Marine Energy: Comparison of Tidal and Wave Energy

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Abstract. Marine energy is one of the forms of renewable energy that is one of the most widely available sources of energy; the oceans cover around 71% of the earth's surface, which means that there can be huge potential in energy. The majority of the technologies that are used to harvest marine energy are still in their developmental stages. Marine energy includes tidal energy, wave energy, osmotic energy, ocean thermal energy, and ocean current energy. Researchers all across the world, as well as people developing industries, are paying attention to the potentially lucrative field of marine energy. Since more than half of the US population lives within 50 miles of the coast, marine energy resources are spread out and in a good place to power cities. These resources are prospective contributors to a reliable, steady sustainable energy infrastructure because they are also quite predictable. This article provides an overview of the current state of the art in marine energy and explores tidal and wave energy in detail including the benefits and limitations of both.

Keywords: Marine energy, Wave energy, Tidal energy, Renewable energy.

1. Introduction

Marine is a renewable energy source produced from the natural movement of water, including ocean currents, tides, river currents and waves [1]. There are numerous opportunities to use marine energy. In 2019, the overall amount of marine energy resources in the US would account for roughly 57% of the nation's electricity production [2]. The nation's energy demands would be significantly aided by marine energy technology, even if just a small percentage of this technical resource potential is utilized. To harvest electricity from these abundant water resources, researchers are experimenting with and implementing new technologies.

Marine energy systems use the movement of waves, currents, and tides, as well as the heat transfer from deep cold water to surface water, to make clean energy. Tides and currents can be used to power turbines, and some wave energy converters use buoys to get energy from the ocean's movement both up and down and side to side.

Since more than half of the US population lives within 50 miles of the coast, marine energy resources are spread out and in a good place to power cities. These resources are prospective contributors to a reliable, steady sustainable energy infrastructure because they are also quite predictable. For instance, marine energy resources complement other forms of renewable energy sources like solar and wind perfectly due to their daily and seasonal cycles [3].

Most marine energy systems are submerged or otherwise located at sea, allowing them to produce clean energy while maintaining breathtaking vistas of the ocean and other bodies of water [4]. Further research into blue economy applications, improvement of desalination systems for the provision of clean drinking water, and exploration of the uncharted ocean can all be powered by these technologies [5].

There is a pressing need to develop and secure more sources of sustainable energy beyond those that are now available as the world's demand for clean electricity, renewable fuels, and essential materials for energy and industrial processes grow at an exponential rate [6]. Researchers are fully aware of the ocean's enormous potential to create dependable, renewable energy for a multitude of purposes. The Water Power Technologies Office of the Department of Energy believes that wave, tidal, and ocean current energy can create enough electricity to power millions of homes.

2. Tidal Energy

2.1. Introduction to Tidal Energy

Tidal energy is generated by the rising and falling of the tides as a result of the gravitational interaction between the Earth, the sun, and the moon. Tidal currents are formed when water moves faster and with enough energy to be used [7]. With the correct generators in the right settings, tidal energy is converted into usable forms of power, such as electricity. Water desalination and pumping into reservoirs are only a few of the many uses for the energy generated by the fast vertical motion of Surface Ocean waves. Fig. 1 illustrates the generation process of tidal energy.

