Islamic University of Technology

Department of Mechanical and Production Engineering

A Review of the Technologies for Wave Energy Conversion

A Thesis by

Fardin Mahatab

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Bachelor of Science in Mechanical Engineering
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CERTIFICATE OF RESEARCH

This thesis titled "A Review of the Technologies for Wave Energy Conversion" submitted by Fardin Mahatab (170011058) has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering.

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DECLARATION

*I hereby declare that this thesis entitled "*A Review of the Technologies for Wave Energy Conversion*" is an authentic report of our study carried out as requirement for the award of degree B.Sc. (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka, under the supervision of Dr. Md. Hamidur Rahman, Professor, MPE, IUT in the year 2022*

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

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ABSTRACT

The primary objective of this article is to provide a comprehensive overview of the wave energy extraction techniques currently in use. The overview will describe the potential of wave technologies as well as their limitations. In addition, the article will explore the various factors that influence the power performance of Wave Energy Converters. Key factors and their effects on pertinent existing wave energy converter technologies, including capacity factor, dimensionless normalized wave power, and capture width, are discussed. We will compare and discuss the most promising technologies in conclusion.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

1.1 Energy

Energy is the capability to perform labor. Energy can exist in numerous forms, including potential, kinetic, thermal, electrical, chemical, and atomic. In addition, there is heat, function, and energy transfer between bodies. After energy has been transferred, its definition is always applied. Therefore, heat transmitted can be converted to thermal energy, while work performed can manifest as mechanical energy. Every form of energy is linked to motion. Kinetic energy, for example, is possessed by all moving objects. Due to its structure, a tensioned system, such as a bow or spring, has the potential to generate motion even when at rest; it contains potential energy. Nuclear energy is a potential source of fuel because it is derived from the subatomic particle structure of the nucleus of an atom. It is impossible to create or destroy energy, but it is possible to transform it into other forms. This principle is known as the conservation of energy or the first law of thermodynamics.[5]

When a box falls down a slope, for instance, its potential energy from being high up on the slope is converted to kinetic energy, or energy of motion. As the movement of the box is slowed by friction, the kinetic energy of the box's motion is converted to thermal energy, resulting in heating and heating. There are numerous ways to transform one form of energy into another. Numerous types of devices, including heat engines, generators, batteries, fuel cells, and magneto hydrodynamic systems, can generate usable mechanical or electrical energy. According to the International System of Units, energy is measured in joules (SI). One joule equals the amount of work performed over one meter by a force of one Newton.[7]

1.2 Sources of Renewable Energies

About 80% of the world's rising energy demand is met by fossil fuels, resulting in climate change. The adverse effects of global climate change and the limited availability of polluting fossil fuels increase the demand for limitless, clean energy. BP's statistical assessment of global energy predicts that the remaining years of coal use, natural gas consumption, and coal extraction will be 50.7 years for coal, 52.8 years for natural gas, and 114 years for coal. The environmental impact of renewable energy sources such as geothermal, hydropower, modern biomass, solar, tidal, wave, onshore, and offshore wind is minimal when compared to fossil fuels. This dissertation focuses solely on the subject of marine energy.[6]

Although more than 70 percent of the planet's surface is covered by water, the vast energy reserves it contains remain largely untapped. In addition, the density of water is approximately 800 times that of air, implying that the greater the density, the greater the power generated at a given speed [9]. Wave energy converters (WECs) and marine current energy converters (MCECs) have been constructed and evaluated on a global scale in order to harvest the kinetic energy inherent in ocean waves and currents, respectively. Costs associated with installation, operation, maintenance, and decommissioning prevent these technologies from advancing past the experimental phase [14]. Cost-cutting measures include meticulous planning and the selection of an offshore deployment method, in addition to the use of remotely operated vehicles (ROVs) to automate specific tasks.

Due to the immense forces involved, extracting energy from marine energy sources is difficult, and operating WECs in energetic waters further complicates installation [15, 16]. Operations rely heavily on weather windows for offshore deployments, which are fraught with inherent dangers. By conducting a risk assessment of the leased vessel's permitted operating sea conditions, safety issues that may arise during offshore installation of marine energy devices can be prevented.

1.3 Wave Energy

This article refers to wind-produced ocean waves as "waves." The majority of solar energy is therefore concentrated [10]. The sun's rays strike the earth and warm the air, causing energy fluctuations that propel the wind. It transfers and concentrates solar energy onto the wind. Waves are generated when wind blows over a body of water. A portion of the air's energy is transported by the waves, which redistribute the sun's energy [12]. It begins with a slight pressure difference on the ocean's surface, which is caused by wind turbulence, and results in minor irregularities or small waves. The combination of the resonance between the vertical wind pressure and these small waves and the sheer force caused by the higher wind speeds at the crests compared to the troughs causes the waves to grow [21].

The wind's friction on the water and the pressure differential caused by the wave's sheltering effect on the lee side versus the wind side continue to increase as the waves grow larger [29]. Throughout these processes, there is a continuous transfer of energy from the winds to the waves. Their ultimate magnitude is determined by three factors: wind speed, wind duration, and the fetch, or distance over which the wind blows.

Figure 1: Wave Energy [4]

Wave energy is a renewable energy source because it stores the natural energy waves provide. Waves also derive their energy from the wind that blows across the sea's surface and are capable of transmitting their energy over vast distances with minimal loss; consequently, wave energy is a crucial component of renewable energy [17]. If captured, the intermittent and oscillating stream of wave energy in the oceans, known as kinetic energy, could significantly contribute to a network of clean energy. The wave's energy is quantified and evaluated using its height, frequency, size, and water density [4]. Despite the fact that the majority of wave technologies are intended to be installed near the ocean's surface, they can be utilized near shore, inland, and offshore, depending on the region.

In general, wave energy devices are classified based on the mechanism used to capture or harness the energy contained in the waves, their location, and their power takeoff [23]. Possible locations include the coast, the near-shore, and the open ocean. Examples of power take-off include the hydraulic ram, elastomeric hose pump, pump-to-shore, hydroelectric turbine, air turbine, and linear electrical generator [1]. When evaluating wave energy as a technology, it is essential to differentiate between the four most prevalent approaches: point absorber buoys, wave activated bodies, oscillating water columns, and overtopping devices.

1.4 Wave Energy Conversion

CO2 emissions from fossil fuels have severe effects on the ecosystem. In addition, widespread use of fossil fuels depletes oil, coal, and gas reserves at an alarming rate. Converting renewable wave energy to fossil fuels could be a viable alternative [18]. Wave energy has been extensively researched as a renewable energy source over the past several decades, but it is not yet competitive with other energy sources on the market due to a lack of significant technological advancements. This energy is extremely difficult to economically harness and convert into substantial amounts of power. This is the principal obstruction [20].

Numerous attempts were made throughout the previous century to harness the power of ocean waves, with some achieving limited short-term success but ultimately failing due to technological or economic constraints. However, the viability of Wave Energy Converters is the subject of ongoing research (WEC). Existing WECs can be divided into two categories: offshore and coastal [32, 33].

Devices that float in deep water or are submerged and anchored to the seafloor constitute offshore WECs. By laying cables on the seafloor, the harvested energy is transmitted to land. Along the coast, shoreline WECs is frequently situated in shallow water and is occasionally combined with shoreline defenses [42, 43]. Offshore WECs can utilize the vast potential of an environment with a high wave energy density, but they are hindered by severe wave loading, expensive underwater cable connections for electricity transmission, and challenging maintenance [39]. As a result of the energy being lost in shallow waters, the generation potential of shoreline WECs is low. However, they may be more cost-effective due to their lower up-front and ongoing costs as well as their greater accessibility [28].

Shoreline WECs can be built concurrently with shoreline defenses, reducing production costs. Notable and newly designed WECs include the Oscillating Water Column (OWC), Pelamis, Wave Dragon, and Oyster [11, 12]. Existing WECs are founded on a variety of unique concepts. OWCs are chambers in which the water level rises and falls in response to variations in wave height, causing air movement that regulates the air turbine. Ocean Power Delivery Ltd's Pelamis is a buoyant, tethered device that is propelled by waves and harnesses their energy. Oyster is a relatively recent WEC development that is well-suited to shallow water depths, and research is still ongoing [18].

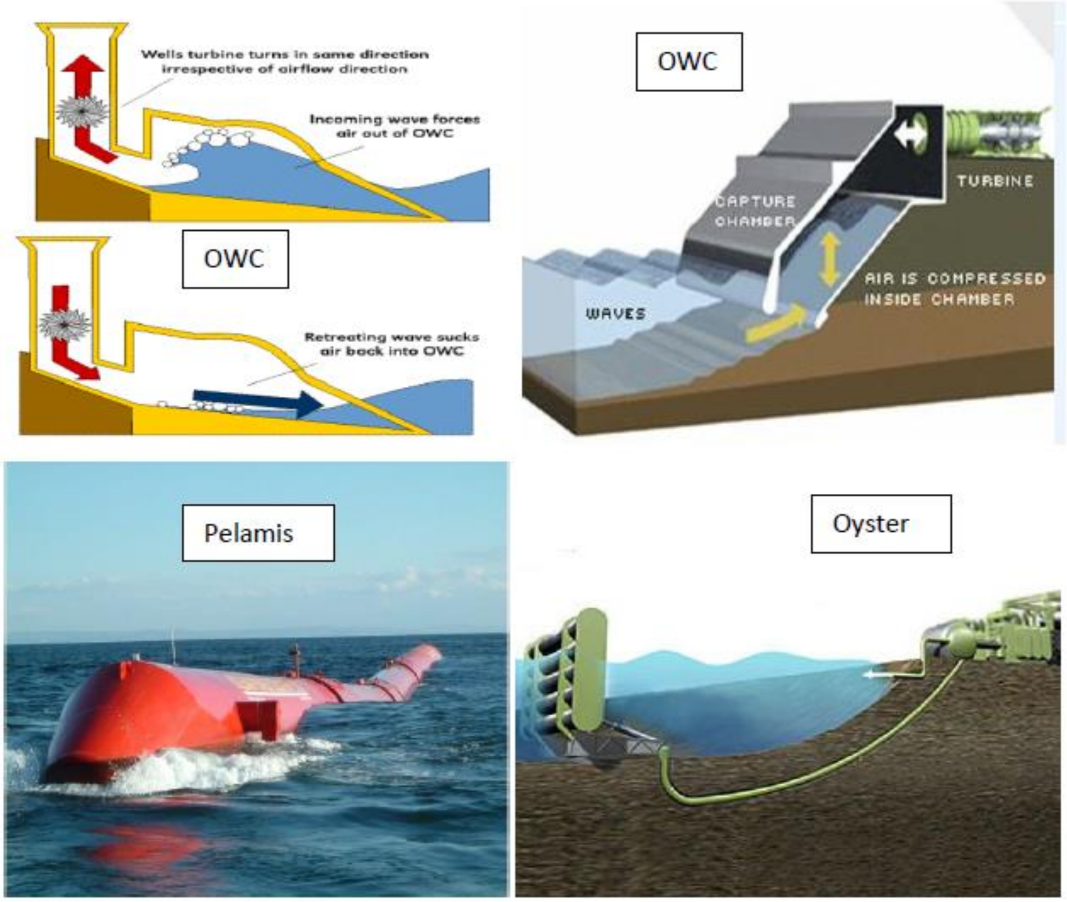


Figure 2: Recently developed WECs [2]

