Chapter

Offshore Renewable Energy

Giovanni Rinaldi

Abstract

Offshore renewable technologies hold the potential to satisfy a considerable amount of the global energy demand in the coming years. In this chapter, the main sources of renewable energy related to the oceans (waves, tides, and offshore winds) will be characterized and discussed, with reference to the challenges related to their use. Thus, the main devices capable of exploiting these resources will be presented. Their working principal, together with operational and technological requirements, will be described, highlighting strengths and weaknesses of each technology and providing examples of the past and current experiences. The elements of project management, as well as environmental impact and public perception, will be included. Finally, conclusions on the current viability of ocean energy devices will be drawn, together with guidelines for their future exploitation.

Keywords: offshore wind, wave, tidal, marine energy, reliability, availability, maintainability, economics

1. Introduction

While world population and global energy demand are rapidly increasing, the effects of carbon emissions and other contaminants are stimulating the quest for clean, carbon neutral, and renewable energy sources. Despite in the last few decades some technologies like photovoltaic and onshore wind have hugely progressed, these alone seem unlikely to satisfy all the electricity needs. Among the main reasons for this limitation are the unpredictability of the resource and the lack of suitable space in land. As a result, novel and reliable sources of energy are being proposed and investigated. Among these, offshore renewable devices, operating in the oceans and open seas, have been identified as suitable alternatives able to provide a substantial contribution to the energy mix. The theoretical resource from offshore technologies including offshore wind, wave, and tidal energy has been estimated between 260,000 and 330,000 TWh/year [1]. This represents a huge potential, which if properly exploited would be able to satisfy the electric energy demand of coastal locations and remote islands and more in general of all the countries having a direct access to sea. However, the oceans constitute a harsh environment, in which it is difficult to access and operate, with several limitations and augmented difficulties compared to onshore projects. For this reason, a number of technical, economical, logistical, and environmental challenges towards the successful exploitations of offshore resources exist.

In this context, this chapter aims at providing an overview of the current possibilities and experiences in the offshore renewable energy sector. In Section 2, the offshore resource in its various forms (wind, currents, and waves), as well as the most common parameters used to characterize it, will be presented and discussed.

In Section 3 the existing devices and technologies used to produce electricity from offshore resources, together with typical energy metrics, will be described. Among them, offshore wind represents the most advanced and successful offshore sector so far. This is mainly due to the experience with onshore wind projects, for what concerns the power production, and with oil and gas projects, for what concerns the foundation and platform of the device. Tidal energy, which uses a similar system to extract energy from the tides, is steadily advancing towards commercial availability. Despite several attempts and a handful of successful stories, nowadays wave energy still looks like the most challenging sector. Finally, other niche technologies that can be related to the use of offshore resources are ocean thermal energy conversion (OTEC) and salinity gradient (also known as "osmotic power").

In Section 4 other challenges related to the successful deployment of offshore renewable devices will be discussed, together with their implications on current academic investigation and industry efforts.

In Section 5, a summary on the current possibilities and challenges for the successful exploitation of offshore renewable energy devices will be provided, and a series of guidelines for future work considered.

2. Offshore resource

This section provides an overview of the offshore resources from which energy can be extracted. The physical phenomena involving the formation and propagation of winds, waves, and currents are hereinafter described with a view on energy production.

2.1 Wind

Wind is a direct effect of the thermal energy provided by solar radiation on earth. This generates gradients of temperature in the atmosphere, which in turn produce variations of pressure which move masses of air around the globe. Besides being affected by the Coriolis force, the intensity and direction of the propagation of these depend on several factors, such as the conformation of the territory, possible obstacles (e.g., buildings), and the roughness of the area on which the wind blows. Due to the lack of vegetation and other obstacles, the roughness over oceans and open seas is extremely low, allowing the wind to travel and develop undisturbed over long distances. This means that offshore winds are generally stronger but also steadier than onshore winds.

In terms of energy extraction, these features translate in an increased potential, as a result of the possibility to use bigger turbines and have less variability of the resource over time. In this regard, it must be remembered that the power extractable from the wind varies with the cube of the velocity, meaning that even small increases in the wind speed may generate large increases in the energy production. Besides, more stable winds generate less turbulence, with positive effects on the structural integrity of the devices and on the reliability of their components.

2.2 Currents

Ocean currents are driven and affected by primary and secondary forces. Primary forces are those that start the movements of masses of water and determine their velocity. These are mainly caused by the relative motions and gravitational effects of the sun, moon, and earth but also geothermal processes, such as variations in temperature and salinity, and tectonic movements (e.g., earthquakes).

