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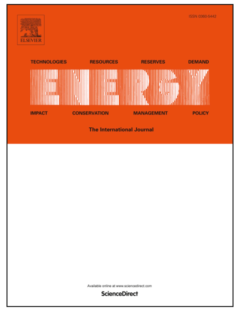

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Overview of Ocean Power Technology

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Abstract

This work discusses and provides a critical expose of some of the newly emerging renewable energy technologies with special concentration on marine energy generation.

The work shows that there are several promising new developments in harvesting marine energy and it examines some of these technologies and discusses their advantages and some of the obstacles that are impeding the commercialisation of these emerging technologies. This includes wave energy harvesting, tidal energy harvesting, ocean thermal energy and the utilisation of salinity gradients for electricity generation.

The work emphasises the fact that these new emerging technologies are currently at the developing stages and has a long way to go before successful commercialisation and wide adoption become the norm.

The work stresses the need for more research and developmental work to address several of the technical issues that need to be addressed including devices designs, their installation and maintenance, the infrastructure which includes the grid and power transmission as well as losses, their use in arrays, and their longevity.

This work underlines the lack of reliable studies on the long term impacts of these technologies on both the marine environment and nearby habitations and highlights the need for proper environmental and social impact assessments of these technologies.

The work concludes that combination of technical, policy and economic advances will enable marine energy technologies to play a large role in combination with currently adopted non-pollution renewable energy resources to provide the world population with their energy needs and contribute to affecting significant reduction in the use of non-renewable and other polluting fuels worldwide.

Keywords: Renewable Energy, Fossil Fuel, Marine Energy

1. Introduction

One of the parameters that determine 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 fuels 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 CO_2 emissions from fossil fuels keeps increasing. The high rise of CO_2 emissions leads to an increase in the average CO_2 content of the atmosphere. The CO_2 in the atmosphere was 280ppm during the pre-industrial era and it is 390ppm at present, 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 main sources of energy generation, contributing significantly to the world Fig. 1 captures some novel types of renewable energy generation mediums.

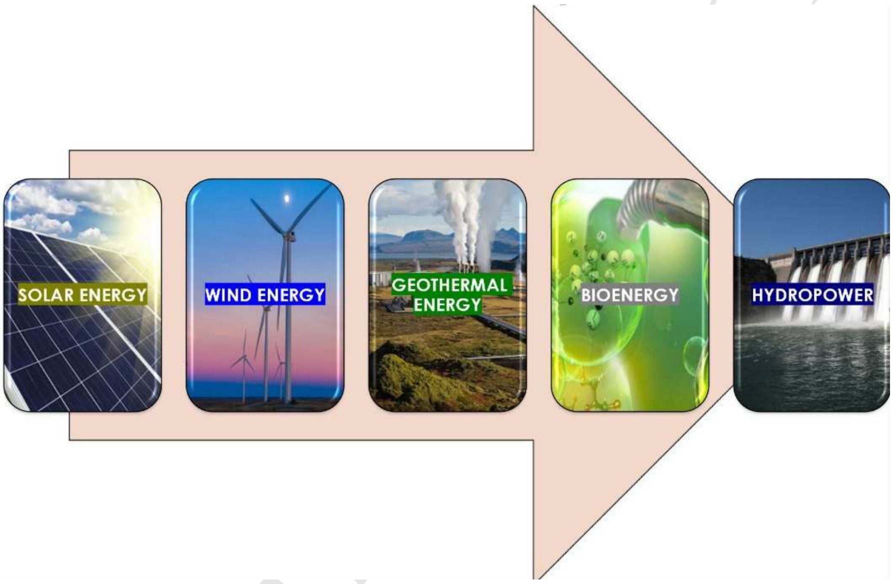


Fig 1. Renewable energy generation media

The new forms of emerging renewable energy generation technologies which are considered to be more environmentally friendly include enhanced geothermal energy (GE), marine energy, artificial photosynthesis (AP) as well as concentrated solar photovoltaic (CSP) and they are depicted 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, impediments, possible solutions and policies to improve the status of the renewable energy industry.

Fig. 2: Emerging renewable energy generation medium

2. Present Day – Renewable Energy

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 accounted for 12.9% of the total 492EJ of primary energy supplied in 2008. Biomass has always been a major contributor to renewable energy accounting for 10.2% and 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 energy required to achieve social, economic and environmental development aspects of human lives [19-20] as shown in Fig. 3.

Fig. 3 Social, economic and environmental aspects of human lives

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% 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 and the contribution of the renewables. In 2015, there was a high increase in global capacity of renewable energy [27] with hydropower contributing 16.6% of the overall 22.7 %. Wind, bio power and solar energy contributed 3.7% [28], 2.0% and 1.2%, respectively. CSP and others only supplied 0.4% [29, 30] as shown in Fig. 4.

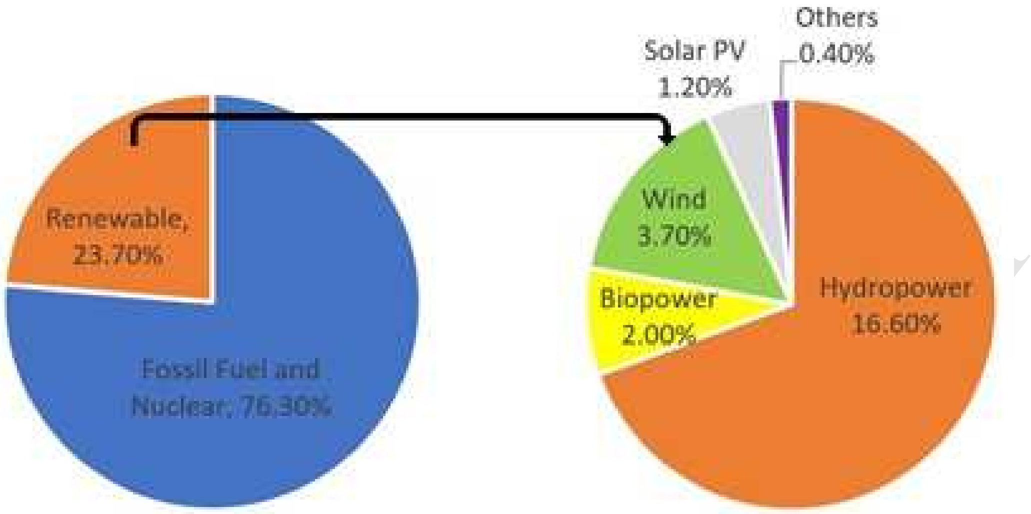


Fig. 4: Global Energy demand [16]

The global status report (GSR) reported that the power sector reordered the highest growth between 2016 and 2018 with its capacity globally being more than 1560GW. The last decade also experienced an increase in 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 $180 billion but saw a sharp decline after 2011.

