Overview of Ocean Power Technology

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Abstract

This review article explores the future of renewable energy by considering new renewable energy generation technologies which are often modifications of existing renewable energy like solar, geothermal, wind, biofuels and biodiesels. Ocean or marine energy is thoroughly discussed. This new technology is currently at the developing stages and has a long way to go before commercialization but major obstacles impeding the advancement of this technology are also captured in this review article. Some possible solutions to these challenges were equally proposed. The work concluded that a good balance between existing renewable energy sources and the emerging ones will create good competition with other energy generation media and this will help reduce the high fossil fuel dependency which has negative implications on the environment.

Keywords: Renewable Energy, Fossil Fuel, Marine Energy,

1. Introduction

One of the parameters that determines the quality of life and the economy is energy. This has led to it being considered as the major issue being discussed worldwide. According to statistics, nearly two billion people around the world do not have constant supply or even any access to power at all [1]. There has been a sudden increase in the demand on energy due to the high dependence on technology and high standard of living, especially in most developed countries. To mitigate the high energy demand, the consumption of fossil fuel is increasing dramatically across the entire globe. In effect, this leads to the depletion of the ozone layer, sudden changes in climatic conditions and environmental pollution, leading to health problems with all living species in the world. The prices of petroleum commodities have kept increasing since the oil crisis in 1973 [2]. It is
anticipated that the rate of energy captured as solar energy must be similar to the rate of energy leaving into the atmosphere to maintain a thermodynamic balance [3, 4]. The share of CO₂ emissions from fossil fuel keeps increasing. The high rise of CO₂ leads to an increase in the average CO₂ content of the atmosphere. The CO₂ in the atmosphere was 280ppm during the pre-industrial era and 390ppm presently, showing a significant increase of 110ppm in recent times [5]. The quality of energy being generated is very important as it contributes to technological advancement. For a sustainable environment, it is imperative that clean, consistent and very secure forms of power are being considered [6-8]. Fossil fuel supplies nearly 85% of the world energy demand [9] but accounts for 56.6% of GHG emissions [10]. There are three categories of energy sources: nuclear resources, fossil fuel and renewable energy sources [11]. Renewable energy is the future of the world’s means of energy generation. It is possible to generate an enormous amount of energy through renewable means, ie. energy from the sun, energy from wind, geothermal energy, energy from the sea, energy from organic material and biofuels [12]. Renewable energy sources produce nearly zero net emissions [13]. They are cheap as well as environmentally friendly [14, 15]. In the 21st century, there are many renewable energy schemes being developed around the world. According to statistics, nearly 23.7 percent of the overall world energy consumption is being supplied by renewable energy but in 1998, it was estimated that renewable energy accounted for only 2% of the world energy [16]. Countries like Germany and other European countries are actively relying on renewable energy as their main source of power generation. Geothermal energy, wind, solar, biomass, biofuel and hydropower are all being considered today around the world as a main source of energy generation, contributing significantly to the world Fig. 1. captures some novel types of renewable energy generation mediums.
These new forms of energy generation are equally environmentally friendly. They are considered as emerging renewable technologies i.e. enhanced geothermal energy (GE), marine energy, artificial photosynthesis (AP) as well as concentrated solar photovoltaic (CSP) shown in Fig. 2. This paper reports the recent development of existing renewable energy sources as well as the emerging ones. The investigation further explores some opportunities, setbacks, possible solutions and policies to improve the status of the renewable energy industry.
Fig. 2: Emerging renewable energy generation medium

The theoretical and sustainable potential of renewable energy is higher than any other form of energy generation medium. The absolute size of the global technical renewable energy potential is unlikely to retard the progress of renewable energy development [17]. Renewable energy in 2008 accounted for 12.9% of the total 492EJ of primary energy supplied that year. Biomass has always been a major contributor to renewable energy accounting for 10.2%; this is often used in most developing countries for cooking and heating purposes. On the other hand, hydropower accounted for 2.3% and the other types of renewable energy accounted for only 0.4%. An investigation conducted by Renewable Energy Sources and Climate Change Mitigation found that 19% of electricity supplied in 2008 was from renewable energy sources. 2% of the global road transport fuel supply was from biofuel while biomass, solar and geothermal together contributed 27% of the global demand for heat [17]. It must be noted that the primary objective of all these renewable
sources are to meet the defined social, economic and environmental aspects of human lives [19-20] as shown in Fig. 3.