Secondary forces are those which influence the direction and nature of the flow and are affected by the seabed composition, bathymetry, and gyres.

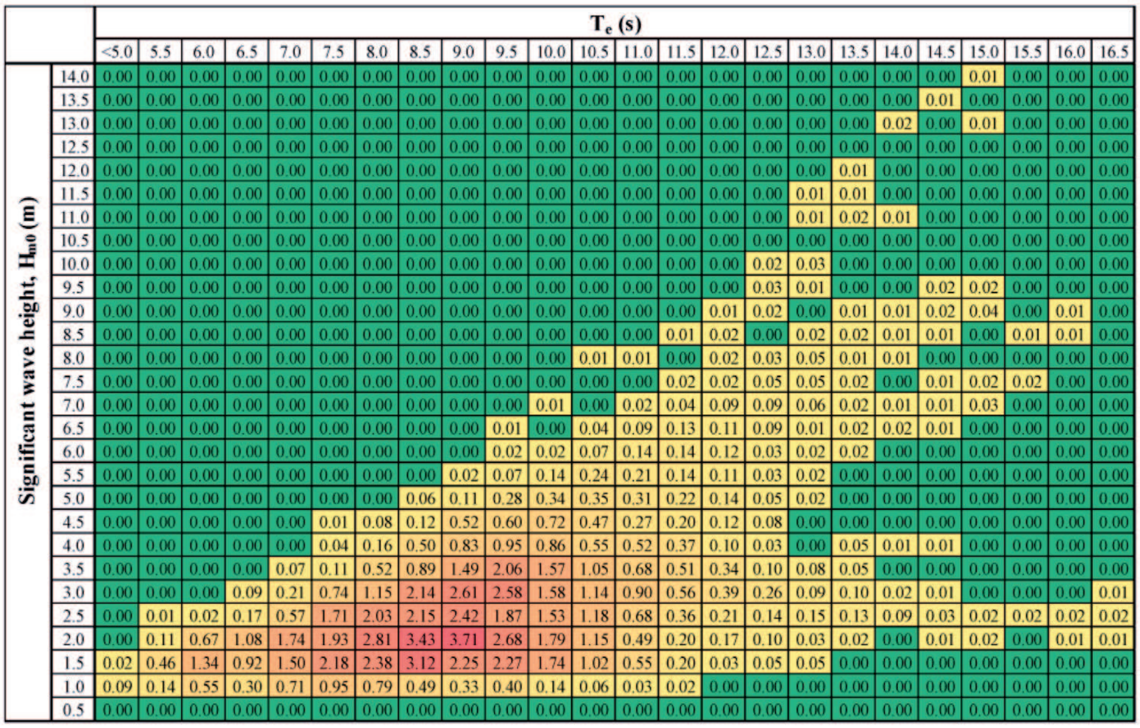
A distinction is often made between tidal currents, generated by the gravitational effects, and nontidal currents, associated to solar heating force mechanisms. Another important distinction is between deep-water circulation, mainly generated by temperature and salinity variations (and therefore also called "thermohaline"), and surface circulation, mainly generated by wind forces transmitting motion to layers of waters below through friction.

The power extraction phenomena are the same regulating wind energy. In this regard, it must be noticed that water current speeds are typically much lower than wind speeds but also that sea water is much denser that air. For instance, for the same area of flow, the energy contained in a current of 1 m/s is the same energy contained in a wind of approximately 10 m/s. As a result, tidal turbines are generally much smaller than a wind turbine of the same nominal capacity.

2.3 Waves

Waves are generated by the action of the wind blowing over the sea surface. The size and other characteristics of the waves are determined by a series of factors. Among these, the most important are the intensity and duration of the wind which generated them, as well as the distance over which the waves can propagate (called "fetch"). In this regard, waves generated at a long distance from the considered region are defined "swell," whereas waves generated by local winds are called "wind sea" or "wind-generated" waves. In general, swells are more energetic than local waves. Other factors which affect the propagation of waves are the water depth and the bathymetry.

Waves are generally measured in terms of their elevation, in meters, at a certain location as a function of time. This can be compared to the up and down movements of the sea surface experienced by a buoy. Other important parameters are the wave period (in seconds) and the wave length (in meters).