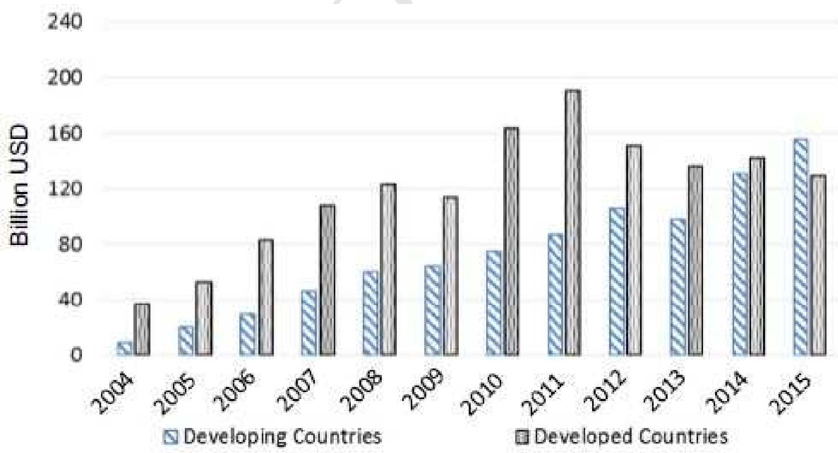


Fig. 5: Investment made on renewable energy by developing and developed countries [18].

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. Intense research activities are taking place 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 currents. 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 energy demands but currently ocean energy supply is a small portion of the world's energy demand. Much research has also been conducted to ascertain the best sites suitable for harnessing ocean energy, the efficiency of the existing ocean energy technologies, the amount of power generated and the impact of these technologies on the environment. Governments around the world continue to introduce policies to incentivise ocean energy capture [32 – 39]. The initial agreement for implementing OES technologies was subscribed to by 3 countries in the 2011 but by December 2015 this number increased to 23 with most 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]. The transformation of marine energy into usable power is under serious investigation due to its potential to supply the world with a large proportion of its high energy demand. Its perceived environmentally friendly nature is one of the reasons why the research community considers it as the possible replacement for conventional power generation media given its fewer emissions, thus reducing the negative effect of climate change. This new technology will reduce the pressure on existing technologies in terms of diversification and can also serve as a backbone to drive the economy.

Four types of marine energy are being discussed in this review report, Wave energy, Ocean thermal Energy Conversion (OTEC), Tidal and Salinity gradient. Comparing the theoretical global energy resource with marine energy potential is quite challenging but wave energy and OTEC are attracting detailed research and many projects are currently being championed. 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 17 MW of capacity. Two of these facilities are cited in Scotland and the last one is cited in France. Sweden currently also boasts of 1MW wave energy facility in the process of commercialization. OTEC projects are also actively being exploited with 10MW schemes under development [39]. The completion of all projects currently under construction will lead to the addition of 15GW to the existing marine energy capacity but this is practically the theoretical peak and the actual capacity that will be added to the existing capacity is lower. 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 as result of energy prices fluctuations and levels of return on investment. 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 surface is less and the waves generated can often 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 crest length. It is possible to generate electricity through these 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.

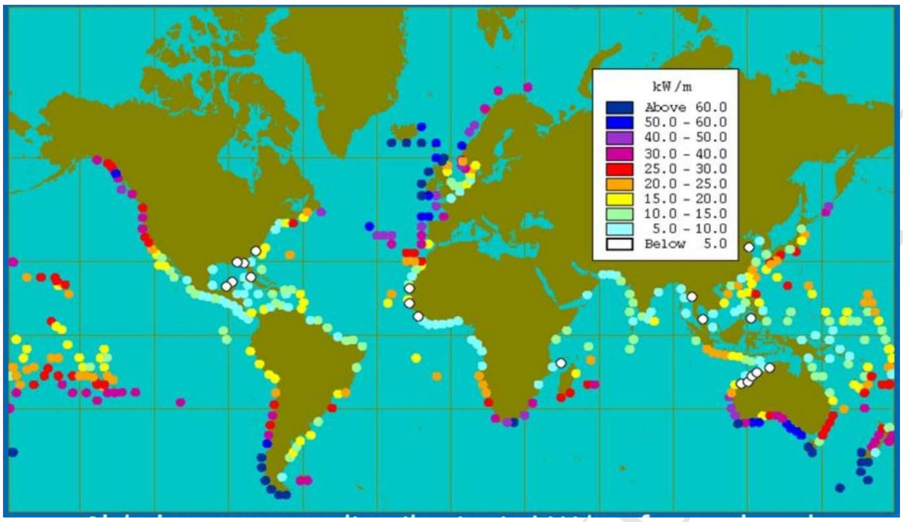


Fig. 6: Global wave power distribution for the entire world [45].

3.2 Tidal Stream

The position of the moon and sun in relation to earth causes the development of ocean tidal waves. This phenomenon leads to periodic motion of the seas and oceans water [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 in a similar way as the turbines used in wind energy but uses water to supply the energy captured to generate electricity. Places with high tidal motion are perceived to have the highest energy potential and 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. 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. Tidal streams are predominantly found along the coastal regions for all the continents [64]. This makes the exploitation of this renewable energy available to all those living closer to the sea but it must be noted that the actual potential that could be harnessed varies from one location to another. There are currently 106 locations identified in Europe to have high potential for tidal stream power generation. If all these locations are exploited, they could generate 48TWh/yr (0.17EJ/yr). Mofar et al [65] showed that there are several locations with high potential for tidal energy generation around the British Isles and the English Channel as shown in Fig. 7.