1.5 Thesis Objectives

The objective of this review is to select and evaluate the factors that influence the performance of a WEC. The factors can be listed into two sets:

- Factors to be considered based on the WEC technology:-

1. Efficiency
2. Location (Near-shore and Off-shore)

3. Kinetic and Potential Energy

- Factors to be considered based on the location:-

1. Wave Energy Potential available that region
2. Type of wave available: I) Swell wave and II) Wind Sea
3. Sea States
4. Installation Depth

1.6 Scope and Limitations of the Study

- The data collected for Saint Martin islands is for wave behavior along the shoreline. [9]
- As a result the mean changes in the capacity factor, capture width and dimensionless normalized wave power cannot be analyzed. [12]
- The optimum installation depth for Saint Martin island is unable to be found due to this although the performance of some of the WECs matches with the reference papers.
- As the damping control methods affect the power production and hydrodynamic behaviors so, control strategies can increase the efficiency of the WECs and help WECs to work efficiently across a broader range of the sea states but, in this study, no control strategies were discussed. [15]
- The role of the PTO is vital in optimizing the performance of WEC but it was also outside the scope of this paper. [14]

1.7 Thesis Organization

This thesis is intended to show an operational view of the factors that affect the power performance of Wave Energy Converters and its importance and aspects in Bangladesh:

- In **chapter 2**, literature review, different types of Wave Energy Converters are described. The type includes Wave activated bodies, Oscillating Water columns, Overtopping devices and Point Absorber.
- In **chapter 3**, the analysis of the different factors that affect the power performance like swell and wind wave, wave energy potential, device location, kinetic and potential energy and installation depth.
- In **chapter 4**, methodology and analysis of the performance of various wave energy converters at different installation depths at Saint Martin’s.
- In **chapter 5,** the result of the analysis is studied.
- In **chapter 6,** the conclusion is made on the thesis which ends with the future scopes.

Chapter 2

LITERATURE REVIEW

Literature Review

Ocean waves are a vast, largely untapped energy resource, and their potential for energy extraction is substantial.

This research is motivated by the need to meet renewable energy goals, but it is relatively immature in comparison to other renewable energy technologies [32].

This review provides an overview of the current status of wave energy and evaluates the device types that represent current wave energy converter (WEC) technology, with a particular emphasis on ongoing research within the countries with wave energy access. This thesis is a review work that looks into the existing Wave Energy Converter (WEC) technologies that are currently in operation and reviews the work done so far by numerous other authors and establishes a set of factors based on which the evaluation of the WEC technologies can be done objectively. The aim is to find the best ways to utilize the select few factors that contribute to the optimum performance of a WEC [19]. There is a lack of convergence on the best method of extracting energy from the waves and although there have been innovations focused on new concepts and design there are so many variables involved that it is difficult to narrow it down to a few that provide the optimum results. This book analyses the different factors like swell and wind wave, shore location of converter, installation depth and wave energy potential to understand the optimum conditions and features that will best utilize the potential of a Wave Energy Converter and its installation site. [21,22,29]

2.1 Type of Wave Energy Converters

Wave Energy Converters or Wave Activated Bodies are devices with movable parts that are instantly activated by the cyclic oscillation of the waves. These fragments have their kinetic energy converted into an electric current [6]. A WAB is exemplified by a single floater coupled to a linear magnetic generator. In other instances, only a portion of the body is submerged and dragged by the orbital oscillations of the water [7]. To maximize the use of this resource, the distance between the moving molecules must be small relative to the wavelength, preferably no more than half a wavelength. Consequently, wave-activated bodies are generally quite compact and lightweight. The prohibitively expensive cost of the power generator required to convert the chaotic oscillatory flux to electricity is the primary drawback of this type of converter [11].

The DEXA, which was developed and patented by DEXA Wave Energy ApS, is an example of a WAB. Two catamarans that pivot make up the device. A low-pressure water-based power transmission system restricts angular oscillations by capturing the resulting oscillatory flux at the hinge. Increasing the flux generation by half a wavelength by separating the catamaran's floaters. A scaled-down prototype located in the Danish portion of the North Sea is anticipated to generate 160 kW. The output of the full-scale models is anticipated to be 250 kW [23, 25, 32].

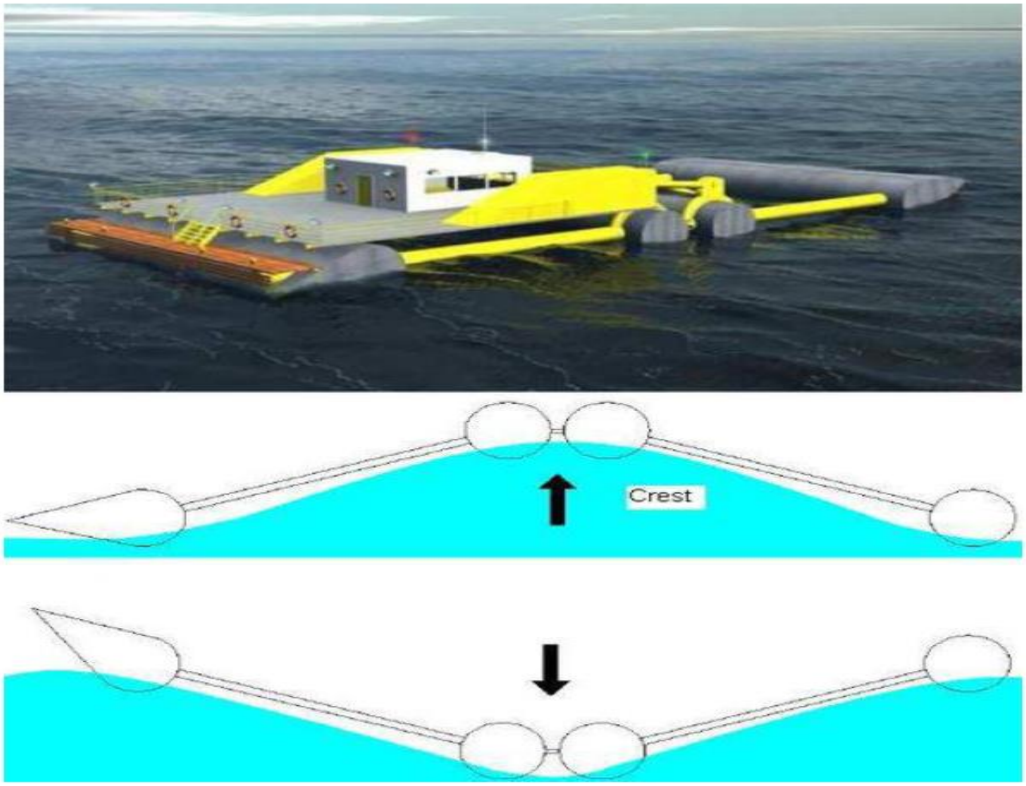


Figure 3: DEXA concept [17]

2.2 Oscillating Water Column

Using the concept of wave-induced air pressurization, oscillating water columns (OWCs) operate in a manner comparable to wind turbines [8]. The apparatus is affixed atop an elevated air chamber that is sealed off. The passage of waves alters the water level inside the closed housing, and the rising and falling water level alters the internal air pressure, resulting in a bidirectional air flow. When a turbine is attached to the top of this chamber, air will flow in and out in response to changes in air pressure. Using a Wells turbine to generate suction or pressure-generating valves to separate the bidirectional flow are two potential methods. OWC devices can be moored offshore or installed near a coastal breakwater. The "Sperboy" is an OWC located offshore [20]. Circular in plan, it is therefore insensitive to the direction of waves. Its dimensions vary based on the desired sea conditions at the deployment site, but a maximum diameter of 30 meters, height of 50 meters, and draft of 35 meters are specified [8]. This design can generate a maximum annual average output of 450 kW. On the inland side, the University of "Mediterranean Studies" in Reggio Calabria developed the "REWEC-3" resonant WEC. Each caisson contains a Wells turbine, unlike conventional concrete caisson breakwaters. These devices are generally regarded as highly efficient [45].

Figure 4: Different concepts of oscillating water columns - Sperboy (above) and REWEC-3 (below) [10]

2.3 Overtopping Device

The overtopping device is a type of wave energy converter that functions similarly to a hydroelectric dam. "Wave Dragon" is a representation of an offshore wave energy converter device capable of overtopping. Its floating arms concentrate waves on a slope, from which the waves enter a reservoir [29].

The resulting difference in water level between the reservoir and mean sea level then powers low-head hydro turbines. With dimensions of 260m in width and 150m in length, the optimal size design proposed will generate 4 MW. When wave conditions exceed 33 kW/m, this method is expected to become economically competitive with offshore wind power in the near future. After a combination of cost reductions and enhanced energy efficiency, the price of electricity will equal that of fossil fuel generation. OVTs can be installed close to shore in front of caisson breakwaters or as an integral component [40].

WAVEnergy, a Norwegian company, is constructing a SeaWave Slot-Cone Generator (SSG) integrated multilevel overtopping wave energy converter device. SSG has the advantage of collecting wave energy in multiple stacked reservoirs, resulting in a high hydraulic efficiency. The reservoir's capacity evens out the irregularity of incoming waves, ensuring a consistent supply of electricity to the grid. This will almost certainly result in a low-maintenance and long-lasting system. Other SSG designs are deployable both onshore and offshore [29].