		T_e (s)																							
		<5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5
Significant wave height, H_{m0} (m)	14.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	13.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	13.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00
	12.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	11.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	11.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00
	10.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.00
	9.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.01	0.02	0.04	0.00	0.01	0.00
	8.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.00
	8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.03	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	7.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.05	0.05	0.02	0.00	0.01	0.02	0.02	0.00	0.00
	7.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.04	0.09	0.09	0.06	0.02	0.01	0.01	0.03	0.00	0.00	0.00
	6.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.09	0.13	0.11	0.09	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.00
	6.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.07	0.14	0.14	0.12	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	5.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.14	0.24	0.21	0.14	0.11	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.11	0.28	0.34	0.35	0.31	0.22	0.14	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4.5	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.12	0.52	0.60	0.72	0.47	0.27	0.20	0.12	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4.0	0.00	0.00	0.00	0.00	0.00	0.04	0.16	0.50	0.83	0.95	0.86	0.55	0.52	0.37	0.10	0.03	0.00	0.05	0.01	0.01	0.00	0.00	0.00	0.00
	3.5	0.00	0.00	0.00	0.00	0.07	0.11	0.52	0.89	1.49	2.06	1.57	1.05	0.68	0.51	0.34	0.10	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.00
	3.0	0.00	0.00	0.00	0.09	0.21	0.74	1.15	2.14	2.61	2.58	1.58	1.14	0.90	0.56	0.39	0.26	0.09	0.10	0.02	0.01	0.00	0.00	0.00	0.01
	2.5	0.00	0.01	0.02	0.17	0.57	1.71	2.03	2.15	2.42	1.87	1.53	1.18	0.68	0.36	0.21	0.14	0.15	0.13	0.09	0.03	0.02	0.02	0.02	0.02
	2.0	0.00	0.11	0.67	1.08	1.74	1.93	2.81	3.43	3.71	2.68	1.79	1.15	0.49	0.20	0.17	0.10	0.03	0.02	0.00	0.01	0.02	0.00	0.01	0.01
	1.5	0.02	0.46	1.34	0.92	1.50	2.18	2.38	3.12	2.25	2.27	1.74	1.02	0.55	0.20	0.03	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.0	0.09	0.14	0.55	0.30	0.71	0.95	0.79	0.49	0.33	0.40	0.14	0.06	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 1.
Scatter diagram of the Atlantic Marine Energy Test Site (AMETS) in Belmullet, Ireland. Data recorded during 1 year. Wave occurrence is reported in terms of their significant wave height and energy period and as a percentage of the total sample recorded. Image retrieved from [2].

For simplicity, regular sinusoidal wave theory is often used to describe sea waves. However, real sea waves are characterized by high irregularity, and spectral analysis is needed for a thorough description. In this case, ocean waves can be represented with good approximation as a superposition of sinusoidal (regular) waves.

The amount of energy contained in waves is usually quantified through the energy flux across a vertical plane parallel to the wave crest. Most of this contribution is given by the upper layer of water, closer to the sea surface. The power or energy flux is proportional to the significant wave height *HS*, defined as the mean wave height (trough to crest) of the highest third of the waves, and the wave period *T*.

A common way of providing information about the wave climate at a certain location for marine energy applications is the “scatter diagram.” This provides the joint occurrence of the combinations of HS and T over a certain period of time (e.g., 10–20 years). An example of scatter diagram is shown in **Figure 1**.

3. Offshore renewable energy technologies

Once the offshore resource is defined, the existing devices and technologies that can be used to convert it into electrical energy are presented. Thus, the three main types of offshore energy converters are described, and common elements of infrastructure for offshore renewables included. A brief description of less common technologies related to marine energy is provided at the end of the section.

3.1 Offshore wind energy

Offshore wind is without doubt the most established and mature among the offshore renewable sectors. It is the only offshore industry which has already reached a commercial stage, with offshore wind farms competing against other renewable energy technologies, even without any subsidized tariff in some countries. Europe is currently the biggest offshore wind market, with most of the turbines installed in the North Sea and countries like the UK, Denmark, Belgium, and Germany are among the top users. However, thanks to the quickly decreasing costs, offshore wind is rapidly spreading also in other countries (e.g., the USA and China). In addition, several offshore oil and gas companies are increasingly looking at diversifying their portfolio with offshore wind installations.

The reasons for this success are twofold. On one hand, as discussed in the previous section, stronger and steadier winds make the offshore wind resource extremely suitable to energy conversion, allowing for the use of devices with high nominal power (e.g., from 2 to 3 MW for the individual turbine, for projects of 10–20 years ago, to 15 MW, for present and future projects). On the other hand, the experience gained with the onshore wind sector allowed for the use of an already mature and established technology, i.e., the three-blade horizontal-axis wind turbine. As a result, the work towards making the technology economically viable could be focused mainly on the adaptation to the offshore environment, reducing the efforts and expenses in order to make the device technically viable.