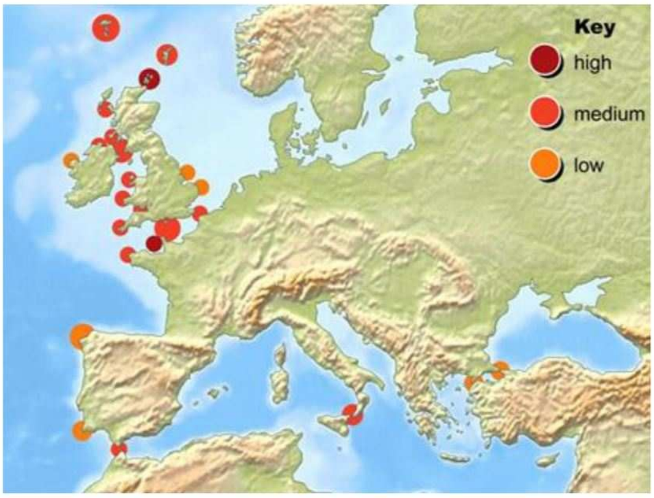


Fig. 7: The world tidal stream potential [65]

As explained earlier, there are huge similarities when comparing wind and tidal power generation. The energy for tidal currents is concentrated within the channels which is different from the diffuse nature wind used to generate energy using wind turbines [67-70]. Tidal energy converters are categorized into 3 groups and are shown in Fig. 8. Ocean currents are also considered as alternative power generation media to reduce toxic emissions to 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/m^2 [74-76].

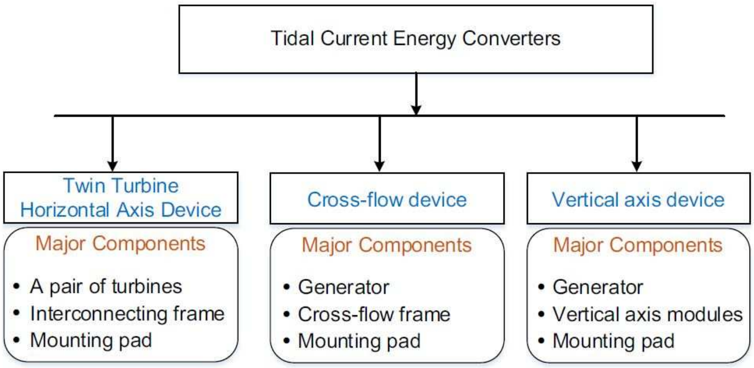


Fig. 8: Some common tidal current energy conversion devices [66]

3.3 Tidal Range.

Ocean tides arise due to gravitational force pull and the interaction of the earth and moon gravitational fields. 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 represents tidal motion behind a barrier and Fig. 10 shows the development and the variation in tidal range across the globe. 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. The Mediterranean has a tidal range of one metre or less. [80].

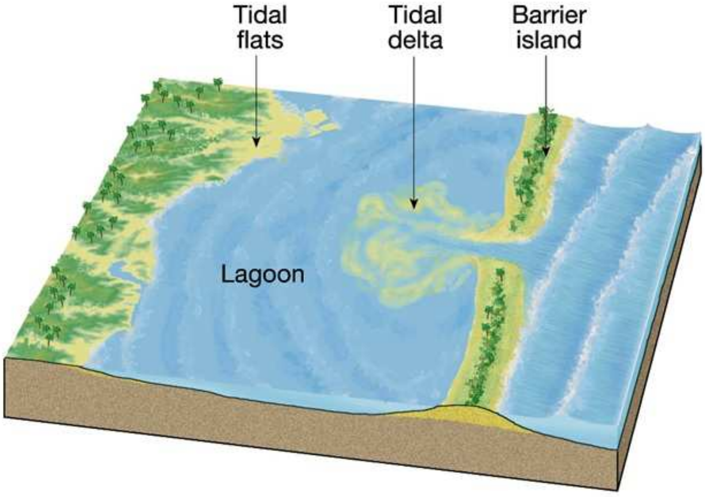


Fig. 9: Diagram showing the creation of tides [81]

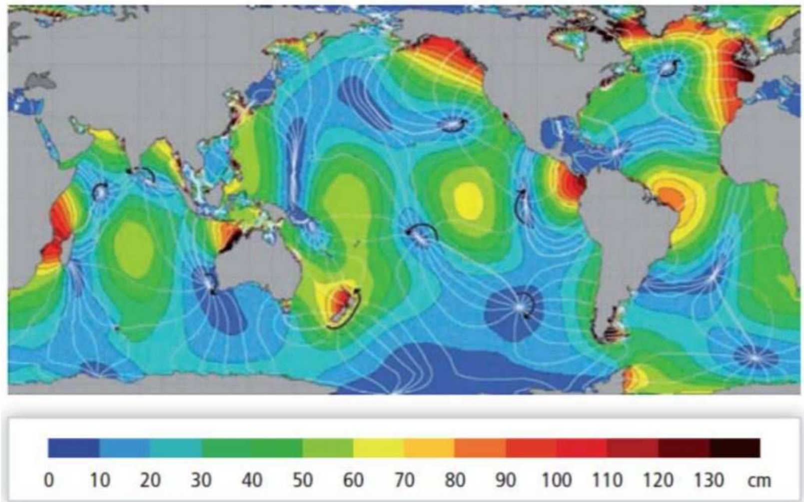


Fig. 10. Tidal range creation across the globe [82]

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 this energy from the sun is stored as heat energy as well [85 – 87]. When the thermal conductivity of the sea water drops, the energy, which is predominantly at the top most part of the ocean, drops exponentially. From Fig. 11 shows that the difference in temperature in the tropics can go vary by 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 layers with high temperature and sea water with low temperature with the aid of varying OTEC state-of-the-art technologies [88].

