industry

According to Ward (2014), CWE company is the main inventor, developer, and Owner of CETO technology which is mostly used in Australia. Carnegie is the most successful WE global company globally, which has delivered an array of largescale energy generators for more than 12 months. The CWE company has tested this CETO technology in the application of WE generation with the aim of improving the global market for the same concept. Further, the Carnegie company has Australian stakeholders of more than 10 000, including 3 500 from Western

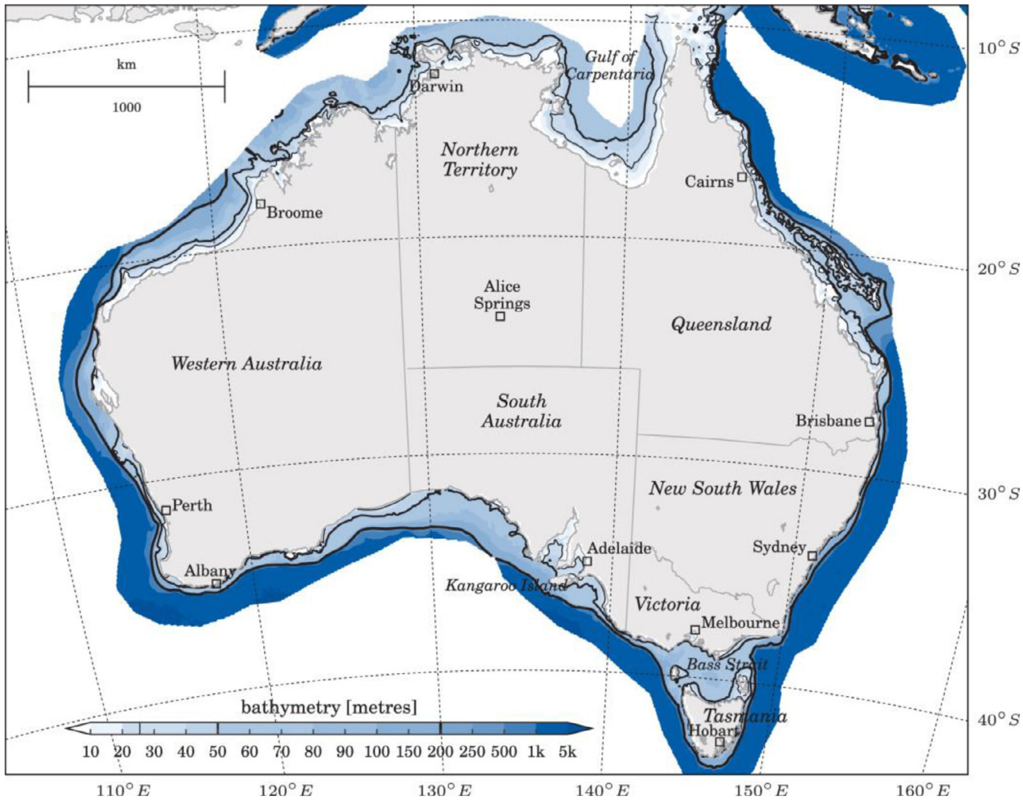


Fig. 19. Australian Map displaying locations where WERs are mainly available around Australia (Aderinto and Li, 2019a).

Australia (Penesis et al. 2016). The Australian CETO, WE team is a combination of employees in the Belmont, North Fremantle, and Fremantle regions. In further, this company greatly influenced to motivate the private sector with the help of the Government to develop and enhance the WE generation technologies in the country. Also, more than $140 fund has been raised by CWE to develop the CETO technology within the country. Further, it has been worked on verifying that WE are the best alternative to stand against the energy crisis as a RES (Ramsay et al. 2016). Some information on two main projects conducted in Australia using CETO technology can be found below.