The operational principle of offshore wind turbines is essentially the same as their onshore counterparts, with the wind acting on the blades of the turbine to make them rotate. Through a shaft, typically connected to a gearbox (except for “direct drive” machines), this kinetic energy is then converted into electricity by means of a generator. At this point, the electricity is transported onshore using subsea cables and then distributed to the grid. Sometimes offshore substations are used in order to collect the energy produced by several wind turbines before exporting it to the shore, in order to reduce losses by increasing the voltage (typically from 33 to 155 kV).

The trends for the future indicate a significant increase in offshore wind projects, with bigger turbines at increasing distances from the shore. However, this means also greater depths, posing new challenges for the installation, operation, and maintenance of the devices. As a result, floating platforms are being investigated as an alternative to the conventional fixed foundations used to install the wind turbine. Traditional bottom-fixed turbines are generally employed for depths up to 50 m, exploiting a series of structures (e.g., monopoles, tripods, caissons, and jackets) to fix the turbine to the seabed. Despite being technologically less mature, floating offshore wind installations are able to remove this limitation, permitting projects in water depths up to 600 m or in shallow waters with irregular seabed, by using different kinds of floating platforms. Some examples of offshore wind turbine foundations, for both bottom-fixed and floating devices, are shown in **Figure 2** [3].

3.2 Tidal energy

Tidal energy converters (TECs) are essentially rotatory machines, similar to wind turbines, but with the obvious difference that they operate underwater instead of open air. Despite a range of concepts and technologies exists, the most diffused design is also in this case the three-blade horizontal-axis turbine. Other concepts include two-blade turbines, vertical-axis turbines, and oscillating hydrofoils. For a comprehensive list of tidal energy concepts, see [4, 5]. Four prototypes for tidal energy conversion are shown in **Figure 3**.

TECs are generally anchored to the seabed by means of gravity-based foundations but can also be embedded in existing structures, e.g., dams (in which case they are called "tidal barrages"). In addition, TECs can be linked to floating structures, in order to take advantage of the same benefits available to floating offshore wind turbines, discussed in the previous section, as well as to allow for easier maintenance.

Their working principle is analogous to that of wind turbines, with blades able to pitch their blades depending on the flow speed, as well as the entire turbine able to

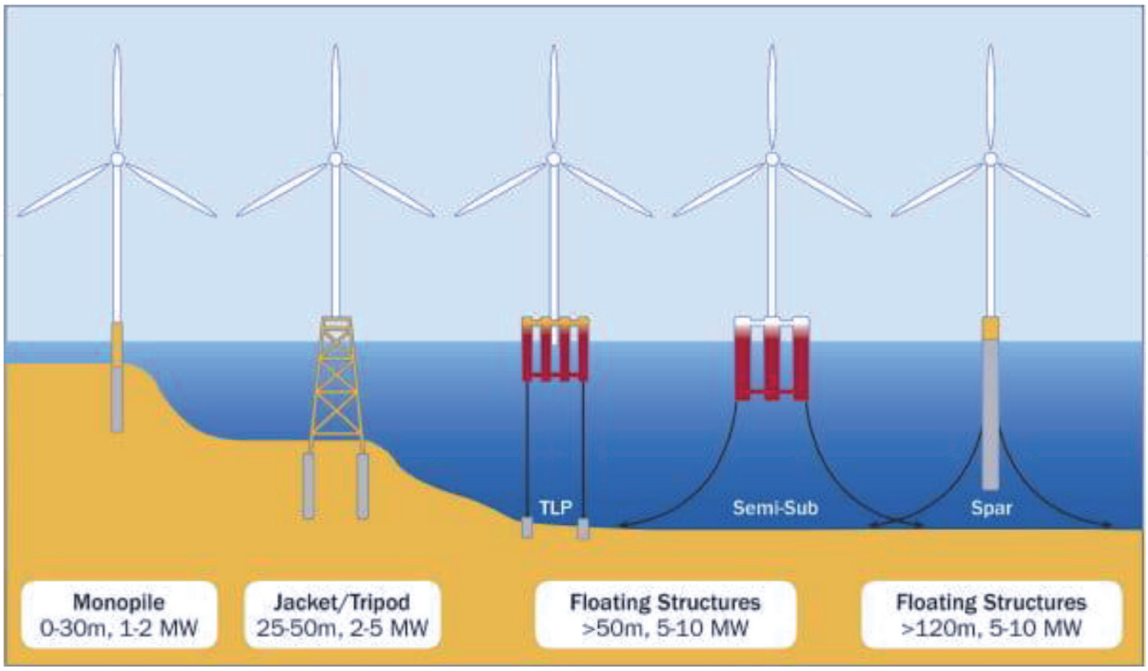


Figure 2.
Typical options for offshore wind foundations in function of water depth and rated capacity of the wind turbine. The first two designs (from the left) represent bottom-fixed solutions, whereas the other ones represent floating platforms. Source: EWEA (2013).