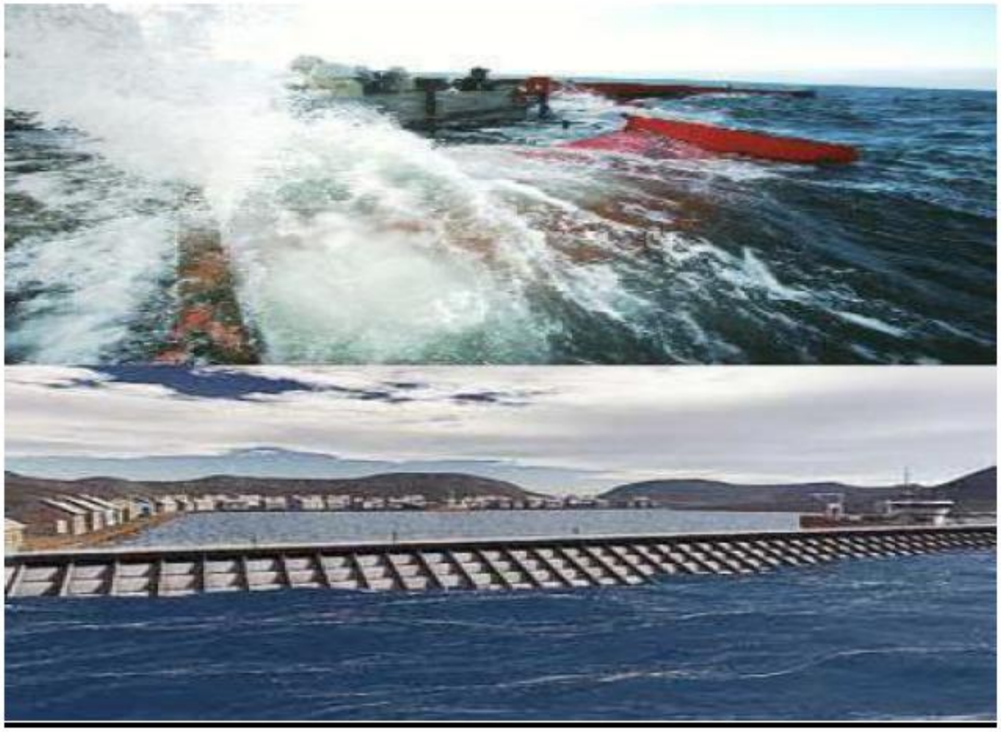


Figure 5: Different overtopping devices - Wave Dragon (Above) and SSG (Below) [29]

2.4 Point absorbers and Attenuator Buoys

A point absorber is a floating object that absorbs energy from all directions by moving near or on the water's surface. It converts the relative motion between the buoyant top and bottom into electrical energy. Depending on the reactor configuration, the power take-off mechanism will take on various forms. It consists of a floating frame with a fixed buoy within a cylinder that rises and falls in response to the height of the waves. The motion of bobbing activates a hydraulic system, which transforms the kinetic energy into usable electricity [34]. The inability of a point absorber to withstand extreme weather conditions is one of the drawbacks of its use. Wave Star ApS's WEC "Wave Star" attenuator has a variety of floaters mounted on adjustable arms [32]. Using a shared hydraulic connection, the motion-generated energy of the arms is captured and converted back into an electric current. This system can withstand extreme storm conditions because the entire structure can be raised along its pillars. This strategy has not yet been executed in its entirety. In Hanstholm, a system producing 600 kW at a scale of 1:4 has been constructed. However, it is believed that production could be increased to 6 MW. The minimal contact with water, which protects delicate machinery and electrical components from corrosion and physical force from the waves, is a significant advantage of these extraction methods [18].

Figure 6: The FO3 point absorber (above) and the Wave Star attenuator (Below) [2]

2.5 Wave Dragon

The Wave Dragon is an offshore floating device that directs ocean waves over a ramp and into a reservoir using two curved wave reflectors. Multiple turbines are used to discharge the water. Wave Dragon is designed to overflow water into the reservoir in order to increase the amount of energy generated. A large floating reservoir serves as the primary body or platform. The wave dragon is large and heavy to prevent the platform from rolling and maintain its stability. The total steel weight of the main body and ramp is 150 tons; therefore, 87 tons of water must be added to achieve the total weight of 237 tons required for operation stability [3].

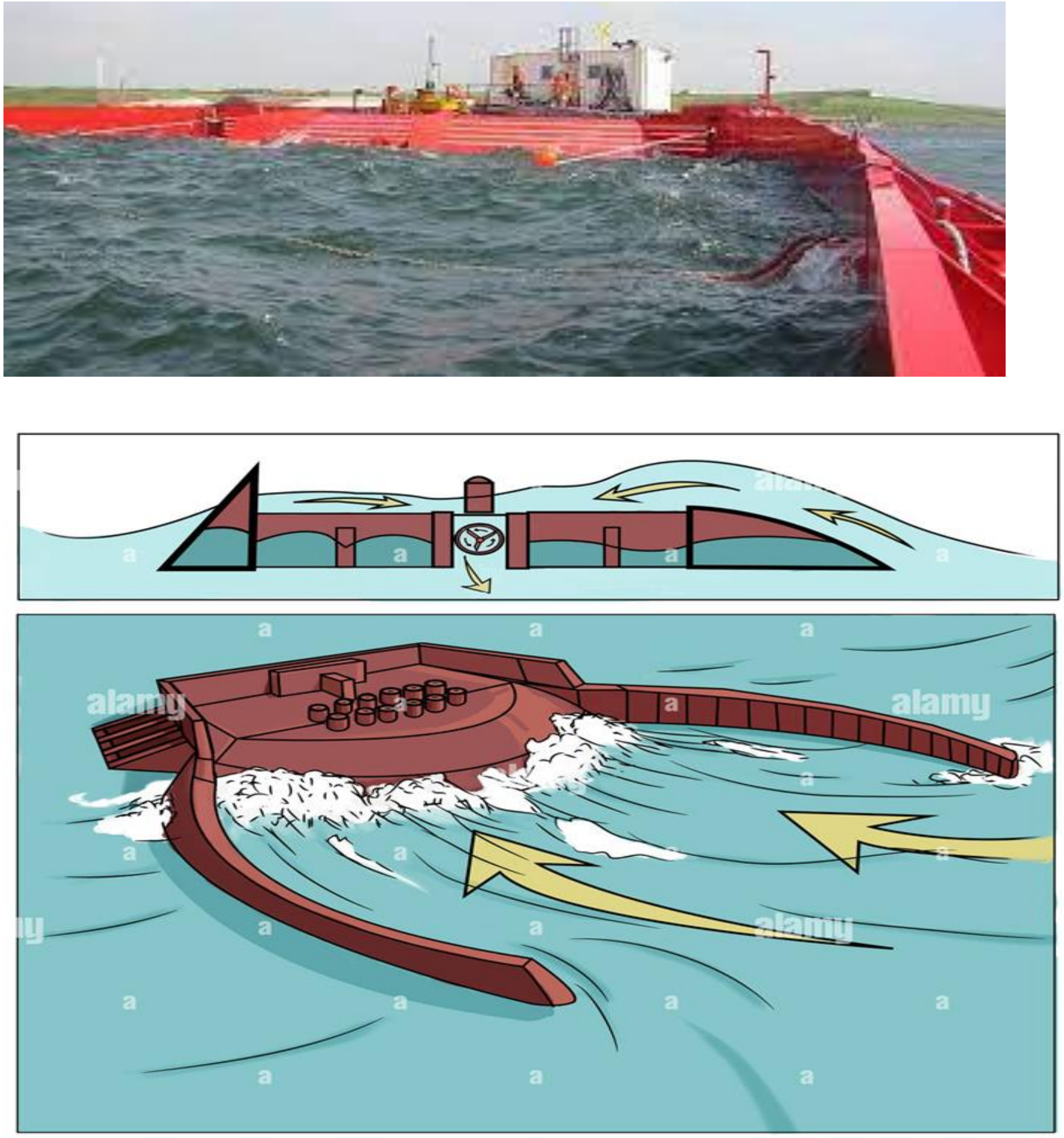


Figure 7: Wave Dragon [12]

2.6 Pelamis

Pelamis is an offshore, floating, slack-moored wave energy converter that consists of semi-submerged cylinders connected by hinged joints. Ocean waves perform work on Pelamis by repositioning adjacent cylindrical sections relative to one another across two joints with degrees of freedom. The two axes that comprise each joint are inclined relative to the horizontal to allow the power take-off system (PTO) to induce a net inclined response that resists and reacts against the relative angular motion of the joints. This motion is the source of the generation of electricity [11].

Figure 8: Pelamis [11]

Chapter 3

3.1 Swell and Wind Waves

Wind-driven ocean waves and swells are the two types of surface gravity waves. Wind seas and swells have distinctly dissimilar characteristics. Wind seas are locally generated, have a short wavelength, are inconsistent, and travel more slowly than surface wind. For growth, they require wind energy. In contrast, swells are typically generated remotely by distant wind, have a longer wavelength, consistent energy, and can travel thousands of kilometers without wind energy. In all oceanic regions, the sea state is a combination of wind seas and swells. Due to a lack of understanding of the energy composition of mixed waves, it is difficult to comprehend air-sea energy transfer [52-54].

3.1.1 Swell

These old wind waves are the result of weakening winds or a change in the wind's direction. Wind waves are renamed swell waves once they leave the area where they originated. Despite the fact that nothing is pushing the wind waves, they still possess momentum. Since wind energy is no longer being added to the waves, the waves will gradually die out, but it will take time; in the meantime, they will become swell. This may seem odd; if they are identical, how can they be distinguished? Well, we've already covered wave heights and periods, but they're particularly applicable here. As swell waves travel, the wave height will decrease, the wave period will increase (and travel a bit faster), and consequently the wave length will also increase over time [48, 51].

Figure 9: Ocean swell [49]

Additionally, its direction is frequently distinguishable, as it does not typically originate from the same direction as the wind. As the surface of the water is comprised of waves of varying heights and periods, it would require practice to distinguish wind waves and/or swell waves from the other waves. Finding swell on a day with calm winds and no wind waves may be the most straightforward method. When the sea surface is calm and the wind suddenly picks up, there will be no wind waves for a brief period of time [61].

3.1.2 Wind Wave

The wind is the source of wind waves, which are generated by the wind. A small portion of the wind's energy will be transferred to the water as a result of the friction between the two fluids, air and water. This excess pressure on the windward side of the waves relative to the pressure on the leeward side is caused by the friction between the two fluids. The energy will then travel as a wave across the surface of the water. There is a unique relationship between wind velocity and the resulting wave height, similar to how kicking a football with varying force will result in different distances traveled. This relationship is dependent on the surrounding environment and is not always valid. If the wind speed is the same, coastal waves may be smaller than open water waves. This is especially true when the wind is blowing from the land and the fetch (the distance the wind travels across open water) is short. Wind waves always travel in the same direction as the wind, as it is the wind that propels them forward [43].

Figure 10: Wind Waves [45]

3.1.3 Energy Density of the Wind Sea and Swell Waves

In the majority of seas, swell carries over fifty percent of the wave energy. Ws demonstrates a distinct zonal banding distribution. The calm belt close to the equator and the subtropical high pressure belts close to 30°N and 30°S have low seasonality and high Ws values (over 90 percent). Seasons significantly influence the spatial distribution of low Ws (50 to 60 percent). From December to February, it is governed by the northern westerlies, whereas in July and August, it is governed by the southern westerlies. Ws is lower along the eastern continental coasts (50 percent) than the majority of western coasts (>90 percent), which relates to wave transport and reflects the enhancement of swell energy along the western continental coasts[39,40].

3.1.4 Frequency of Occurrence High Swell (Wind Sea) Energy Areas

In the global wave fields, there are distinct regions that are dominated by either high or low values of swell or wind sea energy. Researchers have analyzed both types of waves and concluded that swells have a greater impact on energy production than wind waves. Consequently, it is essential to understand the density of swell in a particular region. It is estimated that more than fifty percent of swell energy is contained within wave energy in the majority of the world's regions. Depending on their energy density, waves can be further divided into four groups: • Swell Waves • Wind Sea • Dominant Waves • Dominant Wind Sea [41, 43].