Due to technological advancement, other energy generating media such as concentrated solar are now springing up alongside more established sources like bio energy [17 – 21]. In 2012, 19 percent of the estimated final energy consumed was provided by renewable energy but there was a sharp increase to 23.7% in 2014 [21-26]. Fig. 4 shows the world energy sources. In 2015, there was a high increase in global capacity of renewable energy [27]. Hydropower generated 16.6 percent of the overall 22.7 percent. Wind, bio power as well as solar energy were 3.7 percent [28], 2.0 percent and 1.2 percent respectively. CSP, others supplied only 0.4% [29,30] from Fig. 4.
The global status report (GSR) reported that the power sector recorded the highest growth between 2016 and 2018 with its capacity globally being more than 1560GW. The last decade also experienced an increase for investment on renewable energy resources. Fig. 5 shows the investment made in the last 12 years by developed and developing countries. Global investors around the world invested $40 billion in renewable energy in 2004. In 2011, this amount increased further to $27 billion but saw a sharp decline after 2011.
3.0 Ocean Energy

Current research in renewable energy is geared towards the exploitation of ocean energy, as oceans cover nearly 3/4 of the surface of the Earth. Intensified research and investigations are being conducted daily to determine how this viable energy generation medium can be harnessed to its full potential [30]. Specific strategies being adapted today to explore this type of energy are wave power and tidal current. Consistency and predictability of ocean energy makes them more suitable for energy generation compared to the other type of renewable energy [31]. The energy that can be generated from marine energy sources can supply the entire world with its energy demand. The sad truth today is ocean energy supply just a small portion of the world’s energy demand. Much research has also been conducted to ascertain the best sites suitable for ocean energy generation, the efficiency of the existing ocean energy technologies, the amount of power generated and the impact of these technology to the environment. Governments around the world continue to introduce good policies to expand ocean energy generation media [32 – 39]. In 2015, the overview of marine energy was discussed specifically in chapter 7 of the report. The start of the agreement for implementing OES was done by 3 countries in the year 2011. The countries by December 2015 increased to 23 and the countries that came to join the agreement were mostly from the developing world or from nations who already have a stake in ocean energy [40]. Offshore wind is the commonly known renewable energy source to be considered mainstream but other types of technology as explained earlier are also being developed just as much. These are tidal wave, ocean thermal energy conversion (OTEC) etc [41 – 43]. In summary, the transformation of marine energy into power is under serious investigation due to the potential of supplying the world with its high energy demand. Its friendliness to the environment is one of the reasons why the research community considers it as the possible replacement for conventional power generation media. There are fewer emissions, reducing the negative effect of climate change. This new technology will reduce the pressure on existing technology in terms of diversification and can also serve as a backbone to drive the economy. It is however disheartening that this useful technology has not been exploited to its maximum potential especially in terms of cost and its acceptance by all stakeholders in the energy industry. Four types of marine energy have been discussed in this review report. Comparing the theoretical global energy resource with these marine energy generation media is quite challenging but wave energy and OTEC have much in-depth research and many projects being championed under these categories. Currently nearly 0.5GW of commercial marine
energy generation capacity is being harnessed. 1.7GW is also under construction. Tidal range accounts for nearly 99% of this marine energy generation capacity. Even though OTEC, tidal stream and wave energy makes only small contribution to the marine energy generation capacity, there are currently three tidal streams commercial projects generating 17MW of capacity. Two of these capacities are cited in Scotland and the last one cited in France. Sweden currently also boast of 1MW wave energy in the process of commercialization. OTEC projects are also actively being exploited with 10MW schemes under development. The completion of all projects currently under commercialization will lead to the addition of 15GW to the existing marine energy capacity but this is practically impossible as only a fraction of the current commercial project will be added to the existing capacity. The UK and US are the leaders in the commercialization of this viable technology but other countries like South Korea, Ireland, The Netherlands and China are also harnessing some marine energy. Some projects that were started years ago had to be halted due to the lack of funds from private and corporate bodies. This was due to reduced economic growth and instability in oil prices, as well as the inability of developers of ocean energy technology to meet the initial agreement of producing a cost-effective system. Some companies like Pelamis and Acquamarine falling into administration seems have affected the entire marine energy industry.

3.1 Wave Energy
Transfer of energy occurs whenever wind blows over an ocean surface [43 – 48]. This process depends on the ambient temperature and pressure differences arising from the uneven distribution of solar energy reaching the surface of the earth [49, 50]. The losses due to the wind blowing on the ocean is less and the waves often generated can travel longer distances [51 – 53]. It must be noted that some waves gain energy due to the wind blowing on long open ocean stretches. Waves possess kinetic as well as potential energy [54 – 55]. Fig. 6 shows the global wave power distribution in kW per metre of of crest length. It is possible to generate electricity through this means by using a wave energy convertor [56, 57]. Research conducted for the international panel on climate change suggested that the entire theoretical wave energy potential was 32PWh per annum [44, 58]. This estimate showed that the yearly potential of wave energy was twice that of the global electricity supplied in 2008, which was 17PWh/yr [4, 59]. Fig 6 shows the potential for
wave energy for some specific countries. The Figure shows that there is more potential for this viable energy generation medium around the mid to high latitudes [60] of the Northern and Southern hemispheres.