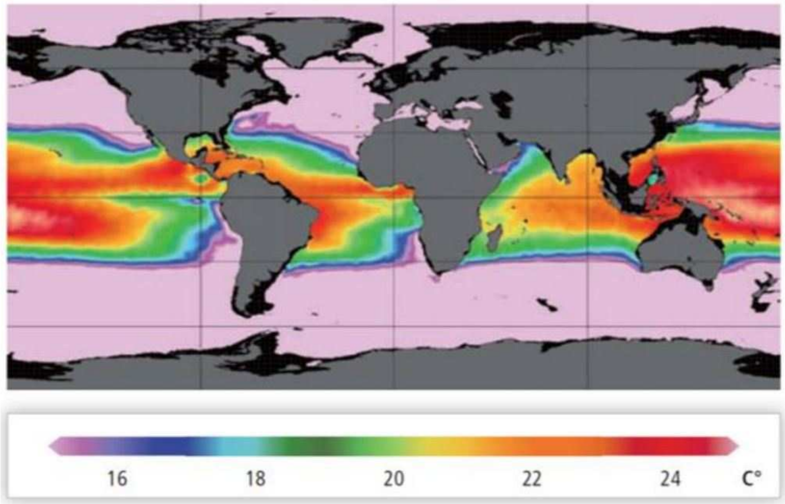


Fig. 11: Temperature difference for all the regions across the globe.

Ocean thermal energy conversion requires a temperature difference of nearly 20°C to operate 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 constant at 25°C as shown in Fig. 12. The system is very effective between 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 to produce 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 (NH_3) as its working fluid. The hybrid cycles involve amalgamation of open as well as closed cycles. OTEC equally have the potential for supplying all the world energy demand.

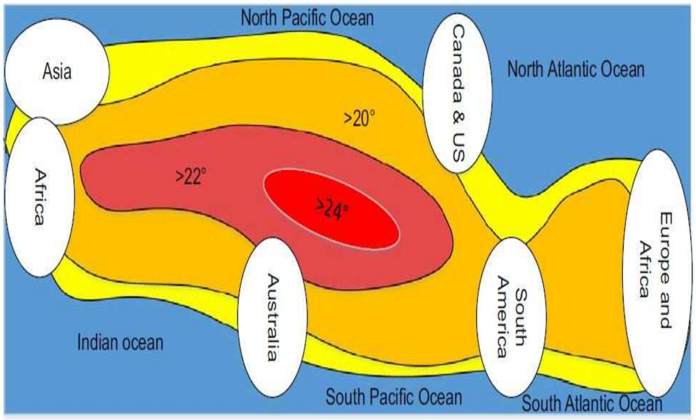


Fig. 12: The temperature difference for various regions shown in a contour [66]

4.0 The various technologies currently used in energy generation from the Ocean

4.1 Wave Energy

Wave energy devices are subdivided into six main sections. These devices transform the stored oceans energy directly into electricity.

Table 1 gives a summary of the different components of a wave energy device.

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

Parts and Process	Functions
The prime mover	This performs the task of extracting the energy. Material used for building the structure is steel but several current investigations are examining other material options. Composite materials are also used in building the turbine
Foundations and Moorings	This is used to firmly hold the device in position in the sea bed. The foundations could be made permanent with gravity bases, pile–pinned foundations or sometimes using slack moored systems.
Power take off	It is the process of producing electrical energy from mechanical energy generated by waves or tides directly into electrical energy.
Control systems	These systems function as a safety mechanism and also help in

	optimization when the device is operating at varying conditions.
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.

The installation 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.

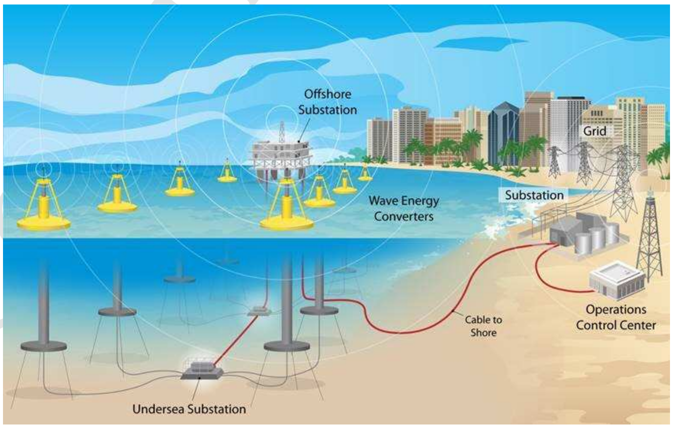
Devices for wave energy are normally placed at one of three main ocean locations. They are found onshore, nearshore and offshore. Table 2 shows a brief description of each of these devices as well as their demerits. Table 3 describes the various characteristics of the types of wave energy converter and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

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

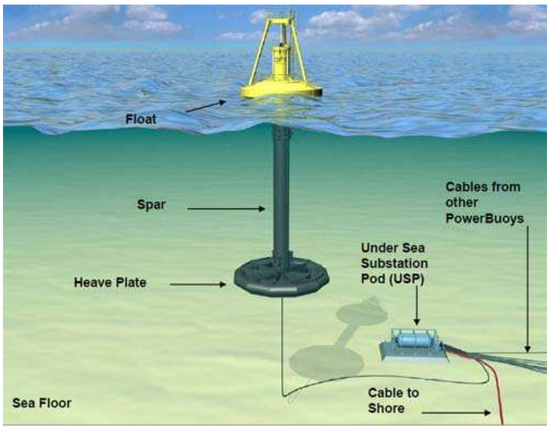
Type of device	General characteristics.
Shoreline devices	They are embedded into natural rock face. They are also normally designed to be close to the utility network, making them more advantageous and also easy to maintain. There is some energy loss because of the proximity of the seabed and its role in the development of frictional stresses between fluid layers due to the concept of non-slip velocity at the seabed-water interface. This reduces the amount of energy that can be captured but they are generally good as it is less likely for them to become damaged.
Near – shore devices	They are found in shallow waters that support the device being fixed directly. It provides a solid base that can support any object that may be oscillating. It has similar disadvantages just like the shoreline

	devices.
Offshore devices	They are found deep into waters and are held to the seabed through the use of mooring devices. They are very difficult to build but have better potential compared to the shoreline and nearshore devices as they are sited far away from the stationery seabed with reduced negative impact on water flow. The operation and maintenance of the device is comparable to the others but they must be designed to be able to withstand unfavourable conditions.