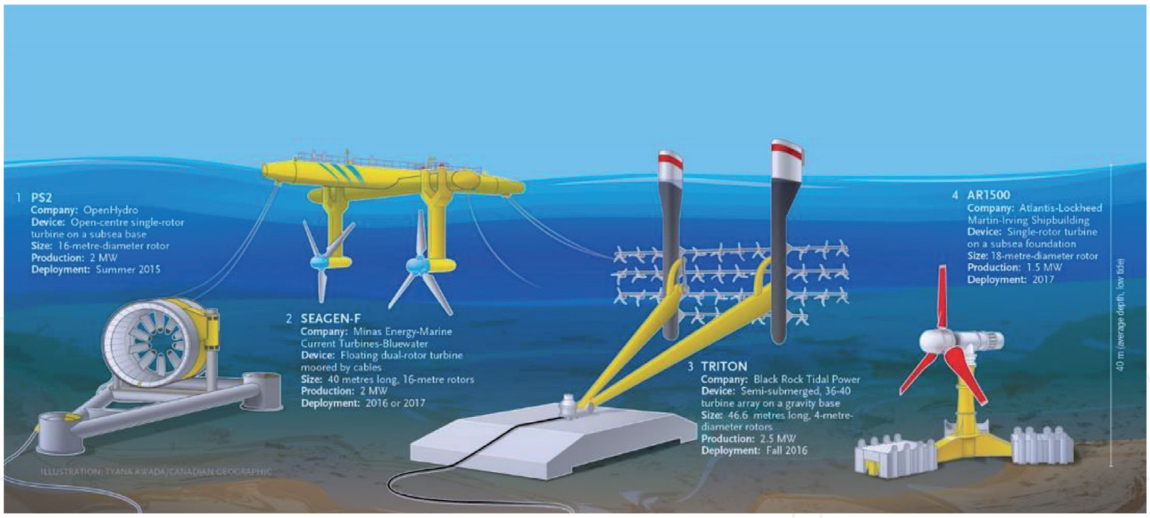


Figure 3.
Schematic drawing of different tidal energy concepts. Infographic retrieved from [6].

spin depending on the direction of the incoming flow. Also in this case, both designs with gearbox or direct drive exist, and the transmission of electricity to shore follows the same technical adjustments available to offshore wind turbines.

Due to the challenges posed by the marine environment (e.g., water tightness, corrosion, biofouling, etc.), the development of the tidal energy sector is being slower than that of offshore wind devices. However, several tidal power plants have been already operational for a number of decades (e.g., the La Rance project, in France, from 1966). More recently, four tidal turbines of 1.5 MW have been installed near the Pentland Firth (northern Scotland, UK) as part of the MeyGen project [7].

3.3 Wave energy

Wave energy can be certainly considered the most challenging of the offshore renewable technologies. Despite a high number of designs and concepts have been conceived to harness the huge potential of the waves, this sector is still far from reaching the commercial stage. Among the reasons for this slow progress, together with the issues applying to all offshore technologies, survivability is probably the main one. Engineering devices able to cyclically withstand the loads of waves, as well as survive extreme conditions during storms in open sea, while producing energy have proven to be extremely difficult. Another fundamental issue in efficiently harnessing wave energy consists in the intrinsic nature of the resource, due to the fact that waves are characterized by strong nonlinearity and their energy distributed over wide areas and varying according to a high number of factors (e.g., bathymetry, winds, depth, obstacles, distances, etc.).

As a result of this variability, hundreds of devices and prototypes have been developed to exploit wave energy. Nonetheless, depending on their working principle, wave energy converters (WECs) can be classified in a limited number of categories, of which the most popular are:

- Point absorbers

- Attenuators

- Oscillating water columns (OWCs)

- Oscillating surge converters

- Overtopping devices
- Submerged pressure differential devices

For a comprehensive review of wave energy concepts, the reader can refer to [8, 9]. A schematic classification of WECs is shown in **Figure 4**. Within the same category, both fixed (either to the seabed or to the shore) and floating devices exist. In addition, several types of power takeoff (PTO) systems exist to convert the kinetic energy of the waves into electricity (e.g., linear generators, hydraulic rams, air and water turbines, elastomers, etc.).

A brief description of the working principle of each of these technologies is hereinafter provided.