![Fig. 6: Global wave power distribution for the entire world [45.]](image)

3.2 Tidal Stream
The position of the moon and sun in relation to earth develops ocean tides. This phenomenon leads to periodic motion of the seas and oceans [61, 62] due to the gravitational forces combining with the earth’s rotation. Tide is the rise and fall of water vertically and often results in a horizontal flow of water into or out of bays, harbours, estuaries and straits [63]. Tidal current is the flow of the water and it is also sometimes called tidal stream. Tidal current devices operate similarly turbines used in wind energy but uses water to generate electricity. Places with high tidal range are perceived to have the highest energy potential. Fig.7 shows areas with high tidal range. Places where there are high constraints to flow of water or local topography with narrow straits and headlands as well as shallow water depth areas are considered to have good potential for power
currents. Defining a specific value for the global tidal stream energy potential is quite challenging but in 1993, the potential estimate for tidal energy was given as 3TW\[^{[63]}\]. Out of these 3TW, 1TW was found in shallow waters. There are some factors like technical, geographical and environmental challenges that reduce the possibility of all these tidal stream potentials being captured. Some of these challenges are geographical, technical and environmental constraints. In reality, to be able to harness the tidal stream potential for any location, the mean speed of the water current at the peak of spring tide must be between 2 and 2.5m/s. This implies that changes in the tides will lead to no water flowing horizontally or even if there is any water flowing, it will be very small. Tidal streams are predominant specifically along the coastal regions for all the continents \[^{[64]}\]. This makes this renewable energy exploitation available to all indigenes living closer to the sea but it must be noted that the actual potential that could be harnessed varies from one place to the other. There are currently 106 places spotted in Europe to have high potential for tidal stream. If these potentials are all exploited, they could generate 48TWh/yr (0.17EJ/yr) of possible resource. Another research showed that the highest potential can be found around the British Isles and the English Channel as shown in Fig. 7.

![Fig. 7: The world tidal stream potential \[^{[65]}\] (Image)

As explained earlier, there are huge similarities when comparing wind and tidal power generation media. The energy for tidal currents is pushed within the channels which is different when compared to energy generated from the wind \[^{[67-70]}\]. Tidal energy converters are categorized into 3 groups. Fig. 8 shows the types of tidal converters. Ocean currents are also considered as alternative power generation media to reduce toxic emissions into the atmosphere \[^{[71,72]}\]. Wind
turbines and ocean converters have similar capacities in terms of rated power but tidal current converters can produce 4 times more energy in a year/m² [74-76].

![Tidal Current Energy Converters](image)

Fig. 8. Some common well known tidal current energy conversion devices [66]

3.3 Tidal Range.
Ocean tides are often created due to gravitational force leading to ocean tides being created. Tidal range is the variance between low and high tides [77-79]. High and low tides occur at the coast every day (diurnal tides). Other parts around the world also experience both diurnal and semi-diurnal oscillations (mixed tides) during the day. The study of tidal range dates back centuries and tidal power is now recommended because the energy produced by tidal range is predictable and consistent. Fig 9. and Fig. 10 clearly shows the creation and the variation in tidal range across each part on the surface of the earth. It increases due to basin resonance which further causes the surface being transformed for an exact location. Places like Canada (17m tidal range), United Kingdom (15m tidal range) as well as the Atlantic and Channel coasts of France (13.5m tidal range) have high tidal ranges. Surprisingly, the Mediterranean has a tidal range of one metre or less. [80].
3.3.1 OTEC

Energy from the sun is the main drive for ocean thermal energy conversion [80 – 84]. It is estimated that nearly 15% of the sun’s rays are directed towards the oceans and these energy from the sun are stored as heat energy as well [85 – 87]. When the thermal conductivity of the sea water drops, the energy predominantly at the topmost part of the oceans drops exponentially. From Fig. 11, the difference in temperature in the tropics can go beyond 25°C between depths of 20m and 1km. It is possible to harness energy from sea water due to the difference in temperature between sea water with high temperature and sea water with low temperature with the aid of varying OTEC state-of-the-art technologies [88].
Fig. 11: Temperature difference for all the regions across the globe.