- Albany, WE project -This project was focused on the coast of Albany Carnegie's License Area in Western Australia. The project location was 30 m down in respective to the wind farm level. Importantly, this area has WERs of more than 1 m swell 100% 24/7 (Penesis et al. 2016). Albany is an area where both extreme swells and storms are present rapidly (Santo et al. 2020). When Albany is compared to the Orkney project in the UK, it can be noted that Albany has Te=10.5 of mean wave period, which is larger than Orkney. This proves that Albany has swells that last for a long period, and these swells are made as the result of the Indian and southern oceans (Santo et al. 2020). This project was dominantly handled by CWE and was estimated to have an expenditure of $ 65 447 683.37 at the beginning. The financial funds were given by the Department of Primary Industries & Regional Development in Australia. Further, Carnegie company has done a proper investigation on the Albany WERs and on the location before starting the project. According to the records, it was approximately around $ 2 million, including the site surveys, mapping and licensing for design, etc. (Penesis et al. 2016). The vision of this project was to build 1.5 MW CETO 6 units supporting Australia's local grid.
- Perth, WE Project (PWEP) – It was the world's first commercial grid - water connected WE project using the CETO technology after developing the concept for 10 years. The project was based on the area of Garden island in West Australia (Ward, 2014). However, this area nationally is a listed heritage that has higher biodiversity. Initially, it was estimated at AU$35 million, and from that, AU$22 million was funded by the Australian Federal Government's emerging renewable program and Western Australia's state government's low emission energy development. Like the Albany project, Carnegie conducted a proper assessment of the environmental aspects, including fauna interaction and underwater sound, with the help of environmental experts to enhance the Sound Environment Management.

4. Comparison of Australian WE generation with other countries

As Liu et al. (2017) states, in terms of utilizing WE, the countries including Denmark, France, Portugal, the UK, Spain, and Europe are dominant in this field. It can be noted that these mentioned countries have already realized the importance of WE and its potential for sustainable power generation.

In terms of test centers, it can be noted that there are a lot of WE test centers all around the world, as shown in Table 9, while funding and policy comparisons can be found in table 10. In the UK, it mainly consists of three main test centers, namely Wave Hub, EMEC and FaB. For testing an array, the Wave Hub is formed. To minimize the associated risk and time for developers, a testing site like FaB is formed. More testing facilities have been introduced with the improvements in technology (Aderinto and Li, 2019b). There are a few test centers already established in Portugal, namely the Pico WE plant, Agucadoura, and pilot zone. Most of these facilities were established in the early period. For the effective operation of roadmaps, the USA started forming required infrastructure such as open water and expandable grid-connected berths, including protocols, etc. Shandong and National WE center are two test facilities in China. Shandong is a comprehensive test facility that tests models and prototypes of WECs. However, even in Australia, it was identified few test facilities/sites such as Albany and Garden Island. Therefore, it is noted that the majority of

Table 9
Comparison of The WE Development in Australia Along with Other Countries.

Country	WE test centres	WER (TWh/yr)	Projects (current or past)
Denmark	Danish test site, Nissum Bredning	–	–
England	Wave Hub, FaB and EMEC	146 - Theoretical, 70 - Practically accessible	Mey Gen (World's largest Tidal array) – 8 GWh of power
Ireland	Atlantic Marine, AMETS, Galway Bay	–	–
Scotland	European Marine	–	–
Spain	Biscay Marine, Canary Island	–	–
USA	Pacific Marine, Hawai'' WE site	400	**1.** To study the performance of the device - 'Pelamis' in California (Aderinto and Li, 2019b), **2.** Sponsored project to reduce the cost to generate power capacity of 90MW to $ 1325/kW in the period of 2024–2027
China	Shandong, National WE center	20 km of the coastal area, 16GW- theoretical, 14.71 GW - practically accessible	–
Norway	Rand Island	–	Statkraft conducted a study on numerical classification of Technologies of the wave, modeling of WE, new models for wave devices, etc.
Portugal	Pilot Zone, Agucadoura, Ocean Plug	10GW	–
France	SEM-REV	–	–
Australia	Albany, Garden Island	2004 TWh/yr of WER (22% of the global resource and is more than the total consumption of energy in 2018/2019, 1455 TWh/year at the southern coast, 61 TWh/year in Northern Australia at the 25 m contour. Tasmania, Victoria, Western and South Australia	**1.** Albany - capacity of 35.44 MW (80% of the electricity needs of the town), **2.** Banks Strait - 15 m wide and generate 0.85 kW/m2 of energy at the southern part of the channel, **3.** AWavEA project, **4.** Field study at Garden Island - to determine the effects of WE extraction