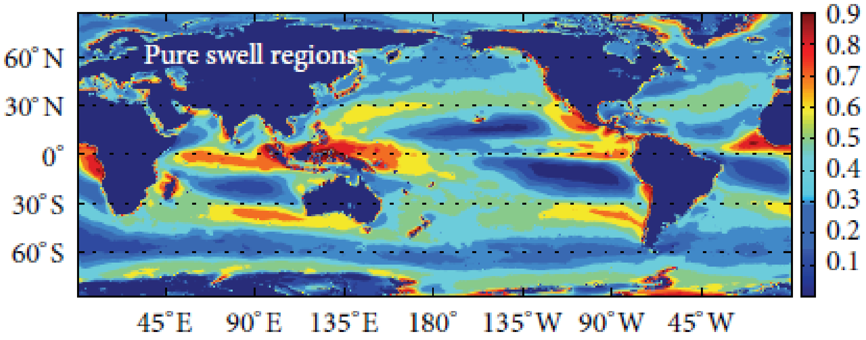


Figure 11: The distribution and frequency of occurrences of pure swell areas [41].

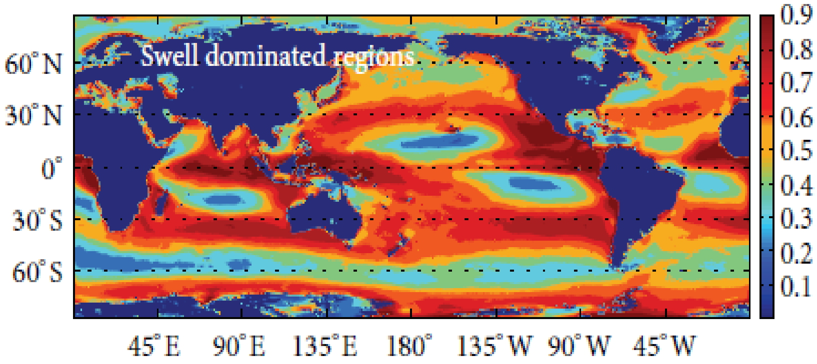


Figure 12: The distribution and frequency of occurrences of swell dominated areas [41].

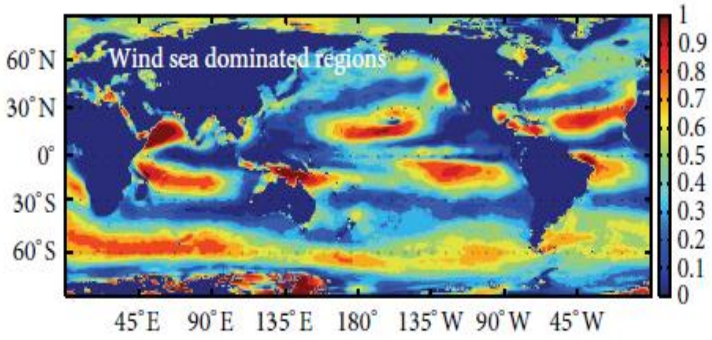


Figure 13: The distribution and frequency of occurrences of Wind Sea dominated areas. [41]

Ws of pure swell area is 100%, swell dominated area ranges between 50% and 100%, and wind sea dominated area ranges between 0% and 50%. Extremely uncommon in the wave fields of the world's oceans are wind sea regions. In closed or partially closed seas, there may be a few small areas of pure wind. High-frequency swell-dominated regions are far from the regions that generate swells (the westerly sea storm regions in the south Pacific, south Atlantic, and southern Indian Ocean), but close to regions with low wind speed [41, 45]. Strong seasonality was observed in the distribution of wind-dominated sea areas, which only occurred in June, July, and August. The majority of wind-dominated sea regions (over 90 percent) are located in the southern, westerly-controlled regions. In a region east of Australia (affected by the southeast trade winds in the northern hemisphere), the Arabian sea (affected by the Indian summer monsoon), and mid-latitude regions in the northern Pacific and northern Atlantic Oceans, three wind sea dominated regions occur frequently (over 80% of the time) (affected by the southwest trade winds in the northern hemisphere).

In addition, it is crucial to understand how swell and wind can affect the device's power output. This requires an understanding of directional spreading and directional width [9].

3.1.5 Directionality of Waves

In various media, waves travel in opposite directions. "Wave directionality" refers to the capacity to influence the directional behavior of waves. It simply means that we are able to control the wave's propagation direction and modify it accordingly. According to the study of wave propagation, the majority of the directional properties of a wave are determined by its group velocity. In recent studies, the directionality of the wave's propagation has been analyzed by taking the group velocity into account [25].

Additionally, band gap research has been conducted (the portion where the propagation of the waves at a particular range of frequencies is prevented). Therefore, based on the concepts of directionality, the directional behavior of waves can be studied and manipulated to meet specific needs.

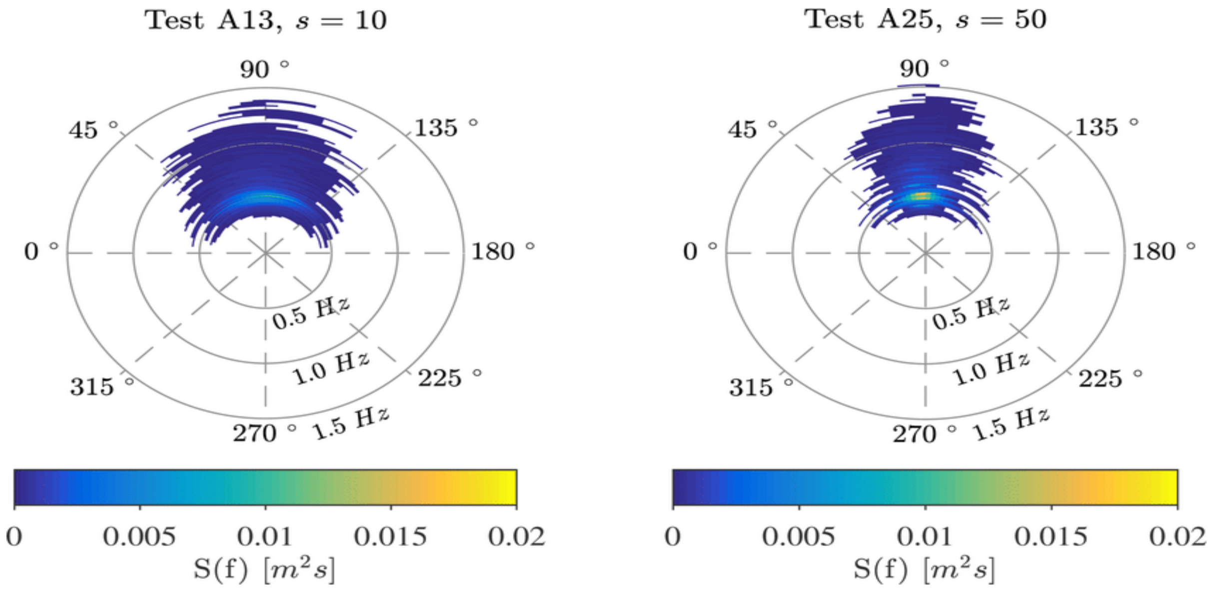


Figure 14: Directional wave spreading for multidirectional waves. **[25]**

For the image on LHS the directional spreading is from 45° to 135°. The mean wave direction is 90°. The directional width is also 90°.

For the image on RHS the directional spreading is from 60° to 120°. The mean wave direction is 90°. The directional width is 60°. [23, 24]

3.1.6 Directional Width

Wind-generated waves have no particular direction. Typical wind wave spectra exhibit a directional dispersion relative to the wind direction. Frequently, parametric models such as, where the angle of wave propagation relative to wind direction is, are used to represent his directional spreading. This model predicts that the directional spectrum is greatest in the direction of the wind and decreases gradually as the angle to the wind's direction increases [26]. The directional width value is 0° for waves with a long crest, and as the crest becomes shorter, the value increases, causing the wave direction to spread. The average value of directional width appears to be smaller during the southwest monsoon than during other times of the year [27].

Prior to and after the monsoon, relatively large values of directional width are observed due to the coexistence of swells and seas. Directional spreading is minimal at the peak frequency (fp), and it increases both above and below fp. The average ratio between the directional widths at twice the peak frequency and those at the peak frequency is 1.9, indicating that the directional width increases as frequency increases [31].

Due to the peak frequency being in a narrow frequency range, the low values of directional width during the Swell Wave monsoon period are restricted to a smaller frequency range (0.08–0.15 Hz). During the pre-monsoon season (February to May), low values of the directional width occur at either low or high frequencies, depending on whether swell or wind sea predominates. When swell dominates, the directional width is low at low frequencies, whereas when wind sea dominates, it is low at high frequencies [32]. At the southern location, directional width values are relatively smaller than at the northern location (annual average = 23.7° versus 25.3°).

According to Snell's law, both the mean wave angle and the directional spread (the range of wave angles) decrease with depth. At 9 meters, the wave height is less than at 30 meters. The range of mean wave direction at 9m (210–250°) is more constrained due to refraction than at 30m (190–250°). At a depth of 9 meters, due to the wave period, waves from 210° in deep water change direction to 217–242°. These waves have a mean wave direction greater than 270° and a directional width of less than 40°. The waves with an average wave direction of less than 240 degrees are predominantly swells with directional widths exceeding 40 degrees [9, 21]. Regarding the numerous research papers, there have been few observations:

- For swell wave: directional width > 30°, Tp > 8s, Hm < 2 m.
- For wind sea: directional width > 30°, Tp > 8s, Hm < 2 m.
- For swell dominated area: average directional width > 40°.
- For wind sea dominated area: average directional width < 40°**. [9,21,22]**

Extensive research and modeling have yielded these data, which are consistent with the general consensus of researchers who have conducted work in this field.

Further research has concluded that:

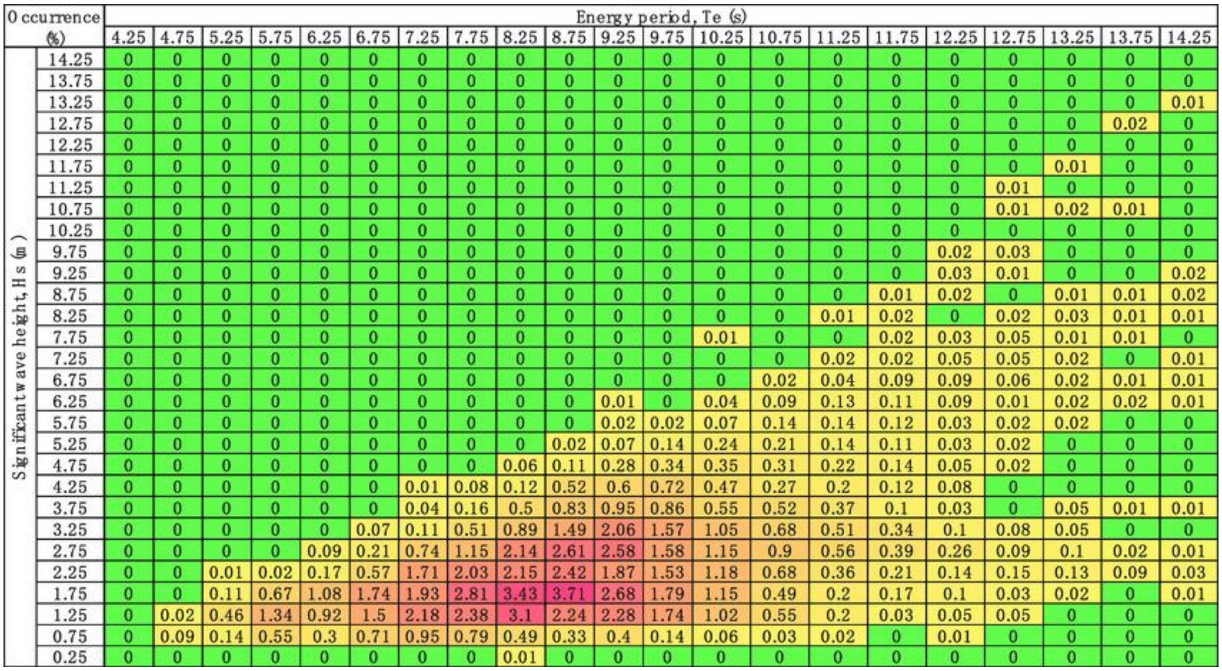
- The variable directionality of swell and wind waves has an effect on the wave frequency.
- If swell is predominant, the directional width at low frequency is narrow.
- If Wind Sea dominates, the directional width at high frequency is narrow [9, 41].