Onshore wave energy device



Near shore wave energy devices



Offshore wave energy device

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

Table 3: Types of wave energy convertors and their characteristics

Location	Type of convertor	Brief characteristics of device
Onshore	Oscillating water column	Using the oscillatory movement of a column of water induced by waves in a chamber, the oscillating water column compresses the air and forces it through the turbine to run the rotor. These were earliest type of converter designs for wave energy generation but today there are many variants of oscillating water columns installed onshore in self-contained structures.
	Overtopping devices	The main function of the terminator wave energy convertors, which are also know as overtopping devices, is to transform wave energy into potential energy. A reservoir serves as the storage basin 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 existing surface of the water. Energy is produced from the reservoir stored water using low head turbines.
Near shore	Oscillating wave surge converters.	Waves can be exploited using the oscillatory wave surge converters to cause an oscillatory motion. They are currently under development.
	Point Absorber	These are pitching devices that harness the relative movement between two bodies in an oscillatory condition., These point absorbers are smaller compared to other wave energy devices in terms of their dimensions and they are non-directional devices and the wave direction has an effect on the performance.
	Submerged Pressure	These are completely submerged into the water with pressure differences driving the flow and producing electricity.

	Differential devices	
Offshore	Attenuator	Oscillatory movement is created because of incoming waves. This movement leads to power take off to be activated. This type of design of attenuators is very useful for both offshore activities and normally floats on the surface.
	Bulge wave devices	They are designed to use pressure from waves to produce a bulge wave that incorporates neighbouring fluid as it moves increasing in size then in speed as it flows through the device. The turbine which is located at the end of the tube is driven using the kinetic energy of the bulge.
	Rotating mass converters	Movement of waves induces pitching on a body that can be exploited using a rotating mass converter that is coupled to an electrical generator.

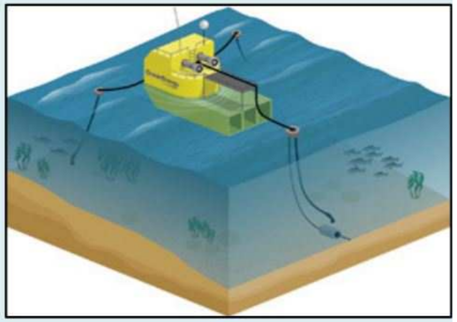
There are currently several companies who intend to research and investigate the exploitation of wave energy as well as the commercialization of this useful technology.

Table 4 shows some of the technologies and the types of wave energy converters these companies are using to generate electricity.

Table 4: The technologies and the types of wave energy converters [85, 92]

Name of device and Company	Technology type	Description	Image view
Offshore Technologies:			
Aquabouy (Finavara renewables, Ireland)	Offshore, point absorber	The AquaBuOY point absorber uses a design that evolved from two already existing devices. These wave energy converters are located in Sweden. The AquaBuoY is made up of a buoy and a vertical tube which is allowed to be in contact with the sea at all its openings. The device heaves up and down due to incidental waves resulting in damping forces being created. These forces serve move 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 pumps and the water masses. This causes the oscillatory motion to run the turbine and generator at high pressure.	
Archimedes Wave	Offshore: Submerged	The AWS is made up of air filled cylinders that are very large and these cylinders are submerged in the water. The	

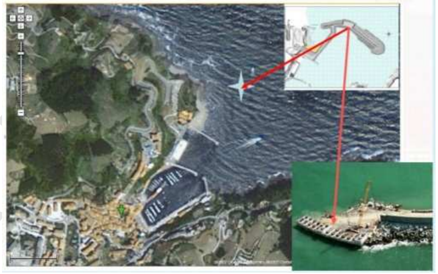
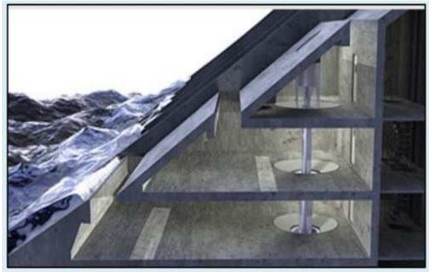
Swing (AWS Ocean Energy Limited, Scotland)	pressure differential	pressure of the water at the topmost part of the cylinder increases as the crest approaches and this leads to compression of the air inside the cylinder to keep the pressures balanced then it expands as the trough passes and this is utilised to generate power.. A prototype was tested in 2004 during a pilot plant programme in Portugal. The IGBT converter transforms different frequency output to utility grade power.	
FO3 (Fobox AS)	Offshore	21 absorbers are positioned in a hydraulic cylinder. Vertical movements result in hydraulic pressure being created and this is utilised to generate power. Numerical calculations may be used to do the design but not to generate power	

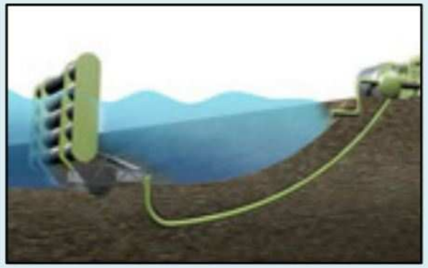
Ocean Energy Buoy (Ocean Energy Limited, Ireland)	Offshore, Oscillating water column	Ocean energy buoy leads to air being pumped in and out via a turbine. Movements of the hull cause the air flow to increase.	
Pelamis (Pelamis Wave Power, UK Scotland)	Offshore, Attenuator	It is a semi submerged, articulated 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 to hydraulic motors that run the generators to produce electricity.	
Power BuoyTM (Ocean Power Technologies, USA)	Offshore, Point Absorber	This is a free-floating point absorber wave energy converter that is moored to the sea bed with the buoy's float moving an up and down on the central spar as the waves pass. This mechanical movement runs a hydraulic pump that forces the hydraulic fluid through a rotary motor that is linked to the electrical generator.	

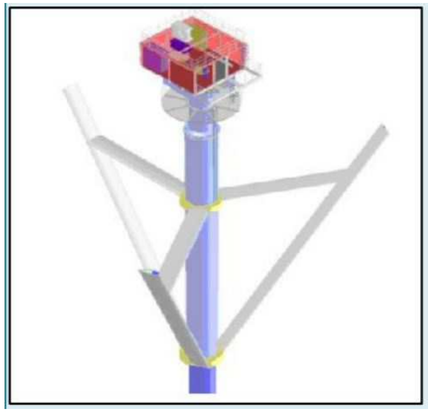
SperBoy (Embley Energy UK, Cornwall.	Offshore, Point Absorber	This is a floating buoy oscillating water column device made of a buoyant structure with part of the column being submerged and enclosed. It follows the same mode of operation for fixed Oscillating water columns. The only difference is that the device can function in deep waters to generate larger amount of energy. This enable the device to maintain good hydrodynamic interaction as the whole body floats. This allows more energy to be generated at a low cost.	
Wave dragon (Denmark)	Offshore, overtopping device	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 helps smooths the flow of the water into the turbines are themselves connected to varying speed generators. This is similar to the approach adopted in hydro power plants.	