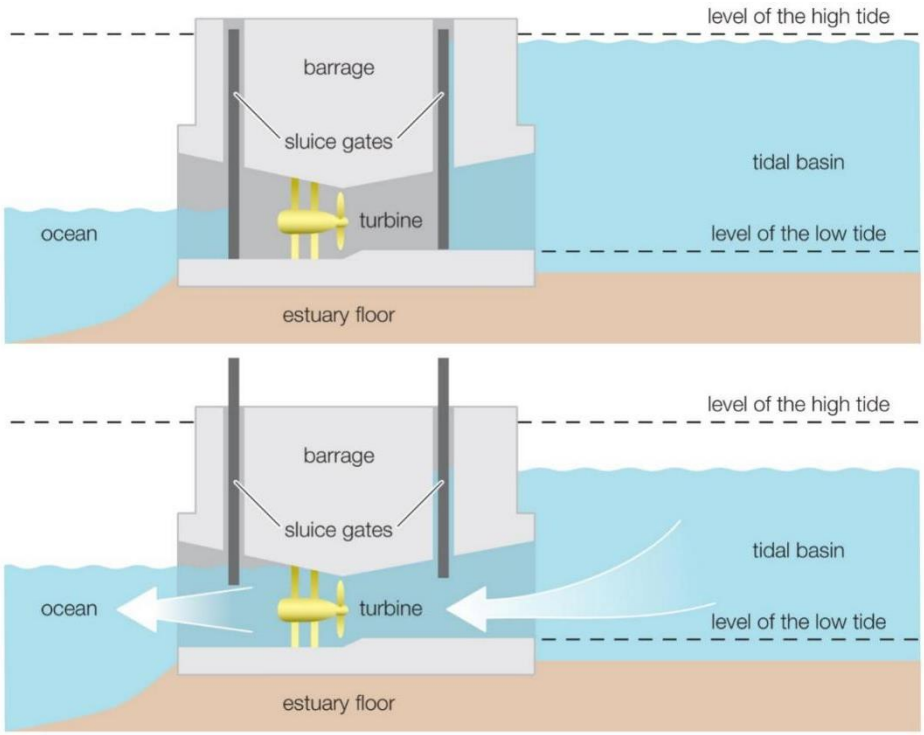


Figure 1. Generation of tidal energy [8]

To maximize tidal energy harvesting, look for areas with considerable tidal range variations, such as the difference between high and low tide, as well as areas where tidal channels and rivers constrict and currents intensify with each tide cycle.

Because water has a higher density than air, tidal energy has a greater output than wind power. At the same turbine diameter and rotor speed, tidal energy delivers tenfold more power. Since wind and solar power are subject to fluctuations in output, tidal power is less susceptible to outages. As a result, tidal energy research is an exciting area of study in the world of renewable energy. Tidal energy usage must be found where prices are less sensitive than those of electricity drawn from the national grid, and it must be made economically feasible to absorb and transform the energy into usable power at scale.

For tidal energy to be efficiently used as a large and reliable source of renewable energy, experts must examine ways to help improve technology and methods that make it more feasible for widespread commercial application.

2.2. Development of Tidal Energy

Sites with big tidal ranges and powerful currents are excellent for capturing tidal energy. Grain mills were powered by tidal energy over a thousand years ago in Europe [7]. Water from incoming tides was stored in ponds, and waterwheels were used to grind grain as the tides left. The 19th century saw the introduction of this method of producing energy by employing falling water and rotating turbines.

Early attempts at tidal power facilities included a barrage strategy like a dam. But ultimately, the industry has not stayed focused on this.

Nova Scotia Light and Power, the U.S. Power Commission in the United States and Canadian governments, and each organization individually undertook four early feasibility studies for large tidal power facilities between 1926 and 1979 [9]. Their whole focus was on certain geographic regions close to the Maine-Canada border. Although the assessments of economic feasibility varied, little progress was made as a result.

A large tidal barrage with 240 megawatts (MW) of energy-producing capacity was built in 1966 in France and is still in operation today. Until a 254 MW array went online in South Korea in 2011, this barrage was the biggest in the world [6].

Tidal stream energy generation, which involves inserting a single device, a group of devices, or an entire array in the stream, has become more popular in the last two decades. When it was first built in 2003, European Marine Energy Centre was the world's largest facility for testing and demonstrating wave and tidal technology. More tidal energy gadgets have been tested at this facility than at any other location around the globe. It provides scale test sites for smaller devices as well as grid-connected test sites for bigger prototypes.

2.3. Applications and Significance of Tidal Energy

Tidal turbines can be installed individually, in groups, floating, and at high tide [6]. Because it is much smaller than a large wind turbine, it also requires more power to generate electricity. Certain tidal energy demonstration projects in the United States have entered various stages of development; the Cobbs Cook Bay tidal energy project in Maine, the tidal energy project on Roosevelt Island, the eastern rivers in New York, and the tidal energy project in western Maine project. But while many demonstration projects are in various stages of development, the United States does not have a single economically viable tidal power plant. Alaska's Cook Inlet has the second-highest tidal range in North America, while parts of Maine have the most potential tidal power stations in the United States [10].

Turbines in the current capture the tidal current and transmit it to the power grid using submarine cables. In areas where land shrinking causes rising tides, such as in straits or inlets, energy can be obtained from tides. When completed, the Megan Tidal Stream Power Station in Scotland will be the largest in the world, with a maximum power generation capacity of 398 megawatts [7].

To create a high tide basin, tidal dams, similar to dams, are built in rivers, bays and estuaries, which are tidal. When the tide is high, this tank can be filled, and the dam's internal turbine can provide energy from two sources. It's like a dam that traps the surrounding water and prevents it from escaping. The two dams in South Korea and France are the two largest tidal power plants in the world, generating 254 megawatts and 240 megawatts, respectively. Canada's second-largest nuclear power plant produces just 20 megawatts of electricity [6].