Table 10
Funding and Policy Comparison Among Few Selected Countries.

	UK	Portugal	US	China
Target	(1) 15% of energy from renewables by 2020 [94], 80% by 2050. (2) An installed capacity of 2 GW by 2020 from wave and tidal stream's energy (3) Target levelised cost reduces to 10–20 p/kWh by 2020 and 5–8 p/kWh by 2050.	(1) 31% of energy from renewables by 2020, not defined by 2050. (2) The installed capacity of tidal streams and WE devices turn to 250 MW by 2020	(1) 25% of Fed. Govt. electricity consumption from RE by 2025. (2) No government target for MHK installation, only industry goal– at least 15 GW installed capacity by 2030. (3) MHK cost aims to be 12–15 cents/kWh by 2030.	(1) Add the percentage of non-fossil fuels to over 15% by 2020 (2) Establish several plants with an installed the capacity of 50 MW by 2015 from ocean energy.
Market pull	Renewable Portfolio Standard (RPS)	Feed-in Tariff	Renewable Portfolio Standard (RPS)	Feed-in Tariff on renewable energy currently, but to Renewable Portfolio Standard (RPS) in the future
	(1) Renewables Obligation Certificates (ROC) Program. (2) Levy Exemption Certificates (LECs) (3) Saltire Prize (Scottish Government) (4) Revenue support through Banded Renewables Obligation	(1) Setting a basic Feed-in Tariff of €80/MWh for projects applicable to the first 20 years. (2) Older scheme suspended.	(1) some incentives in renewable energy, but not expand to ocean energy yet (2) Investment Tax Credit: for eligible tidal projects. (3) Database of State Incentives for Renewables and Efficiency: compile states' incentives to support waterpower development.	(1) Renewable energy electricity price additional bonus. (2) Distributed electricity generation projects exemption Certificates
Technology push	R&D grants: (1) Supergen 2 (2) Technology Strategy Board Marine Energy Program Capital grants: (1) Offshore Renewable Energy Catapult (2) Marine Energy Array Demonstrator (MEAD) (3) Marine Renewables Commercialization Fund (MRCF) (4) ETI Marine Program	R&D grants: (1) Foundation for Science & Technology (FCT) (2) Government enterprise within the Ministry of Economy and Innovation Capital grants: (1) Agência de inovação SA PRIME (Incentives Program for the Modernization of Economic Activities).	R&D grants: (1) Small Business Innovation Research (SBIR) and Technology Transfer (STTR) programs (2) WE Prize Capital grants: (1) Funding Opportunity Announcement (FOA) (2) The Oregon WE Trust (3) DOE, in collaboration with the Bureau of Ocean Energy Management and the National Oceanographic Partnership Program:	R&D grants: (1) Small Business Innovation Research (SBIR) and Technology Transfer (STTR) programs (2) WE Prize Capital grants: (1) Several experiment tests tanks. (2) 3 sea testing centers.

countries have already started generating and testing WE, including Australia.