3.2 Sea States

The accuracy of the sea state is dependent on the observer's subjective ability to convert local wind waves into numerical scales. It is the oscillation of the ocean's surface (waves) caused by wind energy. The significant wave height (Hs), which is defined as the mean wave height of the upper third of the wave height distribution, is utilized as a measure of the sea state's intensity. It provides an analytical tool for estimating the impact of the ocean on operational security and data quality. Frequently, tasks that rely on the characteristics of the local sea surface require a precise and immediate evaluation. A manual containing the power matrix is always included when a WEC is created [32].

Significant wave height (H_{sig}, m)		Power period (T_{pow}, 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
	0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
	1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
	1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
	2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
	2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
	3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
	3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
	4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
	4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
	5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
	5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
	6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
	6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
	7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
	7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
	8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

Table 1: Power Matrix of WEC [32]



0 ccurrence (%)		Energy period, Te (s)																				
		4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10.25	10.75	11.25	11.75	12.25	12.75	13.25	13.75	14.25
Significant wave height, Hs (m)	14.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
	12.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0
	12.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0
	11.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0
	10.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0.01	0
	10.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.03	0	0	0
	9.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.01	0	0	0.02
	8.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0.01	0.01	0.02
	8.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0.02	0.03	0.01	0.01
	7.75	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.02	0.03	0.05	0.01	0.01	0
	7.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0.05	0.05	0.02	0	0.01
	6.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.04	0.09	0.09	0.06	0.02	0.01	0.01
	6.25	0	0	0	0	0	0	0	0	0	0	0.01	0	0.04	0.09	0.13	0.11	0.09	0.01	0.02	0.02	0.01
	5.75	0	0	0	0	0	0	0	0	0	0	0.02	0.02	0.07	0.14	0.14	0.12	0.03	0.02	0.02	0	0
	5.25	0	0	0	0	0	0	0	0	0	0.02	0.07	0.14	0.24	0.21	0.14	0.11	0.03	0.02	0	0	0
	4.75	0	0	0	0	0	0	0	0	0.06	0.11	0.28	0.34	0.35	0.31	0.22	0.14	0.05	0.02	0	0	0
	4.25	0	0	0	0	0	0	0.01	0.08	0.12	0.52	0.6	0.72	0.47	0.27	0.2	0.12	0.08	0	0	0	0
	3.75	0	0	0	0	0	0	0.04	0.16	0.5	0.83	0.95	0.86	0.55	0.52	0.37	0.1	0.03	0	0.05	0.01	0.01
	3.25	0	0	0	0	0	0.07	0.11	0.51	0.89	1.49	2.06	1.57	1.05	0.68	0.51	0.34	0.1	0.08	0.05	0	0
	2.75	0	0	0	0	0.09	0.21	0.74	1.15	2.14	2.61	2.58	1.58	1.15	0.9	0.56	0.39	0.26	0.09	0.1	0.02	0.01
	2.25	0	0	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
	1.75	0	0	0.11	0.67	1.08	1.74	1.93	2.81	3.43	3.71	2.68	1.79	1.15	0.49	0.2	0.17	0.1	0.03	0.02	0	0.01
	1.25	0	0.02	0.46	1.34	0.92	1.5	2.18	2.38	3.1	2.24	2.28	1.74	1.02	0.55	0.2	0.03	0.05	0.05	0	0	0
	0.75	0	0.09	0.14	0.55	0.3	0.71	0.95	0.79	0.49	0.33	0.4	0.14	0.06	0.03	0.02	0	0.01	0	0	0	0
	0.25	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0

Table 2: Power Matrix of Sea States [32]

The Grid boxes in the table to LHS of the previous page the power matrix shows how much Electrical Power the converter will produce in each sea state. This means that for that particular sea state the device will produce some amount of electrical power per meter of wave-front. The Grid boxes in the table to RHS of the previous page the power matrix shows the Occurrence of each sea state throughout the year. The occurrence shows the percentage of time that this particular sea state will occur at that region [32].

3.3 Shore location

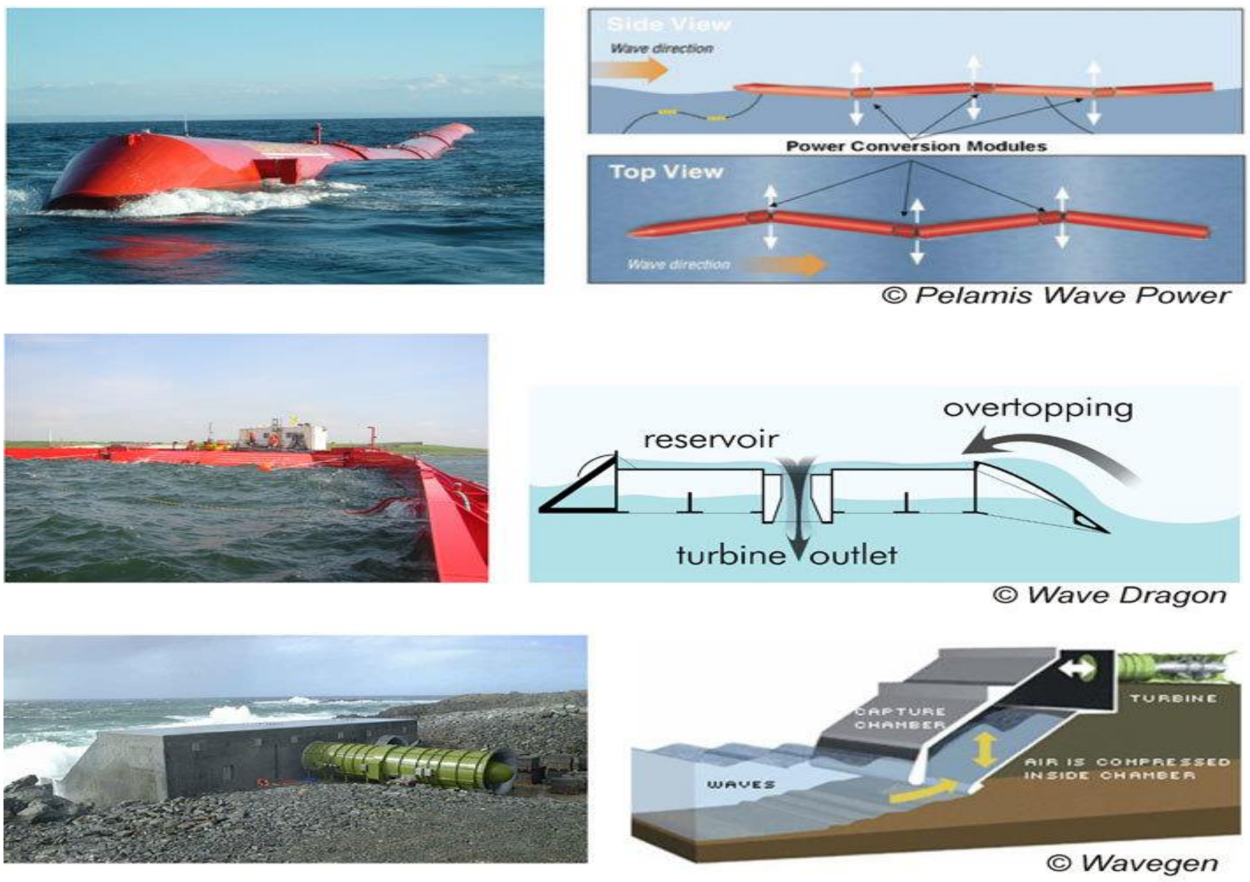
Onshore devices are built and installed on land. The location may be on the coast or within structures such as breakwaters. In most cases, adjacent depths are less than 15 meters. These devices are ideal for locations where the shoreline is located on a rocky platform with steep bathymetry. On the south coast of Efate, these geological features can be found [60].

Near shore WECs: Near shore devices convert near shore wave energy into electricity at an inland facility. These devices are typically attached to the seafloor, which creates an ideal environment for oscillating bodies to operate. Examples of such devices include the 2005, 2003, and 2007 proposals for Oyster, Archimedes Wave Swing (AWS), and Searaser, among others. Oyster converts the energy from near-shore waves into electricity. Oyster is a wave-powered pump that propels high-pressure water to a land-based hydroelectric turbine [57].

Offshore energy converters are deployed without a land-based installation in deep waters (Between 30 m and 100 m). These instruments, which are sometimes classified as devices of the third generation, are classified as oscillating bodies. Offshore wave energy converters are typically more complex due to issues with mooring points, maintenance, and underwater electrical cables. However, in recent years a few have been effective [31].

The efficiency and cost of wave energy converters vary. The cost of operation and maintenance, as well as the effect on the environment, can vary greatly, making it difficult to determine which location would benefit most from a specific device type. Due to the fact that not all wave energy converters are at the same stage of development, it is impossible to compare their prices and efficiencies. Other, more advanced wave energy converters, on the other hand, have a measured (i.e., verified) efficiency. Prior studies indicated that the gross near shore wave energy resource is significantly less than the gross offshore wave energy resource, suggesting that the deployment of wave energy converters in the near shore is unlikely to be economically viable [32]. It is argued, however, that the gross wave energy resource is not an appropriate metric for determining the productivity of a wave farm, and the exploitable wave energy resource is proposed as a replacement metric.

Calculating a site's potential using the exploitable wave energy resource is deemed superior because it accounts for the directional distribution of the incident waves and the wave energy plant rating, which limits energy capture in highly energetic sea states [31].



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© Wave Dragon

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Figure 15: Converters at different shore locations [32].

The majority of wave energy converters (WECs) have been designed as offshore devices, where wave energy densities are greatest. Deployment of WECs in the near shore has often been disregarded due to the lower gross energy densities, without further consideration of the differences between offshore and near shore wave energy resources; the near shore resource has often been viewed as a less energetic version of the offshore resource. However, the interaction of the seafloor with incident waves and surrounding landmasses modifies the characteristics of the wave climate from offshore to near shore, so a simple scaling of the wave climate is inadequate to describe the near shore wave climate [7].