Like levees, tidal lagoons use built-in turbines to absorb energy from currents and partially absorb it with artificial mud walls. They also rely on huge tidal ranges to generate electricity. Unlike dykes, tidal lagoons can be built on existing shores to continuously generate electricity during high tides with minimal impact on the environment. While there are no examples of tidal lagoons that have been exploited and their power generation potential has yet to be proven, the UK and China have developed a few. Due to the existence of dams and lagoons, most tidal development projects around the world do not focus on levees and lagoons.

In the past, tidal energy has been used on land in the national power system. Tidal energy also benefits other established or emerging marine businesses (such as aquaculture, marine mineral extraction, marine research, or military activities) within the US Department of Energy's "Blue Economy" program. While maintaining the health of marine ecosystems, marine resources can be harnessed to achieve economic growth, improve living conditions, and increase jobs.

2.4. Benefits and Limitations of Tidal Energy

Here are some benefits of tidal energy:

Clean, renewable, sustainable, and underutilized tidal energy is a great way to address both current and future global energy needs. Tidal energy is stronger than wind because water is hundreds of times denser than air, making it more forceful [7]. This type of renewable energy is highly sought after since it creates no waste or greenhouse gases, is more efficient than wind or solar energy, and is also denser.

Another advantage of using tides as a renewable energy source is the greater regularity and predictability they provide compared to other renewable energy sources like wind and solar. It is easy to forecast low and high tide cycles, and they rarely vary abruptly.

However, tidal energy also has some limitations:

Several substantial obstacles continue to constrain the tidal energy sector, with cost being the most difficult. The creation of tidal arrays and grid integration needs time-consuming, costly engineering and manufacturing effort. No tidal technology has yet emerged as the market leader, allowing supply chains to form and starting to reduce installation and maintenance costs, even though various tidal technologies that potentially boost affordability are being investigated.

Some market participants have given up trying to create tidal energy solutions since it has taken so long. Tidal energy facilities can only be built in a select few sites since not all coastal bays and tidal channels match the criteria necessary to produce power. There are a few places where lengthy underwater cables are required for the transmission of produced power because they are remote from the grid.

Cost and geographical constraints aren't the only issues to deal with. As tidal energy arrays are constructed and put into service, they have the potential to alter water quality and the ambient flow field. These underwater structures may also have a negative impact on marine life and their habitats, posing a risk of fish and marine animal collisions with rotating turbine blades and disrupting their ability to communicate and navigate [7]. Because of this, some delicate species might avoid electromagnetic fields produced by power lines or alterations to their habitat. The main goal of research efforts in this field must be to reduce costs, create equipment that can withstand ocean forces, and reduce environmental effects to increase the economic feasibility of tidal energy.

2.5. Recent Development in Tidal Energy

Tailor-made power arrays of different shapes and sizes are being built throughout the world to harness the power of tidal streams and currents. This is the first of its kind tidal stream array in Scotland's Pentland Firth, which separates Scotland's mainland from its northern islands. More than 35 gigawatt-hours of power have been generated and delivered by the first four turbines of the MeyGen tidal energy project since it began operating in phases in 2018. The 400 MW of energy generated by the area's swift currents will be captured by 61 underwater turbines once they are fully operational.

Wales, a new centre of industry, is working on several projects. One of the components of this development will be a premier maritime engineering centre. It would include a 90-kilometer demonstration zone where future tidal energy-generating technologies may be deployed. It was authorized by the governments of Wales and the United Kingdom in 2020.

New and enhanced tidal current technologies are being developed by developers in nations including, France, Scotland, Japan, Canada, Korea, the United States, and China where test sites and technology deployments are in various phases of implementation [7]. The ability to test new technologies in real-world maritime environments is critical to the long-term viability of the industry. To boost the efficiency of tidal energy generation systems, decrease biofouling, lessen environmental consequences, and find a road to commercial viability, engineers are attempting to improve these technologies.

3. Wave Energy

3.1. Introduction to Wave Energy

Renewable energy is a big issue in today's world since it is infinite, sustainable, and doesn't generate greenhouse gases that are terrible for the environment and people's health. Wave energy is a great example of a long-term energy source.