It is noted that few the countries, such as England, Norway, and Australia, have already launched either small or medium WE generation projects. My Gen in England is the largest array in the world that generates approx. 8GWh of power. Thus, the USA conducted a sponsored project that investigates reducing the cost of generating power capacity of 90MW to $ 1325/kW from 2024 to 2027 (Mwasilu and Jung, 2019). On the other hand, even in Australia, few projects have been conducted. Albany is one of the famous projects that was overseen by Carnegie WE company. This project aimed for a capacity of 35.44 MW which can cover 80% of the town's electricity needs. Another field study was conducted at Garden Island to determine the effects of WE extraction (Hemer et al. 2018a). Thus, it was identified that not all companies and countries had not started WE.

The support from the national policy is very significant for new industries like WE to accelerate its development. In western countries, roadmaps have been published to form a national commitment to the development of WE. As a result, the policies related to WE generation have been released (Liu et al. 2017). UK RE roadmap that DECC introduced, National Renewable Infrastructure in Scotland, and Ocean Energy Map in Ireland are some of the best examples. However, there is no significant evidence of any roadmap publication in Australia to develop WE (Alldritt and Hopwood, 2010). In further, countries like the UK have established a set of policy incentives to promote technology innovation. In the case of funding, most countries seem to have started funding the WE developers, and funding schemes such as the Marine Renewable fund in the UK, funding for prototype development in Ireland, and the feed-in Tariff are some of them. Importantly, even in Australia, the authorities such as the Western Australian Government and ARENA have started funding the WE project. Albany is one of the funded projects (Negro et al., 2012).

According to the latest update, it is identified that around 70 TWh/year WERs are practically accessible in the UK. It covers 20% of the UK's electricity consumption (Evans et al., 2013). Portugal is very rich in ocean ESs but particularly WE. The attention on WE were driven due to the oil crisis experienced in 1973. According to the estimations on 'Utilization of WE,' it was reported as 10 GW, but only a half is extractable (Henriques et al., 2013). According to statistics, the USA has the potential for an amount of approximately 400 TWh/year, which is 10% of the total national demand for electricity. Then, 2100 TWh/year amount of WERs is found in the USA. The development of RE, especially from water, is mainly principled by the Department of Energy (DOE) in the UK. Currently, it is taken actions for the improvements in 'Resource Characteristics' to cover the USA energy requirement (Glickson et al., 2012). In the case of China, it was identified to have 16 GW of WE distribution along a coastal area of 20 m. Yet only 14.7 GW can extract and identified that WERs had not distributed uniformly though out the area.

In terms of targets, the UK has its own targets of achieving increased installed capacity and reduction of LCOE. 'Renewable Portfolio Standard' (RPS) has been introduced as the market policy in the UK with a few other programs like Renewable Obligation Certificate (ROC). Also, RPS, it can be noted that to motivate the researchers and students, more incentives and training opportunities such as supergene have been introduced. It is believed that the development of ocean energy is accelerated by education and incentives in the UK. In Portugal, they are determined to achieve 31% of energy through RE means by 2020 and are expected to reach the capacity of 250 MW. In terms of incentives, a high-quality feed-in tariff was implemented in 2015, with a basis of $ 80/MWh for the initial 20 years. In terms of funding, most of the scientific fields, including WE, are mostly funded by FCT (Pontes, 2007). In the US, few plans were formed targeting the reduction in LCOE, etc. It is mostly functioned to achieve acceleration in the market and development in technology. Yet, there are only a limited number of WE project due to massive requirements of capacity. In 2020, the council of China introduced an action plan namely development strategies plan to minimize the energy consumption of non-fossil fuels, to 15% at the year of 2020. In China, more of the incentives were introduced to motivate energy development of ocean. In 2006, new market incentives were formed focusing RE inclusion with tax preferences, financial support etc. (MacGillivray et al., 2014). However, of the total incentives, only a few are addressed the WE development in China. After joining the international organization, China became an active partner in OES, and currently, China can be considered the most active north pacific member. When compared to Australia, there is one major company that engages mostly in WE project, namely Carnegie. Also, even though there is no significant roadmap, there are few parties who invest in the WE project. Western Australian state and ARENA are two of them (Brito and Huckerby, 2011).