To accurately evaluate the wave energy resource potential of the nearshore, a more accurate representation is required. Even though it has been years since the first WEC was deployed, the debate between Near-shore and Off-shore WECs continues. However, research conducted over the years has uncovered several significant differences between the two [10].

Near-shore

The waves' Energy Density is stable.

The possibility of storm-related damage is minimal.

The costs of mooring are minimal.

Maintenance is effortless. [8-10]

Off-shore

Significant Wave Height in excess of the Hs value. [9]

Wave amplitude has increased.

Period of Time is variable.

It is not reliable. [10]

The price of docking is expensive.

The weather conditions are severe. [8-10]

How these variations affect the power performance of a Near-shore and Off-shore WEC is still unknown. There is no conclusive evidence to suggest a substantial difference in power production, despite the fact that there are a number of key differences. The justification lies in the following figure:

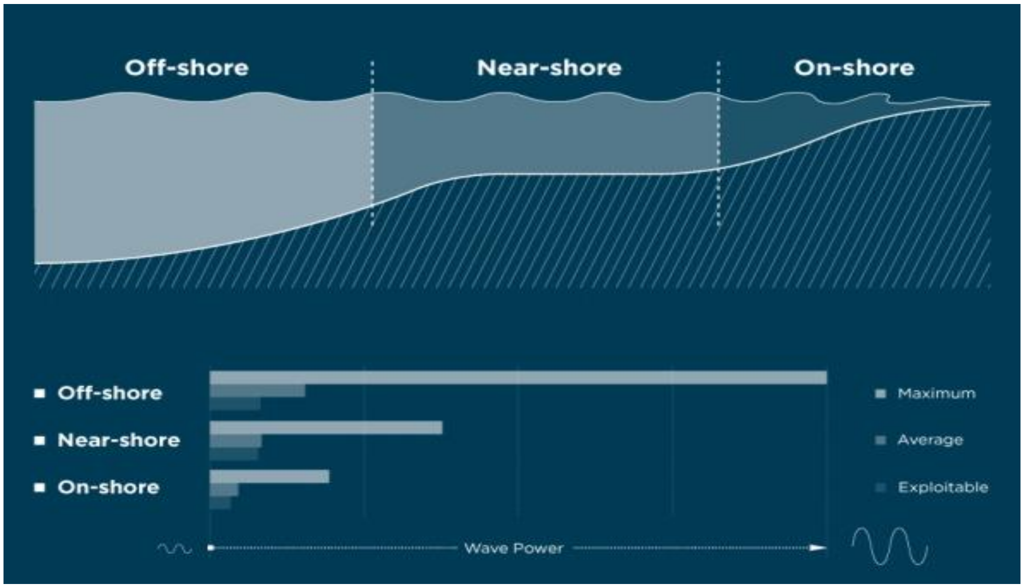

Figure 16: Power index [16]

For an Off-shore WEC, the maximum available wave power may be significantly higher, but the exploitable wave power for Near-shore and Off-shore WECs is comparable for the following reasons:

Since the density of the waves is inconsistent, the majority of their energy cannot be utilized. The waves do not sustain themselves. Their frequency and directionality differ significantly. Predicting the wave period and wave height is difficult. [13] As a result, it is difficult to match the sea state's power matrix. [14] Due to the disparity in the power matrix between the WEC and the sea states, it is challenging to operate the WEC under optimal conditions. [11, 13]

When all of these factors are considered, the effect on productivity is nearly identical for Near-shore and Offshore.

3.4 Kinetic and Potential Energy

The wind that blows across the surface of the ocean causes waves to form. In many regions of the world, the wind is consistent and strong enough to generate continuous waves. In waves, both kinetic and potential energies are present. Potential energy is proportional to the amount of water that is displaced from the mean sea level. Waves consist of both Kinetic energy and Potential energy. Kinetic energy is carried by the movement of water particles, while potential energy is carried by the position of a wave.

Everyone is aware of this fact; however, the proportions of kinetic and potential energies in a wave depend on the shape of its orbit. [15] Researchers have been attempting to comprehend the dynamics of the energy contained within a wave in order to determine if this knowledge will allow them to utilize the wave's potential more effectively. Currently, we understand that the power conversion unit within WEC converts the energy within a wave into electrical energy, but the mechanism for extracting this energy varies. This is significant because we need to determine which of the two types of energy the converter utilizes. As there are numerous converter technologies, each has a preferred energy source. Consequently, it is essential to comprehend the proportion of each type of energy in a wave and the type of converter that makes the most efficient use of each type of energy. In this regard, we have found that the proportion of kinetic and potential energy is dependent on the orbital shape of the wave.

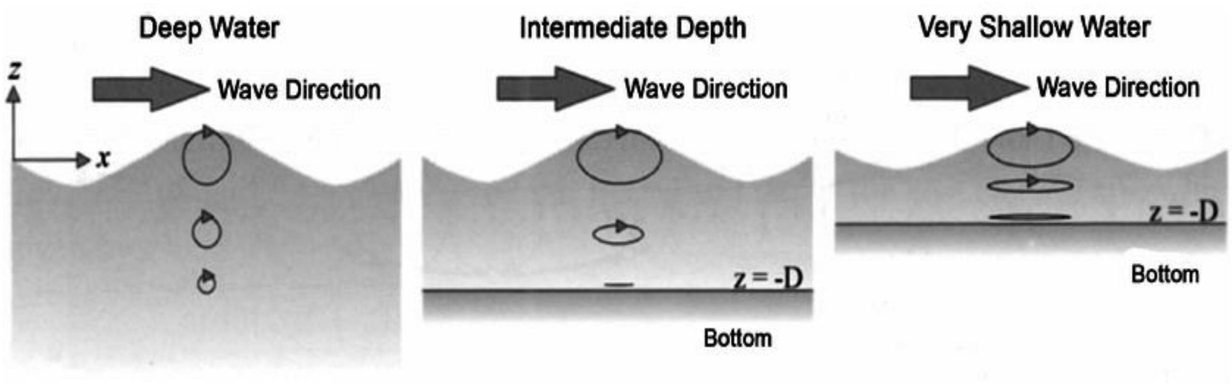

Figure 17: Shape of Wave Orbit at Different Depths [16]

The wave will travel along the vertical axis more if its shape is more circular and it will contain more kinetic and potential energy. However, if its shape is elliptical, it indicates that the wave will travel more horizontally and have less energy. Waves in deep water have a more circular orbit, which causes them to have a greater vertical displacement. These waves possess a greater kinetic and potential energy. [17] As waves approach shallow water, the shape of their orbit becomes more elliptical. It moves more horizontally than vertically. These waves' potential energy is decreasing [17]. More devices that utilize the potential energy of waves are deployed in deeper water.

For this reason, Aqua Buoy, AWS, Oyster2, Pontoon, Wave Bob, and Wave Star are deployed in deep water or offshore. [15, 17, 18]. Attenuators such as Pelamis, Sea based AB, and Ocean tec are among the devices that require the wave's kinetic energy [15, 17, 18].

The remainder of known WEC devices make variable use of both types of energy.

3.5 Installation Depth

A converter's installation depth is a crucial characteristic. It is crucial to comprehend at what depth we must deploy the converters in order to extract the maximum amount of energy, given that waves are constantly breaking and difficult to predict. To comprehend this, the performance of various Wave Energy Converters installed at varying depths must be evaluated. There may be a variety of methods for evaluating this performance, but the vast majority of research has used these parameters to evaluate the performance at various depths. HeaveBuoy, AquaBuoy, HeaveBuoy, OEBuoy, Oyster, Pontoon, Pelamis, Oceantec, Seabased AB, SSG, WaveBob, AWS, Oyster2, SSG, WaveDragon, Langlee, and WaveStar are among the fifteen distinct WECs taken into account in the methodology for a comprehensive analysis [12].

This paper examines the capacity factor (cf), capture width (Cw), and the ratio of the expected annual wave energy to the rated power of the considered WECs (REP) and dimensionless normalized wave power to analyze the wave energy at specific locations (PEn).

The cf is the ratio between the total electrical energy produced by a device and its nominal power (Pn) during the same time period [17].

Understanding the performance of a device's power generation is dependent on the capacity factor, which reveals how much of the device's total capacity is utilized to generate electricity in a given situation. In addition, it provides the ratio of full-load operating hours during a specified time interval. The capacity factor is computed by using the following equation:

$$c_f = \frac{P_E}{P_n}$$

The capture width is an additional important energy capture parameter (Cw). It is the ratio between annual predicted wave power and annual theoretical wave power (Pw). Using the following equation, its unit, which is measured in meters, can be determined:

$$c_w = \frac{P_E}{P_w}$$

Dimensionless PEn was independently analyzed for each WEC at each location considered in order to provide a more comprehensive analysis of the geographic disparities in anticipated electric power for each WEC considered [18-20].

The PEn compares a converter performance to itself in different locations and is computed using the formula:

$$P_{En} = \frac{P_E}{P_{ET_{\max}}}$$

PE is defined as the estimated absorbed wave power at representative sites for the device under consideration, whereas PETmax is the geographically maximum value that varies based on the location where the device is operated.

All of these parameters are ratios between different types of power. A rise in the capacity factor indicates a rise in electrical power production. Increasing the capture width increases the amount of wave energy the converter can absorb. When the Dimensionless Normalized Wave Power rises, the amount of wave power that can be exploited also rises. These parameters will assist us in determining how the performance of each converter varies at different installation depths. Consequently, we are able to determine which device performs better at a given depth [24-26].

In order to comprehend and evaluate the performance of the Wave Energy Converters, tests are conducted in a different geographical location whose origin is known to us, but the Wave Energy Converters' performance is evaluated in our own environment.