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

Onshore and Nearshore technologies:			
EnergeTech OWC (Oceanlinx, Australia)	Near shore oscillating water column (OWC)	The OWC is positioned near shore with the bottom and an oscillating water column capable of producing 500kW. There is also a parabolic steel arm that forms a harbour for tuning the device to increase its ability to absorb the waves. There is also a reef that reduces the possibility of extreme loads as a result of the impact of the wave. The converter was first tested on Port Kembla, Eastern Australia. The company was rebranded as Oxeanlinx and they are currently developing other type of devices.	
LIMPET OWC (Wavegen ltd, UK)	Onshore, Oscillating water column	This is 250kW onshore OWC. It was developed between 1998 and 2000 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 is located on the Pico Island in Portugal. The turbines used are symmetrical and they run in different directions based on the direction of the air.	
SSG Waveenergy AS, Norway	Nearshore overtopping device	This is an overtopping wave energy device made of 3 reservoirs positioned directly on top of each other.	

Wave star, Wave star Energy, Denmark	Nearshore, multi point absorber	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, 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 that functions as part of a protective system that activates the storm security system. Remote connection using the internet aids in the control of device.	
Oyster aquamarine (Northern Ireland)	Near shore oscillating wave surge converter	This is a near shore device mounted at the bottom of the shore and built to interact effectively with all the dominating surge forces in most shallow water waves.	

Wave roller (AWEnergy, Finland)	Near shore oscillating wave surge.	There is movement of a plate due to the back and forth motion of the waves that interact with the bottom of the device. A piston pump is used to gathers the kinetic energy generated. Using a generator, the kinetic energy is transformed into electricity.	
Waverofys (Ecofys, Denmark)	Submerged Pressure differential	The rotor of this device can also run using circular currents. Using high torque, the waves can turn the rotor attached through a gearbox to a vertical shaft that is coupled to a generator. The force of the waves rotates the blades directly. There is transfer of energy as the shaft rotates. The two types of rotor used are the Darrieus rotor and Wells rotor. The rotors are either omni or bi-directional rotors and can function even in currents of different directions	

4.1.1 Tidal Stream

Fig. 14 shows different devices for tidal streams power generation that convert water kinetic energy into electricity.

There are basically six different types of tidal stream devices as shown in Table 5. Tidal stream power generation has experienced good technological advancement compared to wave energy according to recent research [89].

Nearly 3/4 of all research and development investments are geared towards horizontal axis turbines (HAT) and this is largely due to their dominance of the wind industry and their mode of operation being similar. They are also easier to use this technology as there are more expertise and knowledge in their operation given their widespread use in the wind energy industry. The most important goal is for tidal converters to be able to operate at higher fluid density and under varying environmental conditions.

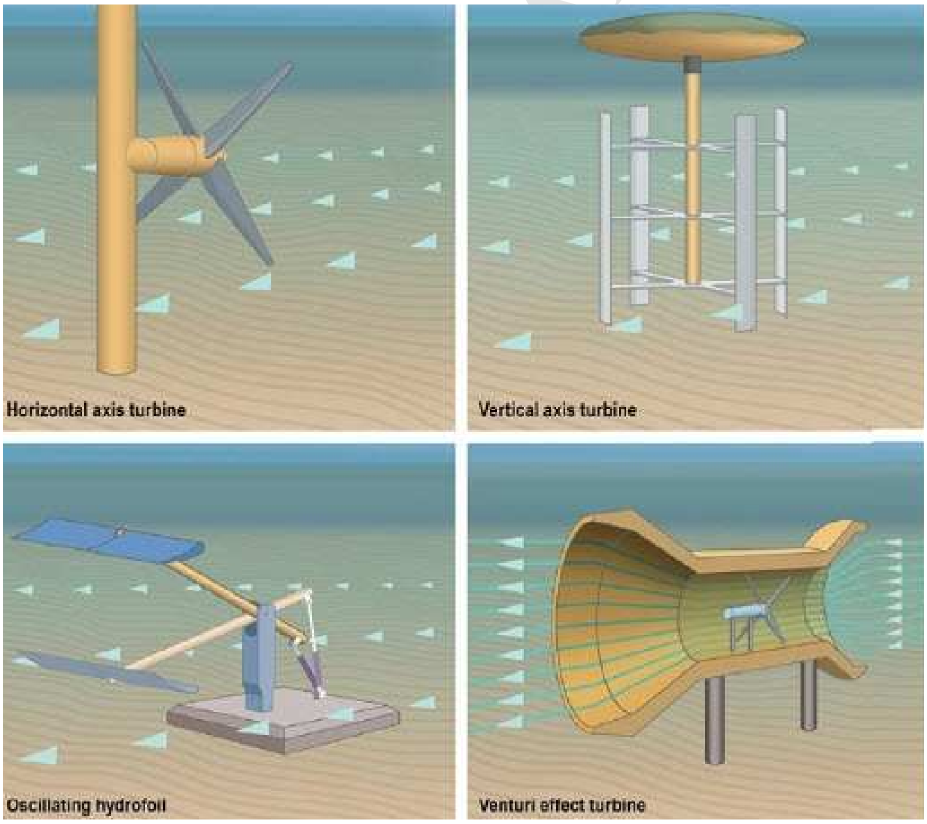


Fig. 14: Diagram of electricity generation using tidal stream [90].