Ocean thermal energy conversion requires a temperature difference of nearly 20°C to perform effectively. This implies that in the case where cold water at 5°C at a depth between 800 – 1000m is being used, the temperature at the surface must be kept constant at 25°C as shown in Fig. 12. The system is very effective at latitudes 35° north and south of the equator. There is some variation that could occur annually but it is possible to harness energy through this means all year round. This entire process of entire energy generation is described as the OTEC cycle. The ocean usually has its surface being warmer than the coldest part of the sea water and this difference is what can be used in producing electricity. The main working fluid used to drive the turbines using OTEC is the vapour produced from warm sea water. The cold water is then used to condense this vapour which results in a difference in pressure that sets the turbine in motion [87,88]. The open cycle, closed cycle and hybrid cycle are the three main techniques for generating energy using the OTEC plant. Open cycle operates with the water from the sea. The closed cycle operates with ammonia (NH₃) as its working fluid. The hybrid cycles involve amalgamation of open as well as closed cycles. OTEC equally have potential of supplying all the world energy demand.
4.0 Various technologies currently used in energy generation from the Ocean

4.1 Wave Energy

Wave energy devices are sub-divided into six main sections. These specific areas on the device coordinate with each other to transform the oceans directly to electricity. These subsections are as tabulated below in Table 1.

Table 1: Various functions of each component in a wave energy device.

<table>
<thead>
<tr>
<th>Parts and Process</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>The prime mover</td>
<td>This has the duty of absorbing energy. Material used for building the</td>
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<td>structure is steel but several current investigations are examining other</td>
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<td>material options. Composite materials are also used in building the</td>
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<tr>
<td></td>
<td>turbine</td>
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<tr>
<td>Foundations and Moorings</td>
<td>This is used to firmly hold the device in position in the sea bed. The</td>
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<td></td>
<td>foundations could be made permanent with gravity bases, pile–pinned</td>
</tr>
<tr>
<td></td>
<td>foundations or sometimes using slack moored systems.</td>
</tr>
<tr>
<td>Power take off</td>
<td>It is the process of producing electrical energy from mechanical energy</td>
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<tr>
<td></td>
<td>generated by waves or tides directly into electrical energy.</td>
</tr>
</tbody>
</table>
Control systems | These systems function as a safety mechanism and also help in optimization when the device is operating at varying conditions.

Installation | This involves positioning of the device and the structure at the precise location where the power generation is expected to occur. It involves the vessels and any other equipment which will help in the installation of the device.

Connection | The infrastructure for wiring the energy generated from the installed device to a nearby grid is very important. Water can also be pumped to the shore for electricity to be generated. To also be compliant with grid codes, good conditioning systems and transformers are also needed.

Devices for wave energy are normally placed at 3 main ocean locations. They are found onshore, nearshore and offshore. Table 2 shows a brief description of each of these devices as well as their demerits. Table 3 describes the various characteristics of the types of wave energy converter and some basic characteristics of each of these converters used to generate electricity.

Table 2: General overview of devices used in wave energy generation

<table>
<thead>
<tr>
<th>Type of device</th>
<th>General characteristics.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoreline devices</td>
<td>They are embedded into natural rock face. They are also normally designed to be close to the utility network, making them more advantageous and also maintenance is quite easy. There is some energy loss because of the frictions with the seabed and the amount of energy that can be captured is less but they are generally good as it is difficult for them to become damaged.</td>
</tr>
<tr>
<td>Near – shore devices</td>
<td>They are found in shallow waters that support the device being fixed directly. It therefore provides a solid base that can support any object that may be oscillating. It has similar disadvantages just like the shoreline devices.</td>
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<tr>
<td>Offshore devices</td>
<td>They are found deep into waters and are held to the seabed through the use of a mooring mass. They are very difficult to build but have better potential compared to the shoreline and nearshore devices. Operating and the maintenance of the device again is better compared to the others but they must be designed to be able to withstand unfavourable conditions.</td>
</tr>
</tbody>
</table>

**Onshore wave energy device**

**Offshore wave energy device**
Near shore wave energy devices

Fig. 13: Some common types of wave energy devices [85].

Table 3: Types of wave energy convertors and their characteristics.