Point absorbers are characterized by being significantly smaller than the wavelength of the waves they operate in. These devices are generally similar to buoys, connected to the seabed, which exploit the upward and downward movements of the waves to produce energy. These can be directly connected to a linear generator, or pump water onshore where a conventional hydroelectric turbine is used.

Attenuators are devices composed of multiple floating bodies connected to one another, which flex in a relative motion as the waves pass by. The device is anchored at one hand, and it is designed to be always aligned to the direction of the coming waves. Hydraulic rams are actioned by the motion of the floating bodies, generating the pressure needed to activate a hydraulic motor which in turn is used to generate electricity.

Oscillating water columns are fixed or floating devices which are characterized by having an internal chamber. This can be partially filled with water as the waves approach the device. The remaining space of the chamber remains filled with air, which is compressed and sucked back according to the motions of the water column actioned by the wave. The air, in turn, drives a turbine which spins always in the same direction regardless of where the airflow comes from.

Oscillating surge converters are gravity-based devices sitting on the seabed, on which a float (or flap) is connected by means of a hinge and is free to move as the

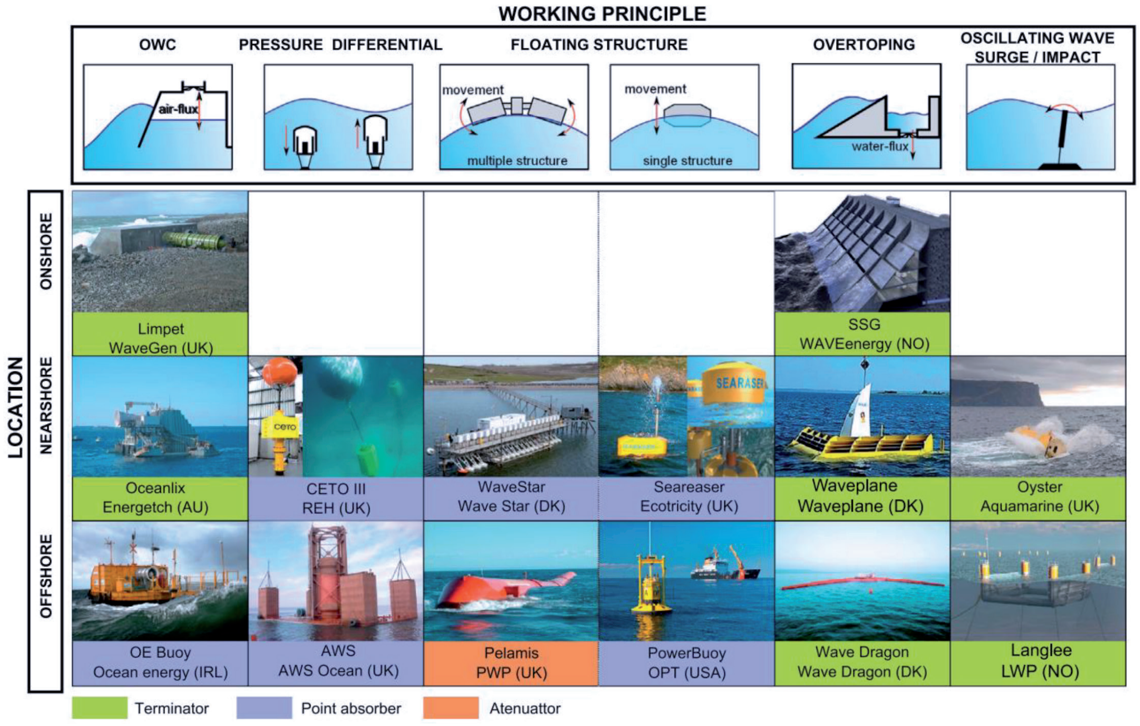


Figure 4.
Schematic illustration of different WECs categories, divided according to their working principle and working location (distance from shore). Image retrieved from [9].

waves push against it. The float is then connected to a pump, which brings pressurized water on the shore for the conversion of energy into electricity.

Overtopping devices are designed in such a way that waves can go over them, adding water in a reservoir above the sea level. Once in the reservoir, the water is then conveyed towards a conventional low-head hydroelectric turbine, which converts the potential energy of the accumulated water into electricity. Also for this kind of WECs, both onshore and offshore (floating) versions exist.

Submerged pressure differential devices are fixed on the seabed and exploit the pressure differential created by the passage of a wave over them. A flexible membrane (e.g., rubber or an elastomer) or an external displacer of the device is cyclically compressed by the waves. This functions as a pump which activates a fluid through a conventional hydroelectric system for energy conversion.