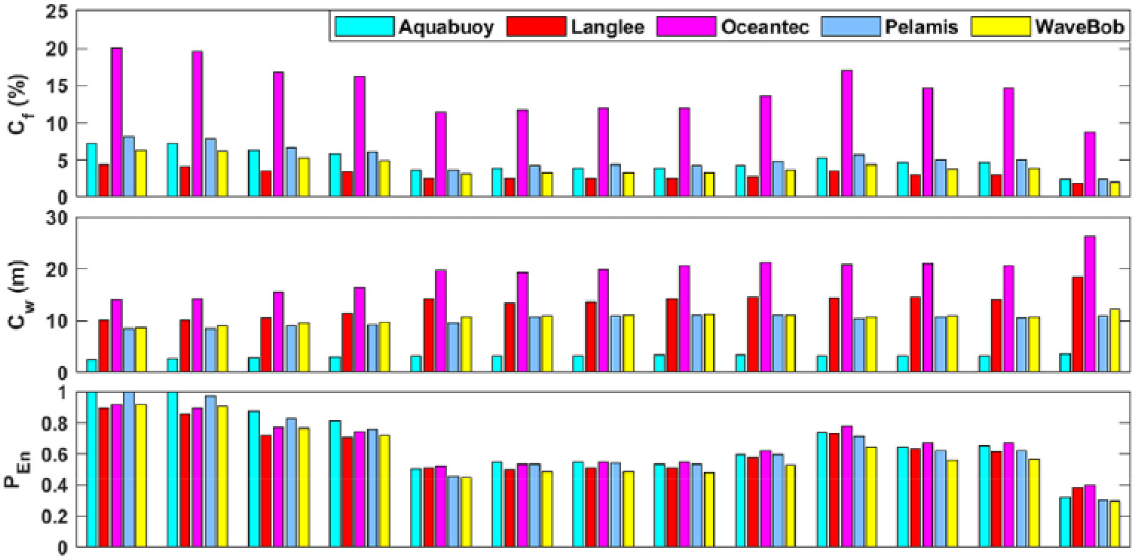

Figure 18: The mean changes of capacity factor Cf, capture width Cw, normalized wave power PEn at a depth of 68-77 m of Aqua Buoy, Langlee, Ocean tec, Pelamis and Wave Bob WEC technologies.**[1]**

3.6 Potential Wave Energy

The Wave Energy Potential of a region is the most significant factor in determining which type of WEC should be deployed in a particular location. Rated power, also known as Nominal Power, is provided by the manufacturer for each WEC device. Regardless of the abundance of the device's energy resources, it is understood that the device will not be able to generate any additional electrical energy above this threshold. In order to design a device with the capability to match the energy potential, it is always necessary to investigate the wave energy potential of a region. The energy profiles of waves are proportional to the intensity and persistence of the wind speed, as well as to the size of the fetch region where the wind is most prominent. Between 30 and 60 degrees latitude are the most energy-attractive regions in both hemispheres, with a total theoretical energy potential of approximately 32,000 TWh per year. In order to better quantify the wave energy potential, numerous monitoring systems have become operational over the past few decades. Satellites orbiting on a predetermined path are an additional source of measurements, sometimes integrating multiple missions into a multi-mission project that compiles a homogeneous data set with a high temporal and spatial resolution [42].

Noting that the accuracy of the beam signal is affected by coastal and island contamination (land presence), the data set may have missing values. Increased data collection opportunities for wave prediction are made possible by modern, powerful computers. It is now feasible to create numerical models on a global and local scale. Combining a localized wave model with data assimilation techniques results in a more precise description of wave conditions, according to new research.

Despite the fact that North American sites contain more significant resources, the majority of WEC research originates in Europe [43]. It has been observed that the wave energy is most consistent around Australia, followed by the United States and Chile, whereas Portugal and France have much lower values. Possible explanations for the results include the fact that the entire coastline of Australia, North America, and Portugal was analyzed for this study [60].

Chapter 4

METHODOLOGY

The purpose of the study was to determine how some of the selected factors affect the performance of converters and which types of Wave Energy Converters are affected by these factors more or less. In order to comprehend this, we evaluated the performance of multiple converters at varying installation depths using a year's worth of wave data from the Saint Martin Islands. This was done with the hope that we would be able to use what we learned from this review to determine the type of Wave Energy Converter that is best suited to the climate of Saint Martin[21]. Therefore, it was necessary for me to acquire additional Wave Energy Converters after data collection. To demonstrate how Installation Depth affects Efficiency and Power Performance, it is necessary to identify the pertinent parameters in a real-world setting [27].

In this case, the true scenario is represented by the wave data collected on the Saint Martin islands in 2021. Only a handful of WECs that perform well in near-shore conditions were selected for this scenario. This is because the collected data concerned wave behavior along the coast. An annual data set is used to collect information regarding the significant wave height, the average wave period, and the dominant wave period. In order to select them, we therefore tabulated information regarding suitable converters [38].

WEC	Efficiency	Wave Energy Potential
Aqua Buoy	20%	12 kW/m
	21%	15 kW/m
	17%	21 kW/m
	14%	26 kW/m
Pelamis	14%	26 kW/m
	15%	21 kW/m
	18%	15 kW/m
	21%	12 kW/m
Wave Bob	40%	12 kW/m
	45%	15 kW/m
	46%	26 kW/m
	51%	21 kW/m
Wave Dragon	27%	6 kW/m
	18%	24 kW/m
	23%	16 kW/m
	21%	26 kW/m
	22%	15 kW/m

Table 3: Wave Energy Potential and Efficiency of WEC [11, 14, 15, 19-21]

WEC	Efficiency	Width
LangLee	7%	25 m
	9%	37.5 m
Oyster 2	15%	18 m
	22%	6 m
	40%	12 m
Oyster	35%-65%	6 m-24 m
Wave Dragon	27%	65 m
	18%	97 m
	23%	300 m
	21%	300 m
	22%	300 m

Table 4: Device Width and Efficiency of WEC [11, 14, 15, 19-21]

This shows the list of converters that give different efficiency based on the capture width.

WEC	Nominal Power
Aqua Buoy	250 kW
AWS	2470 kW
Heave Buoy	2192 kW
Langlee	1665 kW
Ocean tec	500 kW
OE Buoy	2880 kW
Oyster2	3332 kW
Pelamis	750 kW
Pontoon	3619 kW
Sea based AB	15 kW
Wave Bob	1000 kW
Wave Dragon	7000 kW
Wave Star	2709 kW
SSG	20000 kW

Table 5: Rated Power for WECs [11-13, 37-40]

This chart shows the rated capacity of the converter.

So, the methodology used here is that in order to understand and evaluate the performance of the Wave Energy Converters ourselves but in a geographic location that is of known origin to us. So, we gathered the wave data for Saint Martin for the year 2021, and used it to find the capacity factor, capture width and dimensionless wave power. To find these factors we used the average wave period, wave height and dominant wave period for a year.

The data that was used to evaluate the performance is for waves that are along the shoreline. So, these data can correspond to wave data at depths of 5-20 m. So, the converters that are selected are built for near shore and on shore conditions.

Year	Month	day	Hour	Wave Speed	Wave Height	Average Wave Period	Dominant Wave Period	Wave Power (Watt)
			hr	(m/s)	m	sec	sec	P_w
2022	1	1	0	5.4	1.64	7.29	13.79	9666.592829
2022	1	1	1	4.9	1.85	7.89	12.9	13313.08367
2022	1	1	2	4.9	1.78	7.49	12.12	11699.84272
2022	1	1	3	4.3	1.81	7.86	12.9	12695.15177
2022	1	1	4	3.7	1.67	7.6	12.9	10449.72198
2022	1	1	5	4.5	1.84	7.88	12.9	13152.85599
2022	1	1	6	4.2	1.75	7.71	12.9	11640.95678
2022	1	1	7	3.1	1.72	8.02	12.12	11697.4033
2022	1	1	8	2.9	1.78	7.94	12.9	12402.77052
2022	1	1	9	3.9	1.57	7.34	12.9	8919.768154
2022	1	1	10	3.4	1.76	8.18	12.9	12492.13994

2022	1	1	11	3.3	1.67	7.91	11.43	10875.96064
2022	1	1	12	2.6	1.54	7.8	12.12	9119.987557
2022	1	1	13	2.3	1.56	7.96	12.9	9550.375906
2022	1	1	14	2.3	1.61	8.42	12.12	10760.24215
2022	1	1	15	2.3	1.61	8.25	12.12	10542.99261
2022	1	1	16	2.7	1.6	8.42	12.9	10626.98967
2022	1	1	17	2.6	1.66	8.47	12.12	11506.8854
2022	1	1	18	3	1.5	8.43	11.43	9351.220424
2022	1	1	19	3.4	1.55	8.25	12.9	9771.821975
2022	1	1	20	1.1	1.61	8.21	10.81	10491.87507
2022	1	1	21	1.4	1.56	8.25	11.43	9898.316736
2022	1	1	22	1.9	1.51	7.97	12.9	8959.224462
2022	1	1	23	1.6	1.52	7.87	12.9	8964.376939
2022	1	2	0	4.8	1.5	8.19	12.12	9084.993508
2022	1	2	1	5.9	1.53	7.42	13.79	8563.375111
2022	1	2	2	5	1.66	7.38	11.43	10026.07016
2022	1	2	3	4.2	1.61	7.16	9.09	9150.039646
2022	1	2	4	4.9	1.77	7.37	12.12	11383.4059
2022	1	2	5	5.5	1.87	7.6	12.12	13102.52529
2022	1	2	6	6.5	1.84	7.54	12.12	12585.34697

Table 6: A sample of the data collected for Saint Martin

4.1 Performance of Wave Energy Converters at Saint Martin at 5-20 m Installation Depth

Wave Height	Dominant Period	Average Period	Wave Power	Geographically Max. Wave Power	Electrical Power Generated	Capacity Factor	Dimensionless Normalized Wave Power
m	sec	sec	W	W	W		
H_w			P_w	P_{ETmax}	P_E	C_f	P_{EN}
1.64	13.79	7.29	9666.59	18285.64	1933.32	0.007733274	0.53
1.85	12.9	7.89	13313.08	21766.64	2662.62	0.010650467	0.61
1.78	12.12	7.49	11699.84	18932.19	2339.97	0.009359874	0.62
1.81	12.9	7.86	12695.15	20835.55	2539.03	0.010156121	0.61
1.67	12.9	7.6	10449.72	17737.03	2089.94	0.008359778	0.59
1.84	12.9	7.88	13152.86	21531.96	2630.57	0.010522285	0.61
1.75	12.9	7.71	11640.96	19477.09	2328.19	0.009312765	0.60
1.72	12.12	8.02	11697.40	17677.37	2339.48	0.009357923	0.66
1.78	12.9	7.94	12402.77	20150.60	2480.55	0.009922216	0.62
1.57	12.9	7.34	8919.77	15676.43	1783.95	0.007135815	0.57
1.76	12.9	8.18	12492.14	19700.32	2498.43	0.009993712	0.63
1.67	11.43	7.91	10875.96	15715.83	2175.19	0.008700769	0.69

Table 7: Performance of Aqua Buoy

Wave Height	Dominant Period	Average Period	Wave Power	Geographically Maximum Wave Power	Electrical Power Generated	Capacity Factor	Dimensionless Normalized Wave Power
m	sec	sec	W	W	W		
H_w			P_w	P_{ETmax}	P_E	C_f	P_{EN}
1.64	13.79	7.29	9666.59	18581	676.66	0.000406403	0.52
1.85	12.9	7.89	13313.08	10064	931.92	0.000559709	1.32
1.78	12.12	7.49	11699.84	17553	818.99	0.000491885	0.67
1.81	12.9	7.86	12695.15	18207	888.66	0.00053373	0.70
1.67	12.9	7.6	10449.72	10862	731.48	0.000439328	0.96
1.84	12.9	7.88	13152.86	13249	920.70	0.000552973	0.99
1.75	12.9	7.71	11640.96	13969	814.87	0.00048941	0.83
1.72	12.12	8.02	11697.40	10372	818.82	0.000491783	1.13
1.78	12.9	7.94	12402.77	13009	868.19	0.000521438	0.95
1.57	12.9	7.34	8919.77	19292	624.38	0.000375005	0.46
1.76	12.9	8.18	12492.14	19579	874.45	0.000525195	0.64
1.67	11.43	7.91	10875.96	20601	761.32	0.000457248	0.53
1.54	12.12	7.8	9119.99	16345	638.40	0.000383423	0.56
1.56	12.9	7.96	9550.38	23348	668.53	0.000401517	0.41