<table>
<thead>
<tr>
<th>Location</th>
<th>Type of convertor</th>
<th>Brief characteristics of device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore</td>
<td>Oscillating water column</td>
<td>Using the oscillatory movement of a mass of water induced by a wave specifically in a chamber, the oscillating water column compresses the air to run the turbines. They are also considered as earliest type of converter designs for wave energy generation but today, there are many types of oscillating water columns installed onshore in self-contained structures.</td>
</tr>
<tr>
<td>Overtopping</td>
<td></td>
<td>They main function of the terminator wave energy convertors also know as overtopping devices are to transform wave energy into potential energy. A reservoir serves as the storage devices and this helps to run low head turbines. They are designed such that the waves break on a ramp and they are channelled to the reservoir on top of the surface of the water. Energy is produced from the reservoir due to movement of water via the turbines which has a low head.</td>
</tr>
<tr>
<td>Near shore</td>
<td>Oscillating wave surge converters.</td>
<td>Waves can be exploited using the oscillating wave surge converters to cause an oscillatory motion. They are currently under development.</td>
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<tr>
<td>Point Absorber</td>
<td>They are considered as pitching devices that harness the relative movement between two bodies in an oscillatory condition. In terms of dimensions, point absorbers are smaller compared to other wave energy devices and are considered as being non-directional devices. hence the wave direction has an effect on its performance.</td>
<td></td>
</tr>
<tr>
<td>Submerged Pressure Differential devices</td>
<td>They are completely submerged into the water, producing electricity.</td>
<td></td>
</tr>
<tr>
<td>Offshore</td>
<td>Attenuator</td>
<td>Oscillatory movement is created because of incoming waves. This movement leads to power take off to be activated. The design of attenuators becomes very useful for offshore activities as well as normally float on the surface.</td>
</tr>
<tr>
<td>Bulge wave devices</td>
<td>They are designed to use pressure from wave to produce a bulge wave. There is an increment in size and speed of the bulge wave as it flows through the device. The turbine located at all the ends of the tube are driven using the kinetic energy of the bulge.</td>
<td></td>
</tr>
<tr>
<td>Rotating mass converters</td>
<td>Movement of wave inducing pitching on a body can be exploited using a rotating mass converter. An electrical generator is driven due to the rotation of the mass.</td>
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</tr>
</tbody>
</table>

There are currently several companies who intend to research and investigate the exploitation of wave energy as well as the commercialization of this useful technology. Below are some
companies and the type of wave energy converters they are using to generate electricity in Table 4.
Table 4: Types of wave energy converters and the specific company using the device [85, 101].

<table>
<thead>
<tr>
<th>Name of device and Company</th>
<th>Technology type</th>
<th>Description</th>
<th>Image view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology used Offshore</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Aquabouy (Finavara renewables, Ireland)</td>
<td>Offshore, point absorber</td>
<td>The AquaBuOY point absorber uses design conceptualized from two already existing devices. These wave energy converters are located in Sweden. The AquaBuoY is made up of a buoy as well as a vertical tubing which is allowed to be in contact with the sea at all its openings. The device heaves up and down due to incident wave resulting in damping force being created. This force serves as a piston attached to the 2 hose pumps and these pumps contract and expand concurrently resulting in a pumping effect being created. There is a reaction that occurs against the heaving motion due to separation between the hose</td>
<td></td>
</tr>
</tbody>
</table>
Archimedes Wave Swing (AWS Ocean Energy Limited, Scotland) | Offshore: Submerged pressure differential

The AWS is made up of air filled cylinders that are very large and these cylinders are submerged in the wave. The pressure of the water at the topmost part of the cylinder increases as the crest approaches and this leads to compression of the air inside the cylinder to keep the pressures balanced. The opposite of this phenomenon occurs as the trough passes and the air expands inside the cylinder. A prototypes was tested in 2004 during a pilot plant programme in Portugal. The IGBT converter pumps and the water masses. This transforms the oscillatory motion to run the turbine and generator at high pressure.
<p>| FO3 (Fobox AS) | Offshore | 21 absorbers are positioned in hydraulic cylinder. Vertical movements result in hydraulic pressure being created. Using numerical calculations and generators, the hydraulic pressure can then produce electricity. | transforms different frequency output to utility grade power. |</p>
<table>
<thead>
<tr>
<th>Ocean Energy Buoy (Ocean Energy Limited, Ireland)</th>
<th>Offshore, Oscillating water column</th>
<th>Ocean energy buoy leads to air being pumped in and out via a turbine. Movements of the hull causes the air flow to increase due to the enhancement of the relative surface as well.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelamis (Pelamis Wave Power, UK Scotland)</td>
<td>Offshore, Attenuator</td>
<td>It is a semi submerged, articulated structure made of cylindrical parts connected by hinged joints. The wave induced movement of these joints is resisted by hydraulic rams, which supply high pressure oil through hydraulic motors. Electricity is generated due to the hydraulic motors running the generators.</td>
</tr>
<tr>
<td>Power BuoyTM (Ocean Power Offshore, Point Absorber)</td>
<td>Offshore, Point Absorber</td>
<td>This is a free-floating point absorber wave energy converter that is moored to the sea bed; there is movement of the</td>
</tr>
<tr>
<td>Technologies, USA</td>
<td>buoy’s float in an up and down motion on the central spar as the waves pass. This movement mechanically runs a hydraulic pump that forces the hydraulic fluid via a rotary motor linked to the electrical generator.</td>
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</tr>
<tr>
<td>SperBoy (Embley Energy UK, Cornwall)</td>
<td>Offshore, Point Absorber</td>
<td>This is a floating buoy oscillating water column device made of a buoyant structure part of the column being submerged and enclosed. It follows the same mode of operation for fixed Oscillating water columns. The only difference is that the device can function in deep waters to generate a high amount of energy. There is a good maintenance of good hydrodynamic interaction as the whole body floats.</td>
</tr>
</tbody>
</table>
| **Wave dragon (Denmark)** | **Offshore, overtopping device** | This allows more energy to be generated but at a low cost.