In order to estimate the energy that can potentially be produced by a WEC, the scatter diagram of the selected location is used in combination with the power matrix of the device. This expresses the amount of power that is generated by the WEC for a certain combination of HS and T. In most WECs, control algorithms are used in order to tune the response of the device to the frequency of the incoming waves. In order to maximize the energy extraction, the control system aims at maintaining the device in resonance, by making the natural frequency of the device as close as possible to that of the current sea state.

3.4 Other technologies

Other technologies which exploit the oceans in order to produce electricity are *OTEC* and *osmotic power* plants.

OTEC stands for "ocean thermal energy conversion," and it is a technology which exploits the temperature differential between the water on the surface and water at much higher depths (typically beyond 1500 m). A difference in temperature of at least 20°C is desired in order to activate a thermal cycle. As such, this technology is especially suitable for locations benefitting from a warm water surface all year round, e.g., the Maldives [10]. Through heat exchangers, a power turbine is then activated before condensing the fluid and restarting the cycle. The main advantage of this kind of technology is that the resource (the temperature gradient) is practically constant, allowing the power plant to reach a very high availability.

Osmotic power plants exploit the differential in salinity between the fresh water of a river and the salty water of the sea. Electricity is produced by using a series of membranes in a process of osmosis.

4. Offshore renewable device challenges

As discussed in the introduction and anticipated in the previous section, a number of challenges are preventing the offshore renewable sector from giving a significant contribution to the current energy mix. These limitations are mostly technical but also economical, environmental, and social which are currently being faced in order to support the ocean energy sector. The most common problematics to the deployment of offshore renewable devices will be discussed in this section.

4.1 Installation, operation, and maintenance

The oceans constitute a harsh and difficult environment, which requires a series of specific solutions in order to install and maintain the devices. These include offshore assets, like vessels, workboats, and helicopters, but also suitable onshore logistics, like maintenance harbors and electrical substations. Both onshore and offshore formed technicians and personnel are needed to take care of all the phases of an offshore renewable farm, from preliminary surveys to final decommissioning after the life cycle. Health and safety considerations and protocols need to be prepared and followed for each specific plant and operation.

A fundamental difference from onshore power plants is that marine renewables suffer from a higher degree of isolation. In other words, any operation is subject to strict meteorological conditions, which may significantly affect the start and duration of each activity. In fact, suitable conditions must be verified with respect to several variables, e.g., wind, waves, currents, and visibility. If any of the metocean parameters exceeds one of the pre-established thresholds, the operation has to be postponed or delayed until when all the parameters reach a suitable value.

Being huge machines, composed of a high number of different components, the installation of offshore renewable devices requires specialized vessels with lifting capabilities and able to operate far from shore. However, this provides the possibility to create a supply chain for those regions willing to invest in the infrastructures. Similarly, the operation and maintenance (O&M) of the devices is constituted by a series of preventive and corrective activities that require specific assets. Condition monitoring instrumentation is often integrated in order to monitor the status of the components and detect possible malfunctioning of the device. In this way, eventual repairs or replacements can be scheduled beforehand, reducing the risk for failures which might make the device unavailable for extended period of times.

4.2 Economics

The impact of the technical challenges described in the above section is firstly economic. Purchasing or chartering specialized vessels with specific capabilities has enormous repercussions on the finance of renewable projects. The costs of installing and operating a device offshore are also highly variable, depending on the location and the period of the year (prices generally increase in the summer, due to the major request as a consequence of more suitable operating conditions).

Before the installation, the device must be declared functional and technically ready to produce energy. With the exception of the offshore wind sector, which could benefit from analogous onshore machines, bringing tidal and wave energy machines to technical maturity will require a significant economic effort. Each device has to pass through a stage-gate process, during which the device is brought from the initial concept to the full-scale prototype, passing through various phases of numerical and experimental modelling. A technology readiness level (TRL) metric is often used to evaluate the stage of development of an offshore renewable device.

Apart from the device, a number of additional elements are needed to secure the device in the established location and allow for the transmission of electricity to the onshore grid. Moorings, anchors, foundations, electrical substations, and subsea cables are all items that must be specifically designed for each project, adding up to the final cost of the same. In most cases, station-keeping or transmission infrastructures play a pivotal role in the economic viability of an offshore project.

Lastly, the fact that most of the offshore renewable technologies are novel and innovative means that specific parts and components must be designed and manufactured ad hoc. This translates into high costs for each individual component, which cannot be purchased off the shelf and therefore for the final device. Once these technologies will be proven to be functional, series production will aid in reducing the price per component for most of these items. Besides, the novelty of the technology often affects the confidence of possible investors, posing barriers to the financial support of offshore renewables.