Fig. 20 represents the WEC deployment among a few of the selected countries. As indicated in the Fig. 20, in terms of WE deployment, Portugal and UK lead the industry. Initially, during the primary stage of this industry, an 'onshore' converter was used mostly, such as the 'Pico WE converter' in Portugal (Liu et al. 2017). However, the use of 'offshore converters' became famous in the industry as a consequence of rapid development in technology (Liu et al. 2017). In 2004, the first full-scale Pelamis prototype produced electricity in the UK, and the first commercial array was introduced and tested in the 2008–2009 period in Portuguese. Thereafter, more offshore WECs were developed and tested in various test centers around the world, including Wave Dragon and Aquamarine Oyster, etc. Even though the development of WE in the USA is not indicated in Fig. 20 (Liu et al. 2017) yet, there can be a noticeable development of WE in the USA. There are many sea trials on a small scale that are conducted by developers in the USA. The developers like 'Ocean Power Technologies (OPT)' have started focusing on small-scale WECs, as shown in Fig. 20. Then, a major development in WE can be noted in Australia in 2005, as depicted in Fig. 20. However, after that, there is no significant sign of WE development for a long period. Again in 2013, a major development in WE can be noted in Australia.

5. Challenges of generating WE in the Australian energy industry

Most regions around the world, including Australia currently at a stage where they have designed and tested numerous prototypes to exploit the energy from Waves (Felix et al. 2019). Still, there is only limited evidence on the long-term reliability as well as on the largescale commercial viability of using these prototypes within Australia. It is identified that Australia is partially a tropical country, and some of the barriers in tropical countries in generating WE are common to Australia. Also, as described in Felix et al. (2019), the success in extracting and developing energies like 'WE' clearly depends on the long-term availability of source and suitability of regions chosen for the extraction and deployment.

Technical Challenges – Under the technical issues, issues relate to devices, WEC technology, and implementation issues in terms of placement, maintenance, and removal are possible to identify in the Australian WE industry. The technical challenge is associated when designing structures in a way that can maximize the energy performance and in a way that can withstand structural load in the marine environment (UK Marine Energy, 2019). Then, the next challenge when designing technical advancements considering then effects on the environment. Because of funding, it can be noted various technologies within Australia limit the maturity of the WE industry.

Technology difficulties- It experiences different technological challenges due to the primary fact that Ocean Environment is uncertain about performing work (Mwasilu and Jung, 2019). Also, the requirement to install the device deep in the water that could provide electricity and especially at a competitive price, is another challenge in Australia. The installation of a device or any other structure in deep water is obviously difficult and rather expensive due to the wave fluctuations in the power levels and direction. (Jouanne, 2006). Another issue relates to the technology is that the WEC normally involves waves that have a