Table 5: Devices for tidal stream energy generation [66]

Type of device	Description of the device
Horizontal axis turbine	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 that is aligned horizontally. The mechanical energy of rotation is directly converted to electrical energy using a generator.
Vertical axis turbine	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 axis turbine.
Oscillating device or oscillating hydrofoil	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 through a motor. Using a generator, the rotational motion can be transformed into electricity.
Ducted turbines or enclosed tips	These are horizontal axis turbines (HAT) placed in ducts. The duct is contoured to increase the velocity as the fluid passes through. Random turbulence and fluid movement near the turbine is reduced due to the ducted structure and this helps guide the flow of water towards the turbines.
Archimedes Screw	These are made of variation of the vertical axis turbines and the absorb energy from a tidal stream as the movement of the water is directed through a helix.
Tidal Kite	The tidal kite device is made up of kites that can rotate with the tidal motion and they are tethered by a cable to a fixed point. The cable is also used to transmit the generated electricity. The kites are usually equipped with gearless generators

4.1.2 Tidal range generation

There are huge similarities between tidal range generation and hydropower. They both operate using artificial height difference of 2 bodies of water formed using a barricade, commonly known as dam, as shown in Fig. 15. 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 where 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 offer some level of flexibility and are less expensive. They also have lower negative impacts on the environment. Using a single basin plant, a barrier or lagoon is created and this drains 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. 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.

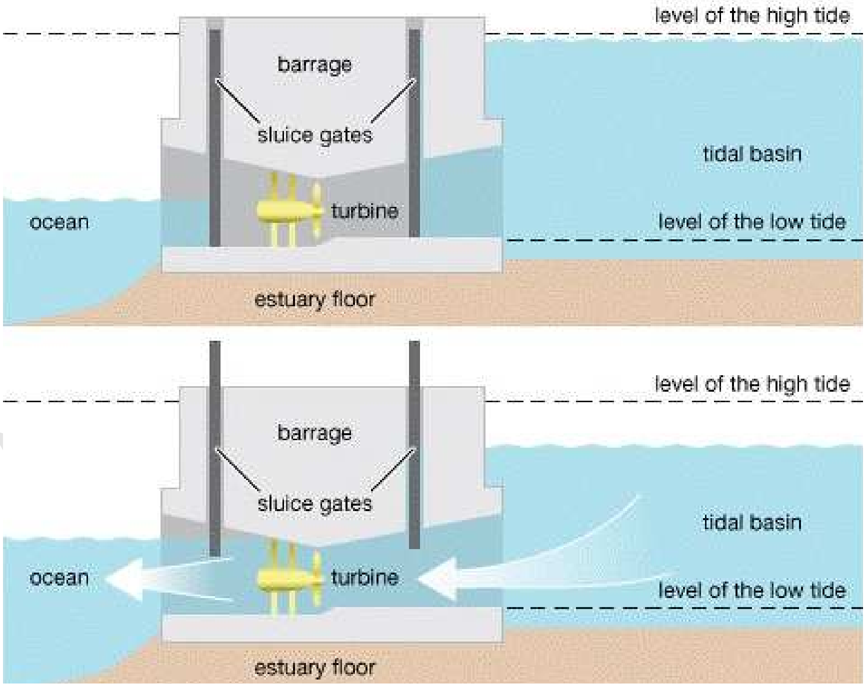


Fig. 15: Operational processes of a tidal range device.

4.2 OTEC

The temperature differences occurring between water layers with high temperature and those with low temperature are utilised to run the turbine. Table 6 gives the characteristics of the three types of OTEC plants used which are also depicted in Fig. 16.

Table 6: Ocean thermal energy conversion devices

OTEC energy devices	Characteristic of the device.
Open Cycle	In a low-pressure environment, warm surface water is flash-evaporated and the vapour generated helps to run a generator. Vapour then condenses when in contact with sea water with lower temperature. Desalinated water is being generated through this process.
Closed cycle	Ammonia, propane or chlorofluorocarbons (CFCs) are used as the working fluid at a lower boiling point that is flash evaporated using warm water by allowing it to flow through a heat exchanger. The resulting vapour is used to run the turbine where it expands and partially condenses. The two phase mixture is then passed to a heat exchanger where it is condensed, pressurised before being sent back to the evaporator for the entire cycle to commence all over again. These power generation cycles tend to function better than open cycles but they are fairly small due to the fact that the secondary working fluid works at higher pressure.
Hybrid	This combined the characteristics of both the open and closed cycle. Warm water, which is used as a primary fluid, enters a low pressure evaporator where it is evaporated then passed to a heat exchanger where its latent heat is used to evaporate the secondary working fluid that is then used to drive the turbine. The secondary working fluid is then condensed and compressed before being sent back to the heat exchanger to repeat the cycle. The condensed water from the heat exchanger is collected as desalinated water.

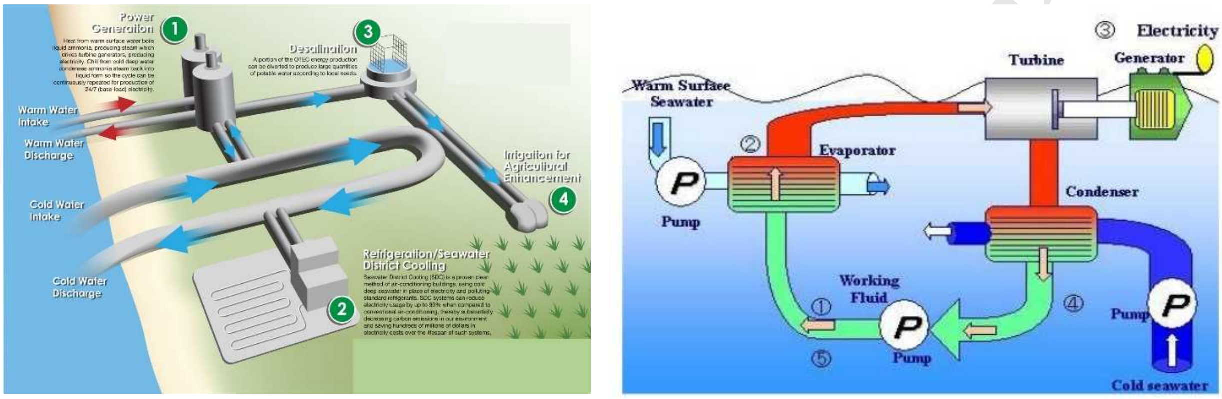


Fig 16: Ocean thermal Energy conversion processes [90]

4.3 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 is nearly 1650 TWh/yr according to an investigation conducted recently [90]. The only challenge relating to the usage of this technology is the costs involved. Tofte was the first site where salinity gradient energy generation was exploited in 2009 [91, 92]. The difference in the chemical potential between the two solutions is utilised to retrieve energy using the reverse electro dialysis technique..