4.3 Environmental constraints

Several concerns have been raised with respect to the environmental impact of offshore renewable farms. These regard possible perturbations to the coastal dynamics (e.g., reduction of the wind and wave climate). Mitigation in this case could be provided through a proper siting and orientation of the offshore farm. However, both elements of the offshore and onshore infrastructure would modify the original landscape and could introduce dangers in the local ecosystem (e.g., spills and leakages).

Concerns exist also about marine organisms affected by the device, e.g., impacted by the blades of a TEC or trapped in the chambers of a WEC. Similarly, new elements and materials might provide the opportunity for invasive species to proliferate. Nonetheless, they might have beneficial effects on the local marine life, by creating new shelters for shellfish and crustacean.

For these reasons, every offshore renewable project is thoroughly assessed through an environmental impact assessment (EIA). This is constituted by a series of studies and surveys, sometimes lasting for years, which aim at identifying all the possible risks to the environment as a consequence of the offshore farm construction and operation. As a result, the viability of the project is assessed and the go-ahead given only in case of favorable conditions. Besides, mitigation measures are proposed in order to minimize the impact of all the identified risks.

Finally, life cycle analysis (LCA) studies are conducted in order to assess the environmental effects (including carbon emissions) related to all the stages of the project, from pre-development and consenting to final decommissioning.

4.4 Social impact

Another source of concern when an offshore renewable project is being developed is the social perception and its possible related consequences. The coastal communities living nearby the selected location might be reluctant to the construction of the offshore farm. Visual impact, noise, and possible effects on the local ecosystem are among the main reasons for this reluctance.

Besides, possible conflicts may arise from sharing the offshore location with existing activities in the same area. These regard competition with navigation (both commercial and touristic) and fishing activities.

Also in this case, suitable agreements and mitigation measures must be identified beforehand through communication and engagement with local public bodies and communities. However, if too complex, planning and permitting procedures may slow down the construction of an offshore farm and make possible investors desist.

5. Conclusions

In this chapter, an overview of the current possibilities and challenges in the exploitation of offshore renewable energy is presented. Oceans and marine areas provide a huge potential for electricity production. In this regard, an important differentiation between theoretical and economic potential must be taken into account. If the first represents the overall resource physically available, the latter represents the final potential of the resource after considering technical, social, environmental, and economic constraints. Thus, any assessment on the energy that can be converted from offshore winds, waves, and currents should take these limitations into account. Nonetheless, the marine environment can provide a reliable, continuous, and predictable source of energy; therefore any effort should be made in order to harness it.

As discussed, within the offshore industry, some sectors and technologies are at a more advanced stage of development than others. Therefore, the performance of some devices must be improved, while the gap between consolidated and novel technologies filled. This can be achieved in different ways, depending on the maturity of the technology. For established technologies like offshore wind turbines, efforts will be made towards improving the reliability and longevity of the devices, in order to maximize the availability and power production, increase the life cycle, and minimize operating costs. For novel technologies like wave energy converters, the focus will be on improving the power capture and conversion, while engineering devices are for surviving in the harshest conditions. For most devices, investigation and improvements of both kinds will be needed in order to obtain an effective and efficient technology.

In all cases, the main aim is the reduction of costs on all the phases of the project. This can be achieved by following the best practices and managing the project adequately. An effective project-management plan covering all the phases of the offshore farm, from pre-feasibility study to decommissioning or repowering, should be implemented. This process starts with studies assessing the feasibility of the project. It continues with the initial design, when not only functional but also easy to maintain (and possibly recycle) devices should be chosen. Thus, due to the risk and expenses related to the installation and maintenance of an offshore farm, a suitable holistic strategy for these phases should be chosen. The decision-making process in this case should be supported by tools specifically created for the offshore renewable sector. Assets management skills are thus required throughout the entire project life cycle. The final objective is to produce a reliable and cost-effective project, able to compete against both other renewable and nonrenewable developments.

Hence, a number of barriers preventing offshore renewables from significantly contributing to the global energy production remain. However, suitable mitigation measures exist and should be adopted. The support provided by governments and public bodies is and remains fundamental until the technologies are fully mature. This will provide the opportunity to meet sustainability objectives while creating new jobs and investment prospects.

Author details

Giovanni Rinaldi
Renewable Energy Group at the University of Exeter, Penryn Campus, Penryn, Cornwall, United Kingdom

*Address all correspondence to: g.rinaldi@exeter.ac.uk

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