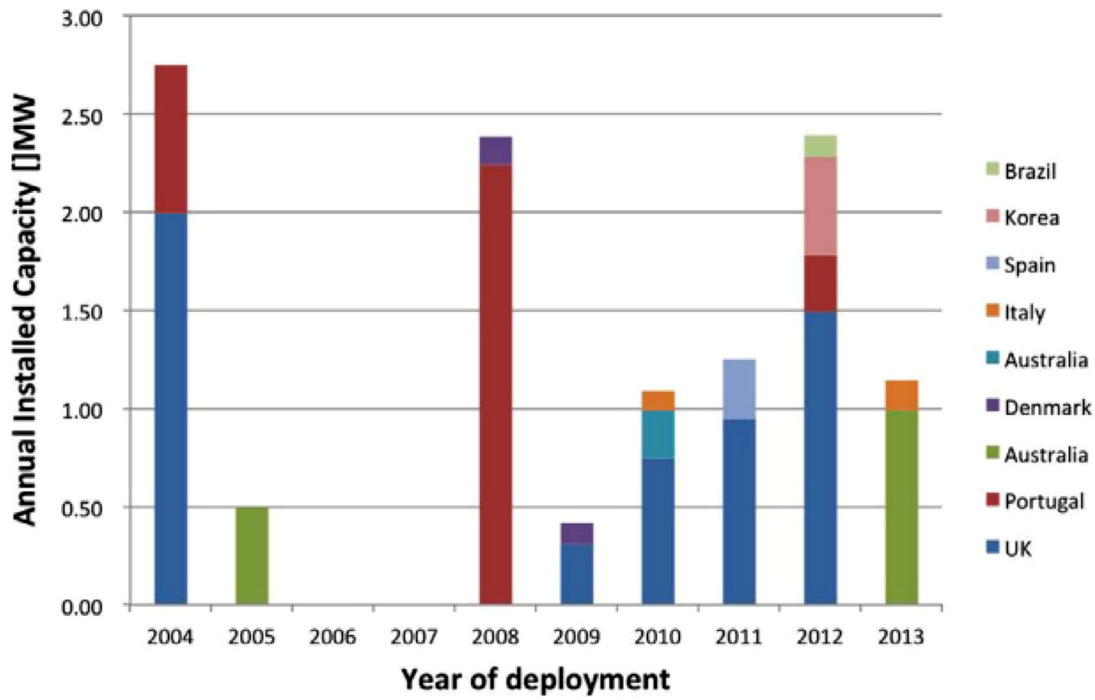


Fig. 20. Graph Showing the Distribution of WEC (Liu et al. 2017).

height of more than 2 m and a period of over 4 s, the waves in Australian coastal are not like these conditions.

Cost difference compared to conventional methods – With the emergence of new technologies, it is common to compare the cost with the existing technologies. This trend is so frequent among Australian developers. Therefore, the failure to deliver economic supplies of electricity using WE is resulted in an unreliability feeling towards the WE Technology among the Energy Developers (Jouanne, 2006), similar to other societies.

Limitation of WER- When it is compared to other REs such as solar and wind, the WE are quite limited to the Southern coastline. Therefore, for further improvements of WE within Australia, a high-capacity factor is required. Also, an additional power supply capacity of 25% is required to increase the market share in Australia (Hayward, 2011a).

Social and Environmental Challenges – Australia is a tourist country where the highest number of tourists visit the country on average. Further, there are some social objections from competing sectors such as sea transport and fishing as well as from the recreational users who surfer on the sea, public utility commission, and electricity corporations resulting from its high installation and maintenance costs in the early stage (Hemer and Griffin, 2010). Also, the high biodiversity of Australia in terms of birds, fish, and turtles has been threatened by the emergence of the WE industry. In fact, the development of WE cause significant impacts on the health and existence of the marine ecosystem. Therefore, these new technologies have been vastly rejected by the public (Felix et al. 2019). Especially PWEP project location is a good example of this.

Lack of high-resolution data – This challenge basically relates to the wave climate of near-shore and on WERs along the southern coastline of Australia (Cuttler et al. 2020). It makes that impossible to accurately predict the wave climate at specific locations along the Southern Australian Coastline. As Michael V.W. Cuttler says, this was a major challenge that was experienced during the 'Albany' WE project in Australia and vastly influenced the failure of the project. (Cuttler et al. 2020).

Policy and Regulation – It can be noted that the policy framework in Australia for WE does not function well; therefore, it has had some uncertainty related several years. The recognition of WE as a RE is very important in maturing within the Australian industry, as emphasized by Bipartisan Government. (Alldritt and Hopwood, 2010). No existence of target policies, market support, and government incentives in motivating the adapting of WE has led some companies to shift (UK Marine Energy, 2019).

Lack of Awareness and Education – One of the main reasons behind immaturity in WE in Australia is the low awareness and poor understanding of the various WE technologies, especially among the decision-makers and in the Australian Community (UK Marine Energy, 2019).