Special cationic and ionic exchange membranes are used to allow the salt solution and fresh water through. The difference in chemical potential between the salt and fresh water generates voltage across the membrane. In a process similar to the fuel cells, membranes are stacked and the total voltage output will equal the sum over the combined membranes stack.

Researchers suggest that the salinity gradient energy that can be harnessed is almost 3.1TW [92]. Fig. 17 shows the predicted worldwide potential for energy capture using salinity gradient techniques.

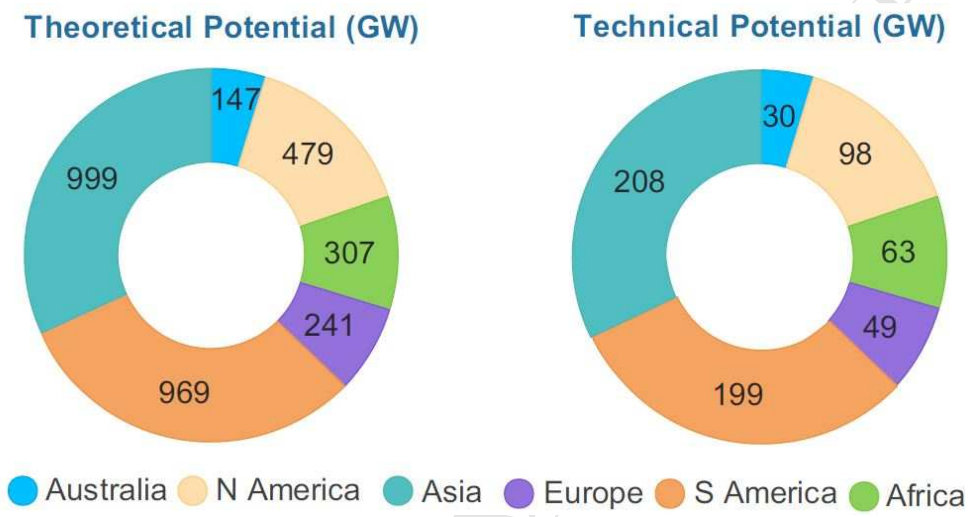


Fig. 17: Salinity gradient for the world in sub regions [66].

4.4 Obstacles impeding the advancement of Marine energy.

Despite the promise of the use of marine energy to make large contribution to energy needs, several technical, social, environmental and economic challenges are hindering the future advancement of marine energy in order to compete with existing energy generation technologies.

Technical challenges include the engineering of the devices, their installation and maintenance, the infrastructure which includes the grid and power transmission as well as losses, their configuration in an array when used in a group, and the challenges of the effect on their working environment on device longevity.

The major challenge with marine energy generation is the high capital cost needed to execute such projects. Compared with other renewable energy generation technologies, the current unit cost of energy generated is much cheaper than that of existing marine energy technologies.

For marine energy to become part of the existing energy generation infrastructure studies are required to quantify the various losses that may occur from the generation stage to the supply stage as they will play an important part in making the technologies viable.

Decision makers around the world must also be willing to formulate policies that seek to explore and encourage the use of these useful energy generation technologies.

Another major issue is related to the environmental implications of these energy generation technologies. 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 reliable studies to ascertain the long term environmental impact effects of marine energy extraction especially on the marine environment and marine ecology including mammals and fish. Also it is important to study the social impact effects of these projects and how they impact on local communities.

For most of the marine related projects, the habitats of other living organisms are negatively impacted or destroyed and this makes most of them environmentally destructive. There is the possibility of corrosion due to the direct contact of a marine device with water in the presence of air if it is properly catered for during the design, fabrication and installation phases. In addition to the negative impact of corrosion on living organisms, it may also reduce the efficiency of the energy device and it longevity [91, 92].

All these challenges must be properly considered to enable marine energy to be successfully commercialised and to be in position to compete with existing energy generation technologies, especially renewable ones.. There must be prioritization if these technically related issues are to be resolved. The challenges of OTEC, salinity gradient and ocean currents impacts must be considered in that order [93 – 101]. This is simply because these technological ideas are still in the early stages of their development and would require more attention and commitment to become economically viable and fully acceptable within the engineering community and the energy generating industry.

5.0 Conclusion

This review article examined the current state of some of the newly emerging renewable energy technologies with concentration on marine energy generation. The work shows that until now the contribution of renewable energy to the exponentially growing total energy needs is still limited.

Current estimates [102] predict that renewables will contribute 29.4% to electric power generation by 2023 but remain very small in the areas of heating and road transport with 11.8% and 3.8%, respectively.

This work highlighted the need for accelerated development of marine energy technologies to help address the need to increase renewables contribution to satisfy energy demands given recent International Energy Agency (IEA) projections that carbon emissions into the atmosphere are likely to rise by 2050 if the situation is not carefully checked [66].

The work gives details of these novel technologies that are being currently developed and tested and provides information on both wave and tidal energy technologies.

The work reviews the current developments in the three areas of on-shore, near-shore and off-shore wave energy generation technologies and comments on their usefulness.

The work also discusses two newly emerging technologies that are under development which are ocean thermal energy conversion and utilisation of salinity to produce electricity.

It is imperative to recognise that the technologies being discussed in this work are either in the developmental stages or in the planning stages of the projects. However, most of the concepts discussed are yet to be commercialized although a lot of research is being conducted to increase understanding and knowledge of these technologies and it is expected this will accelerate the pace at which some of these concepts will develop into commercially viable energy supply means.

All the novel renewable energy technologies discussed in this work can contribute to the goal of meeting the world energy demands if they are properly harnessed.

The work highlights several of the obstacles that are impeding the widespread adoption of ocean power technologies and discusses the need for both technical and economic developments to make ocean energy viable.

The importance of proper environmental and social impact assessments of the long term effects of the development of marine energy projects are captured in this report.. A combination of the novel newly emerging renewable energy technologies in combination with well understood and currently commercially utilised existing renewable energy technologies has the potential to replace non-renewable fossil fuels and other polluting types of fuels as energy generation sources. Governments need to play their part by formulating mechanisms that facilitate research and development of new non-polluting renewable energy resources and enact policies that eliminate the economic disadvantages impeding the development of renewables and to remove indirect subsidies for polluting fossil fuels by accounting fully for their environmental and health impacts worldwide.

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