After Girard and his sons applied for a patent in Paris in 1799 to use wave energy, it was official: the search for wave energy had begun [11]. In 1940, Yoshio Masuda, a former lieutenant in the Japanese navy who is credited with developing contemporary wave energy technology, introduced wave energy to the Japanese Empire. Wave energy didn't take off until the oil crisis of '63. An invention by Professor Stephen Hugh Salter, the Salter duck wave energy gadget, could transform 90% of wave motion into electricity with 80% efficiency [12].

Ocean or sea wave energy is sometimes known as wave energy, ocean energy, or sea wave energy. Energy from the fast vertical motion of Surface Ocean waves may be used for a variety of purposes, including power generation, water desalination, and water pumping into reservoirs.

On the other hand, "wave power" refers to the power generated by waves. Energy is transferred from a wave to the wind when it passes over water. They are harnessed as tremendous sources of energy. To measure the amount of energy generated, water density and water density are utilised. Power generation efficiency improves as wave strength increases. Pumping water or generating electricity can be done with the energy that is obtained. Fig. 2 illustrates the generation process of wave energy.

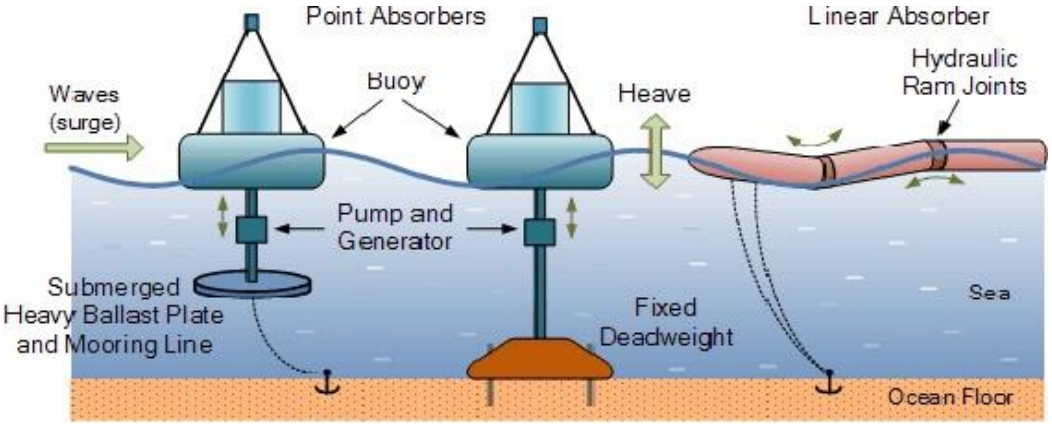


Figure 2. Generation of wave energy [13]

The ability to generate power increases with wave strength. The energy that is gathered can subsequently be used to pump water or create electricity in power plants. There are very few wave generator facilities in existence worldwide since it is difficult to utilize the electricity they produce.

Wave energy is obvious when looking out at a beach and watching waves breaking against the sand. Although it is not being harnessed or used for anybody in that condition, it is still there providing power. And some resourceful individuals would say that it is simply waiting to be put to use to improve our lives and make energy consumption more cost-effective and ecologically friendly. Tidal power, which is completely separate from wave energy, is commonly mixed with it.

However, how are those waves created? Waves are formed when the wind blows over the water's surface vigorously enough. Due to the absence of terrain to withstand the intensity of the wind, this happens most frequently and most severely on the ocean.

Depending on where they are being impacted, many sorts of waves are formed. The storms and severe weather conditions far away are likely what cause the lengthy, steady waves that crash against the shore. Storms have such a strong impact on the water's surface that they can send waves to the coastlines of another hemisphere. For instance, when a big tsunami struck Japan in 2011, it produced tremendous waves that reached the beaches of Washington State and even the shore of Hawaii [14].

If large, choppy waves rise and fall rapidly, it is probably waves created by a nearby weather system. Typically, these waves are brand-new occurrences. A wave energy converter can then be used to capture the electricity from these waves (WEC).

3.2. Development of Wave Energy

To capture wave power and use it to generate energy for ourselves, suitable places must be found. There are only a few places in the world where wave energy is successfully and profitably used on a wide scale. The locations include locales along North America's west coast as well as the states of Washington, Oregon, and California. The shores of Scotland, Africa, and Australia are also included in this [14].

In its simplest form, wave energy may be thought of as a concentrated form of solar energy produced by wind activity flowing across the ocean's surface. The sun's strong rays cause the atmosphere to warm up. Sunlight reaches the earth's atmosphere at differing intensities depending on where it is on the planet. The movement of atmospheric air between hotter and colder places as a result of the difference in global atmospheric temperatures produces winds.