Conclusively, it can be identified that the lack of high-resolution data, social and environmental challenges, limitation of WER, technological difficulties, and poor policy framework are the main challenges that the Australian WE industry is currently undergoing.

6. Discussion

With respect to comprehensive literature reviews, it is obvious the importance of moving to RE sources, and the factors such as rapidly growing energy demand, interest in the carbon economy, and geopolitics related to oil led to this transition. However, it is noted that the process of harnessing WE commercially is very slow in comparison to the exploitation and development of other REs such as solar and wind. The fluctuation in the WE properties in different locations and the WECs' ability to survive in the marine environment are two of the main concerns resulting in the slow progress (Aderinto and Li, 2019a). As explained in the literature, there are three main technologies behind the current WECs, namely OWC, oscillating body, and overtopping. It is also identified that most of the WEC designs in the world are currently under the laboratory testing stage, and only a few of them have been implemented. The categorization of WECs is mainly dependent on the interaction that develops between devices and waves. However, it is noted that even though hundreds of improvements to current technologies have been suggested by researchers, there is no internationally accepted standard technology introduced yet.

Power generation in Australia over the past few years is recorded as flat regardless of the 30% increase in the population: due to the transition to renewable energies like PV. However, still, it can be noted that

51% of Australia's power is generated through coal-based power plants. Therefore the need for transferring to low emission sources is significant (UK Marine Energy, 2019). In terms of renewables, the wind is referred to as the famous RE. Then it is followed by PV, Hydro, Biomass, etc. Even though biofuel and biodiesel gained much propulsion in the last decade, it's not free from emission problems and can be significant in terms of greenhouse gas generation in industrial-scale usage (Hemer et al. 2018b). The high reliability associated with WE is one of the leading factors within other alternative energies such as solar and wind. In the case of WERs availability within Australia, a uniform distribution of WERs cannot be expected due to the seasonal variability and other variations such as magnitude. It is noted that Australia comprises abundant WERs because of the south coast's proximity. Southern coasts can be identified as the best place for WE generation in considering the latitude of 60–70° and the suitable climate for WE generation. Despite that, the area between Geraldton and the Southern tip of Tasmania, Queensland, New South Wales, and West Australia are some of the other areas in Australia abundant with RESs. However, the greatest WE are reported from the southern half, which is within (25–35 kW/m), while the northern shelf accounts for only or less than 10 kW/m, making it not suitable for harvesting purposes. Therefore, focusing on harvesting and generating WE from the areas abundant with WERs is a good move for Australia to develop in terms of WE. When considering the commercialization of WECs in Australia, the process is noted to be very slow. It has been identified that only a few types of WECs are commercialized properly, and even some of them are still in the testing stage. OceanLinx in Kembla port, BioWAVE, PowerBuoy, and Nautilus are some of the WECs that are being tested in Australia. It is believed that with the establishment of one accepted standard technology or WE converter, the commercialization of WE and WECs would be much easier. Despite the competitive nature with other RERs, Cost of WE generation is an important factor in making WE reliable for many users. LCOE is calculated considering the operational, capital, and maintenance cost, and it is noted that the western and southern coasts of Tasmania have the lowest LCOE due to the high availability of WERs.

However, the development of WE compared to other REs, as well as the commercialization of WE, are noted to be very slow, and it is obviously due to the challenges associated. It has been identified that technical aspects, technological aspects, the lack of high-resolution data, rules & regulations, social and environmental challenges, and investment feasibility are some of the challenges Australia is facing currently in developing WE (UK Marine Energy, 2019). Therefore, with the mitigation of these challenges, significant developments can be achieved in the WE industry in Australia. As Felix et al. (2019) proposed, the Australian WE technology, as well as the generation, can be improved through two key strategies, which are by identifying the best technology from the current technologies in Australia as well as in other countries and reducing the cost of WE devices while improving the performance & reliability towards on this energy source.