This is an overtopping wave energy converter which is slack-moored. With the aid of two curved arms, waves are directed to a central ramp and this causes an upward movement of the wave as well as overtop into a reservoir. The reservoir causes the flow of the water to be smooth and the turbines are also connected to varying speed generators. This approach is almost the same as hydro power plant due to the fact that the energy that can be generated is dependent on the head of the water. |

| **Wavebob (Wavebob ltd, Ireland)** | **Offshore; Point Absorber** | It is an axi–symmetric point absorber that flows freely. It is possible to set this every season or very often to become economically viable. Using the hydraulic PTO, the Wavebob can be |
controlled instantaneously using a control system that is autonomous in order to get the maximum power

Nearshore technologies.
| EnergeTech OWC (Oceanlinx, Australia) | Near shore oscillating water column (OWC) | The OWS is positioned near shore with the bottom and oscillating water column which is 500kW. There is also a steel arm that is shaped parabolically and this forms a harbor for tuning the device’s ability to absorb the wave. The converter was first tested on Port Kembla, Eastern Australia. There is also a reef that reduces the possibility of extreme loads as a result of the impact of the wave. The company was rebranded as Oceaneinix and they are currently developing other types of devices. |
| LIMPET OWC (Wavegen ltd, UK) | Onshore, Oscillating water column | 250kW onshore OWC. It was developed between 1998 and 2000 around in Scotland. It was designed for 500kW. The general population close to the project complained due to the noise the plant. A sound muffler was used. |

| Mutiku Breakwater (MOWC, EVE, Spain) | Near shore Multi oscillating water column | The idea of this project is to fuse the oscillating water column technology with a Wells turbine. |
Pico OWC (Wave Energy Centre, Portugal) | Nearshore oscillating water column.

This is a European Pilot project using the oscillating water column concept. It can be seen in Portugal specifically on the Pico Island. The turbines used are symmetrical and they run in different directions based on the direction of the air.
<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Device Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSG Waveenergy AS, Norway</td>
<td>Nearshore</td>
<td>Overtopping device</td>
<td>This is an overtopping wave energy device made of 3 reservoirs positioned directly on top of each other.</td>
</tr>
<tr>
<td>Wave star, Wave star Energy,</td>
<td>Nearshore,</td>
<td>Multi point absorber</td>
<td>This is a multi point absorber made of several floats which are set into motion by the waves to activate the cylinders. Once the cylinders are activated, an oil flows into a transmission system and the pressure built runs the hydraulic motor. During unfavourable conditions like storms, the floats are guided to a safe position. For larger machines, the floats can be seen 20 metres above the water surface. The waves are detected through the usage of a sensor located on the seabed and this function as a</td>
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<tr>
<td>Oyster aquamarine (Northern Ireland)</td>
<td>Near shore oscillating wave surge converter</td>
<td>This is a near shore device mounted at the bottom of the shore and built to communicate effectively with all the dominating surge forces in most shallow water waves.</td>
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<tr>
<td>protective mechanism that activates the storm security system. VPN connection aids in remote controlling of device using the internet.</td>
<td></td>
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<tr>
<td>Wave roller (AWEnergy, Finland)</td>
<td>Near shore oscillating wave surge.</td>
<td>There is movement of a plate due to the back and forth motion of the waves at the bottom with this device. A piston pump then gathers all the kinetic energy generated. Using a generator, all the kinetic energy is transformed to electricity.</td>
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<td>Waverofys (Ecofys, Denmark)</td>
<td>Submerged Pressure differential</td>
<td>The rotor of this device can also run using circular currents. Using high torque, the wave can turn the rotor for the power to be absorbed using a generator fixed attached through a gearbox to a vertical shaft. The waves therefore directly push the blades forcefully. There is transfer of power as the shaft rotates. The two types of rotor used are the Darrieus rotor and Wells rotor. The rotors are either omni or bi-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>directional rotors and can function even in currents of different directions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.1.1 Tidal Stream

The devices for tidal streams shown in Fig. 14. transforms kinetic energy from water in motion into electricity. There are six different types of tidal stream devices as shown in Table 5. Tidal stream, according to researchers, has seen a good technological advancement compared to wave energy and nearly 3/4 of all research and development investments are geared towards horizontal axis turbines (HAT). This is largely due to HATs dominating the wind industry and their mode of operation being similar; it is also easier to use this technology as there are more experts in its operation. The most important goal is for tidal converters to be able to operate at higher density and under varying environmental conditions.