Table 8: Performance of Langlee

Wave Height	Dominant Period	Average Period	Efficiency	Wave Energy Potential	Wave Power	Geographically Maximum Wave Power
m	sec	sec	%	kW/m	W	W
H_w			η		P_w	P_{ETmax}
1.64	13.79	7.29	40	12	9666.59	18285.64
1.85	12.9	7.89	40	12	13313.08	21766.64
1.78	12.12	7.49	40	12	11699.84	18932.19
1.81	12.9	7.86	40	12	12695.15	20835.55
1.67	12.9	7.6	40	12	10449.72	17737.03
1.84	12.9	7.88	40	12	13152.86	21531.96
1.75	12.9	7.71	40	12	11640.96	19477.09
1.72	12.12	8.02	40	12	11697.40	17677.37
1.78	12.9	7.94	40	12	12402.77	20150.60
1.57	12.9	7.34	40	12	8919.77	15676.43
1.76	12.9	8.18	40	12	12492.14	19700.32
1.67	11.43	7.91	40	12	10875.96	15715.83
1.54	12.12	7.8	40	12	9119.99	14171.06

Table 9: Performance of Wave Bob

Wave Height	Dominant Period	Average Period	Wave Power	Geographically Maximum Wave Power	Electrical Power Generated	Capacity Factor	Dimensionless Normalized Wave Power
m	sec	sec	W	W	W		
H_w			P_w	P_{ETmax}	P_E	C_f	P_{EN}
1.64	13.79	7.29	9666.59	18285.64	2609.980064	0.000372854	0.53
1.85	12.9	7.89	13313.08	21766.64	3594.532591	0.000513505	0.61
1.78	12.12	7.49	11699.84	18932.19	3158.957535	0.00045128	0.62
1.81	12.9	7.86	12695.15	20835.55	3427.690978	0.00048967	0.61
1.67	12.9	7.6	10449.72	17737.03	2821.424935	0.000403061	0.59
1.84	12.9	7.88	13152.86	21531.96	3551.271116	0.000507324	0.61
1.75	12.9	7.71	11640.96	19477.09	3143.058331	0.000449008	0.60
1.72	12.12	8.02	11697.40	17677.37	3158.29889	0.000451186	0.66
1.78	12.9	7.94	12402.77	20150.60	3348.748042	0.000478393	0.62
1.57	12.9	7.34	8919.77	15676.43	2408.337402	0.000344048	0.57
1.76	12.9	8.18	12492.14	19700.32	3372.877784	0.00048184	0.63
1.67	11.43	7.91	10875.96	15715.83	2936.509373	0.000419501	0.69

Table 10: Performance of Wave Dragon

Chapter 5

RESULTS

We compared the performances of the various Wave Energy Converters to find out a convergence to point out the converters best suited to the climate of Saint Martin's.

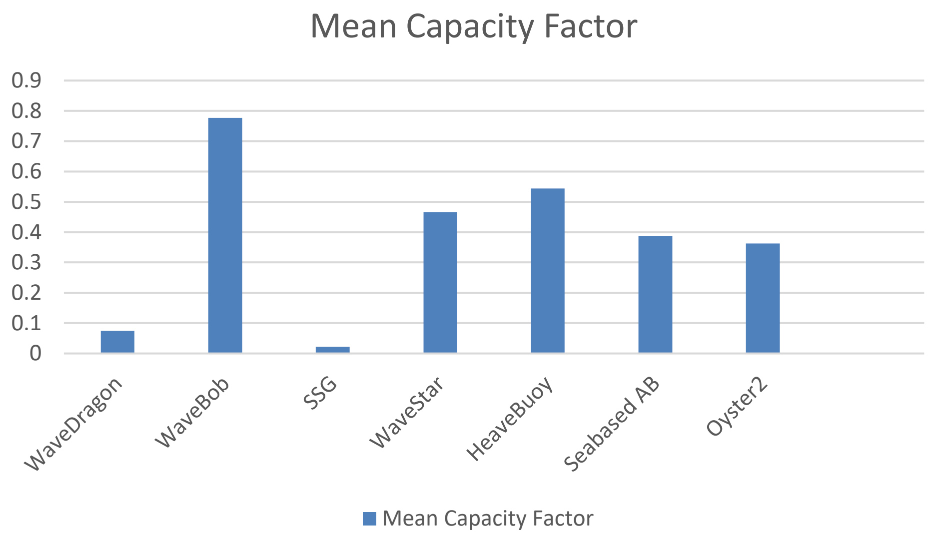

Figure 19: Mean Capacity Factor for a region in Saint Martin at a depth ranging from 5-20 m

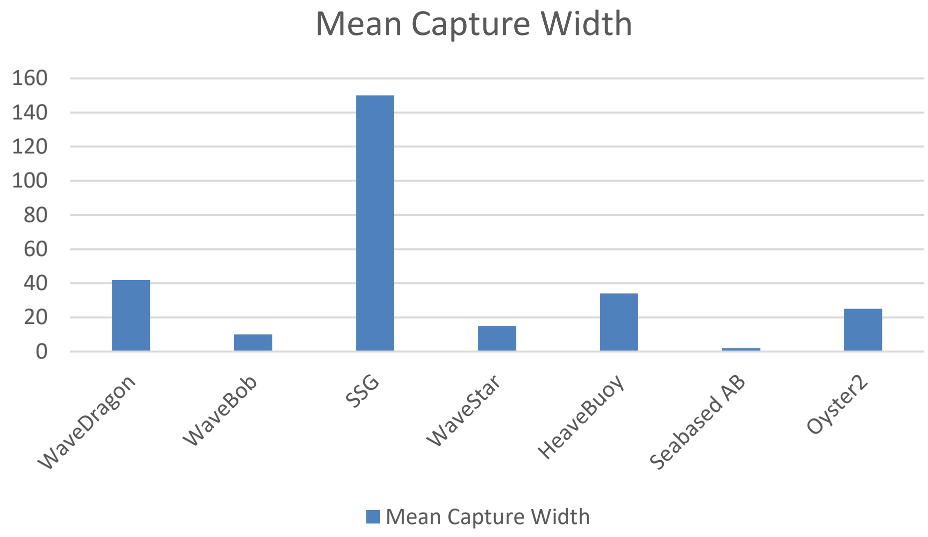

Figure 20: Mean Capture Width for a region in Saint Martin at a depth ranging from 5-20 m

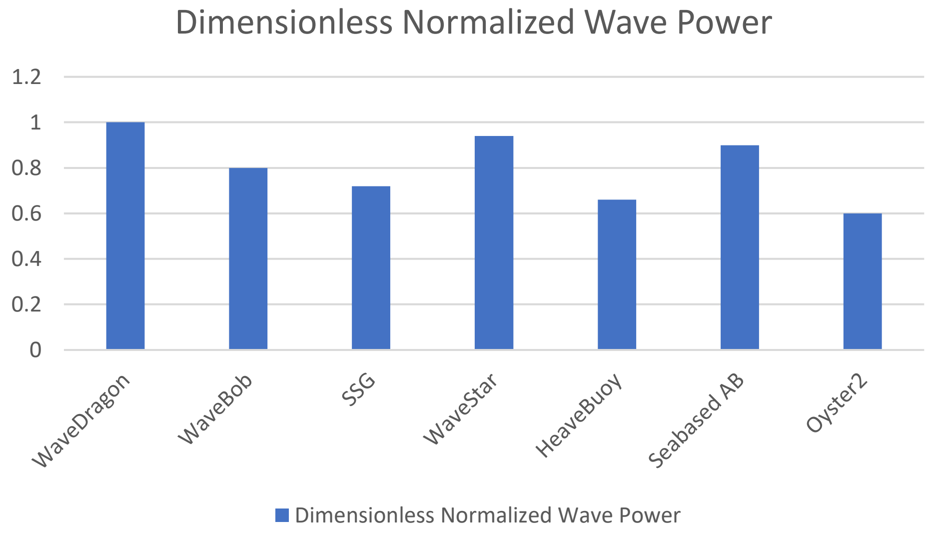

Figure 21: Dimensionless Normalized Wave Power for a region in Saint Martin at a depth ranging from 5-20 m

The results match for the Wave Dragon, SSG and Oyster2 with the other papers for Capture Width.

For Capacity Factor the results from the Heave Buoy appear similar to the reference papers.

For the rest of the WECs the results appear varied.

This review focuses on the wave power production performances of the WECS and narrows down the factors that can help to optimize its performance. The following most important remarks have been obtained:

At different locations and depths, different WECs are more suitable for installation.

The converters SSG, Wave Dragon, Oyster2, Ocean tec and Pontoon work well in seas that contain moderate amount of wave power. They work well from coastline to deep water region. [19]

SSG, Wave Dragon, Oyster2, Ocean tec and Pontoon require a high capture width compared to other devices when they are being deployed from the shoreline to offshore.

For an offshore WEC the maximum distance for installation that will produce optimum performance have been in the range of 45-50 km. Research has shown that this is an acceptable distance for the plantation of wave energy plants. [1]

In order to utilize the high potential locations it is important to know the energy matrix of the sea states and provide WECs to work efficiently across a broader range of the sea states by utilizing the control strategies. This review has been focused on evaluating the power production capacities of WECs and what factors to exploit but it needs to be considered that power production performance does not necessarily imply economic production performance.

Chapter 6

6.1 Conclusion

The data collected for Saint Martin islands is for wave behavior along the shoreline. As a result the mean changes in the capacity factor, capture width and dimensionless normalized wave power cannot be analyzed. The optimum installation depth for Saint Martin Island is unable to be found due to this although the performance of some of the WECs matches with the reference papers. As the damping control methods affect the power production and hydrodynamic behaviors so, control strategies can increase the efficiency of the WECs and help WECs to work efficiently across a broader range of the sea states.

The converters SSG, Wave Dragon, Oyster2, Ocean tec and Pontoon work well in seas that contain moderate amount of wave power. They work well from coastline to deep water region. [19]

SSG, Wave Dragon, Oyster2, Ocean tec and Pontoon require a high capture width compared to other devices when they are being deployed from the shoreline to offshore.

For an offshore WEC the maximum distance for installation that will produce optimum performance have been in the range of 45-50 km. Research has shown that this is an acceptable distance for the plantation of wave energy plants.

This review can be concluded from the following observations and based on the performance analysis at various installation depths it can be considered satisfactory.

6.2 Future Recommendations

The examined WECs are full-sized, high-wave-condition-designed devices. Since the waves in Saint Martin are not as high as those in the ocean, it is strongly suggested that future research scale the devices and make them smaller in order to increase the capacity ratio and productivity of WEC technologies. In addition to installation and maintenance costs, potential environmental hazards, grid connection points, and other sea-based applications, the viability of WEC machines is also dependent on other factors.

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