Cost reduction – Cost is a critical element that makes the WE competitive in the energy industry. As explained in Hayward and Osman (2011b), 'Operation and Maintenance is the major component in which it varies according to the WEC technology. As it is suggested by Felix et al. (2019), cost reduction can be achieved through sharing the infrastructure of the existing offshore wind parks. Further, the cost can be reduced by following some of the common cost reduction pathways that are normally being implemented, even in the case of solar and wind energy generation. When the technology becomes more efficient and mature, it can be manufactured more cheaply than the current.

Performance Improvements - The performance of devices is required to improve the lifespan of devices and equipment by making the components in a way that they can resist storms and further by enhancing the capability of exploiting more energy. To overcome the technological difficulties, the devices, as well as the technologies, can be tuned in respective to Australia's wave conditions so that a better efficiency can be enhanced. Improvements to installation and recovery techniques assist in upgrading the operation and further assist in the maintenance by reducing the repair time overall (Felix et al. 2019). Also, tropical countries like Australia have a high temperature, salinity, and humidity, giving more possibility of corroding rapidly; therefore, the devices should be designed to mitigate the considerable negative impacts.

Convergence of WE technologies – The convergence of technologies is required instead of having various WE technologies. It requires further commitment and collaboration of developers as well as policymakers on WE technology. Also, it is necessary to identify internationally recognized methods and transparent processes to be more effective and efficient in WE technologies. Despite improving the performance, it is also required to attempt to reduce the shortcomings in current technologies to achieve low emission systems (UK Marine Energy, 2019).

7. Conclusion

With the increasing energy demand, RE is introduced as a solution to the rapidly growing global warming and greenhouse gasses emission. Even though WE is less utilized compared to other energies, it is believed that it has the potential to cover the major proportion of the world's energy need and Australian energy generation, but the size of that contribution is determined by a number of factors. Therefore, the reliability of WE in terms of different factors is highlighted in this review. After the introduction on RE, a review of the feasibility of developing WE as a RES in Australia was presented by looking into the current energy status of Australia, WERs availability, WE technologies, WE generation, and Some WE projects in Australia. Despite that, a comparison between Australia and other successful countries was made to identify the barriers in Australia in terms of generating WE. Further, it highlighted some of the Australian technologies and devices that have been tested or installed currently in real-time. The study was extended by making a comparison between the major developers in the WE industry and for Australia to identify some of the contributing factors in other countries that might have led to the development of the WE generation for them. In fact, challenges and barriers affecting the generation of WE in Australia were identified and listed in terms of technical, technological, social, and environmental factors, along with the recommendations for the improvement of performance within the country. However, it was noted that some of the barriers that are common in tropical countries are still valid in Australia also. It was mainly recommended two strategies which were the cost reduction, improving the performance & lifetime of the device or technology, and identifying the best method among the current technologies. Lastly, the study was concluded by suggesting some of the recommendations to improve WE technologies and generation within the same country. Specifically, some points could be drawn after doing a thorough review of the areas mentioned above. First, it was clearly identified that Australia has a major region with abundant WERs, mainly on the Southern coast, while having a latitude between 60 and 70° which is considered a suitable climate for Wave generation. As a result, the wave confronts even more competition in Australia than it does globally. In fact, these energy sources are mainly available in the South, Southwest, and Southeast areas of Australia. Also, as most of the studies have proven, Australia WER has the potential to produce more than 1300 TWh/yr, which is five times the Australian energy demand. Secondly, as Australian statics shows, 71% of Australian primary energy is covered by fossil fuels while only 29% accounts for REs, while the wind and PVs are the main RE power source regardless of the WERs availability around the country. To support WE to stand as a major renewable resource, the country has developed different technologies and devices too. Yet, the country has not shown any reliable evidence of the same energy production, although it is predicted that by 2050, 10% of energy requirements will be obtained from WERs.

Authors' contributions

All the authors had participated in preparing the manuscript.

Declaration of Competing Interest

The authors declare that there is no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cles.2022.100021.

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