Fig. 14: Diagram of electricity generation using tidal stream [90].
Table 5: Devices for tidal stream energy generation [66].

<table>
<thead>
<tr>
<th>Type of device</th>
<th>Description of the device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal axis turbine</td>
<td>These operate through the same principle as wind energy devices and the energy is obtained using the lift from tidal flow to rotate a turbine and this turbine is aligned horizontally. The mechanical energy of rotation is directly converted to electrical energy using a generator</td>
</tr>
<tr>
<td>Vertical axis turbine</td>
<td>The only difference between the vertical axis turbine and the horizontal axis turbine is the orientation of the turbine. The turbine is aligned vertically for the vertical axis turbine but performs the same function as the horizontal.</td>
</tr>
<tr>
<td>Oscillating device or oscillating hydrofoil</td>
<td>It is made up of hydrofoil positioned at the bottom of a swing arm and this allows the arm to be in an oscillatory position. The arm being in a pitching mode is controlled by a control system. The movement then pumps hydraulic fluid via a motor. Using a generator, the rotational motion can be transformed into electricity.</td>
</tr>
<tr>
<td>Ducted turbines or enclosed tipps</td>
<td>They are horizontal axis turbines (HAT). They are made to increase the velocity as well as concentrate the flow of the fluid. Turbulence likely to occur near the turbines is reduced due to the ducted structures and this guides the flow of water towards the turbines.</td>
</tr>
<tr>
<td>Archimedes Screw</td>
<td>They are made of variation of vertical axis turbines, absorbing power from a tidal stream as the movement of the water is directed via a helix.</td>
</tr>
<tr>
<td>------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Tidal Kite</td>
<td>The tidal kite device is made up of a tethered design concept. The kite moves via the flow and this causes an increase in the flow velocity through the turbine.</td>
</tr>
</tbody>
</table>
4.1.2 Tidal range

There are huge similarities between tidal range and hydropower. They both operate using artificial height difference of 2 bodies of water formed using a barricade (commonly known as dam, shown in Fig. 15) and using gravitational potential energy, electricity can be generated through a low head turbine. These often come as either a tidal barrage or tidal lagoon. The tidal barrage functions just like the hydroelectric power plant. The water is dammed into an inlet. The gravitational potential difference occurring between the two bodies of the water at each side of the barrage runs the electric turbine [66]. A tidal lagoon has an independent enclosure often found metres away from estuarine areas. They often some level of flexibility and are less expensive. They also do not affect the environment negatively. Using a single basin plant, a barrier or lagoon is created and this drain or fills as the tide is generated and this reduces the amount of electricity being generated. The Multi basin schemes are usually filled and emptied at varying times. This implies that power can be generated constantly always. Tidal range technology is predictable and can be the best source of electricity but there are also some concerns raised about the impact it may have on estuarine environment and other socio-economic activity like shipping and tourism.
Fig. 15: Operational processes of a tidal range device.
4.2 OTEC

The temperature difference occurring between relative water surface with high temperature and that with low temperature are used to run the turbine. There are three types of OTEC plants as shown in Table 6. Ocean thermal Energy conversion processes is also indicated in Fig. 16.

Table 6: Ocean thermal energy conversion devices

<table>
<thead>
<tr>
<th>OTEC energy devices</th>
<th>Characteristic of the device.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Cycle</td>
<td>In a low-pressure environment, a warm surface water is flash evaporated and the vapour generated helps to run a generator. Vapour then condenses through the sea water with lower temperature. Desalinated water is being generated through this process.</td>
</tr>
<tr>
<td>Closed cycle</td>
<td>Ammonia, propane or chlorofluorocarbon (CFC) is used as the working fluid at a lower boiling point and it is flash evaporated using warm water by allowing it to flow via a heat exchanger. An electrical turbine is run using the working fluid from Fig. 16 that is vaporized but it condenses once it gets into contact with the heat exchanger and then directed back to the evaporator for the entire cycle to commence all over again. They function properly when compared to the open cycle but they are fairly small due to the fact that the secondary working fluid works at higher pressure.</td>
</tr>
<tr>
<td>Hybrid</td>
<td>The electricity is first produced using closed cycle system but the open cycle OTEC system evaporates the water instead of discharging it but there is condensation of the water producing cool water.</td>
</tr>
</tbody>
</table>
4.2.1 Salinity gradient.

Salinity gradient power is described as the energy generated due to the salt concentration difference between two liquids. The generation of this energy involves two stages. They are classified as standalone which involves a plant placed between the sea and a water body and the hybrid production method. The hybrid process involves desalination or waste water treatment. The main idea is the usage of osmotic power [66]. These potentials are absorbed in the form of pressure on a semi–permeable membrane. The mouth of the river is considered the best position for the pressure and this is often between the junction of the fresh and seawater. The potential of energy that can be harnessed using salinity gradient according to an investigation conducted recently is nearly 1650 TWh/yr. The only challenge relating to the usage of this technology is the cost involved. Tofte was the first site where salinity gradient energy generation was exploited in the year 2009 [91,92]. The difference in chemical potential between 2 solutions are united together using the reversed electro dialysis method. With the help of the exchange between the cation and ion, fresh water and concentrated salt are joined together. This results in the creation of a voltage on the membrane because of the difference in the chemical potential. Summation of the potential of the individual membrane is the best way of determining the entire potential for the whole system. The idea of generating energy using chemical potential was initiated back in the 1970s and was called pressure retarded osmosis. Pressure retarded osmosis also involves using the difference between seawater and fresh water. It is sometimes also called natural osmosis. The
freshwater and seawater can easily mix. Researchers suggest that the salinity gradient energy that can be harnessed is almost 3.1TW. The potential for countries worldwide is captured in Fig. 17.

![Figure 17: Salinity gradient for the world in sub regions [66].](image)

4.3 Obstacles impeding the advancement of Marine energy.

Many obstacles today are hindering the future advancement of marine energy in order to compete with existing energy generation media. The challenges are categorized into economic, technical, social and environmental. The idea used in the installation of the device, the configuration of the array and even the resource in general are all classified under technical challenges. All these challenges must be critically analyzed if commercialized marine energy that can compete with existing energy generation media is to see the light of day. There must be prioritization if these technically related issues are to be handled as OTEC, salinity gradient as well as ocean current must be considered in that order [91 – 99]. This is simply because these technological ideas are still in the early stages of their development and would hence require more attention and commitment to become fully acceptable in the engineering community. Decision makers around the world must also be willing to formulate policies that seek to explore these useful energy generation media. The major challenge with marine energy generation is the high capital cost needed to execute such projects. Using other renewable energy generation media, the per unit cost of the energy generated is cheaper than that of marine energy. Another major issue is related to the environmental implications of these energy generation media. Most ocean energy schemes have a life span of over twenty–five years while that of tidal barrages can exceed even a hundred years.
Currently there are no investigations being conducted to ascertain the effect of marine energy in terms of its environmental and social effects, especially for tidal range energy generation. The issues related to infrastructure can be categorized into ones relating to the grid and ones relating to the supply of the energy once its been generated. For marine energy to fit into the existing energy generation infrastructure, it must be well researched and the various losses that may occur from the generation stage to the supply stage must all be properly investigated to make the system viable. For most marine related projects, the habitats for other living organisms are destroyed, which does not make them very environmentally friendly. There is the possibility of corrosion if it is not properly catered for due to the direct contact of a marine device with water in the presence of air. This may also reduce the efficiency of the energy device if it is not considered during the design process [100, 101].

5.0 Conclusion

The review article showed some renewable energy technologies which are currently emerging like ocean energy. The work clearly shows that renewable energy in 2014 contributed to only 22% of the world’s energy demand. The IEA has made projections that carbon emission into the atmosphere is likely to rise by 2050 if the situation is not carefully checked. This review also reported the best method of reducing carbon dioxide emissions into the atmosphere by selecting the right technology for a specific location. The report also explained in detail the current nature of these novel technology mostly under development. Some of the obstacles reducing the commercialization of the technology was also presented and discussed and some possible solutions suggested as well. All the novel renewable energy technology discussed in this report can meet the world energy demand if they are properly harnessed. It was also observed that the technologies discussed are either in the developmental stages or in the planning stage of the project. However, most of the concepts discussed are yet to be commercialized though a lot of research is being conducted every year to increase the pace at which each of these concepts might reach commercialization. The likely challenges were recognized and the best solutions to make the idea economically viable presented. A combination of the novel renewable energy technology with that of the existing renewable energy technology has all the potential to replace fossil fuels as energy generation sources. Governments must also play their part by formulating policies that seek to explore the use of emerging renewable energy sources.


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