There is a certain amount of kinetic energy transferred to the water below when the wind blows over an ocean [11]. In actuality, it is possible to imagine the ocean as a vast energy repository that stores kinetic energy that is sent to the seas by the sun's rays and then transported over the water's surface by the waves. This leads us to the reasonable conclusion that waves are a sort of energy and that the movement of the ocean's surface is caused by energy rather than water.

Through the huge oceans, these waves may travel without using much energy. As they go closer to the beach, where the water is much shallower, their pace lowers and their size substantially increases [12]. Finally, a tremendous quantity of kinetic energy is released as the waves crash on the coast.

3.3. Applications and Significance of Wave Energy

The lack of fossil fuels has increased the demand for sustainable alternatives like wave energy. An international energy crisis is being caused by several variables that are driving up the cost of oil, gas, and coal. Energy demand has increased as a result of the global recovery from COVID-19, but supplies are insufficient. Among the reasons are decreased gas output in Europe, decreased oil investment in the US, and decreased coal production in China. There have also been delays in international transportation.

Due to concerns about a supply interruption, the crisis in Ukraine is currently driving oil prices to new highs. In light of this, wave energy's dependability is a major draw. In contrast to the unpredictability of wind and solar energy, waves are consistently present and store more energy [15].

However, two factors play an important role in the utilization of wave energy. The first is stress called shear stress, which raises the flow of water due to the friction between waves and wind. The second reason is the difference in pressure due to the waves moving up and down. Also, since the amount and efficiency of energy produced depend on wavelength, speed, and altitude, these are the best as they are directly proportional to the efficiency of power generation, and the properties of water waves also have some effect on energy generation. influences. Wave energy can be expressed as an exponential curve because as we are underwater the wave energy gets smaller and smaller because the wind acts more on the water surface than it does underwater. This is because it also depends on the water level. After extensive research into the multiple characteristics and aspects of waves, many wave power plants employ different techniques for generating electricity due to distance and engineering [16]. The following four techniques are examples:

Water Column with Vibration: This device has an air column at the top of the water column, which is not fully submerged in the water. When the water column is filled and emptied, the air at the top of the water column is pushed by the water, the air is compressed, and the piston is connected to many turbofans; it has nothing to do with the direction of the airflow. The corresponding generator will work due to the movement of the turbine.

Attenuation: The technology shown in Fig. 2 consists of several components, separated by 30 meters from each other, that float in the water like snakes, parallel to the waves. As the waves ebb and flow, the units move forward, finally sending power to a hydraulic pump that drives a stationary generator, which is then carried to shore by submarine cables.

Up to 3 kilometres from the shore, the instruments act like a pontoon. This is an absorber, as it utilizes a built-in piston or magnetic induction motor to transfer the kinetic energy it absorbs to an oil hydraulic pump, which injects it into a submarine cable. The kinetic energy comes from the waves at the top of the device and around it.

Power generation: The most widespread application of ocean energy is the generation of enormous amounts of electricity in wave power stations around the world, which can provide an average of several gigawatts of electricity per hour. The first wave power station, called Agucadoura, was built in 2008 and has a capacity of 2.25 megawatts per hour. After this, there are several different power systems and power systems, see Table 1, which lists the specific situation in several countries. This power station is a revolution in the power industry.

Desalting: The method of making sea water drinkable is called desalting. Because the process consumes a lot of energy, some companies have linked it to wave energy to meet this requirement. CETO is a technology that uses reverse osmosis technology to remove excess ions and particulates from seawater and generate electricity and desalination. Reverse osmosis is a method that reverses the conventional osmosis process. Australia first applied the technology to the seabed in 2015 with success.

Water Pumping: Additionally, wave energy technologies help pump water for storage in tanks or for other purposes, such as powering hydraulic turbines. A gadget that uses such a technique is called Searaser, and it comprises a piston between a surface buoy and a sea floor buoy. The piston pushes water into an 8 pipe, which conveys the water to the necessary area, often a higher place along the beach, since both buoys are raised and lowered by the action of the waves. Alvin Smith, the invention's creator, conducted Searaser's initial practical testing in the United Kingdom in 2009, where it was chosen as one of the "Top 15 innovations of the decade" by the British Library.

Wave Energy Converter (WEC): Moreover, a wave energy converter (WEC), which is a power plant, converts the wave energy that hits the coast into electricity. This power plant's operational concept is both innovative and straightforward. An entrance in the chamber allows powerful waves to enter and exit the waterproof chamber.

With each wave, the water rises and falls in the chamber, which causes the turbines to push air forward and backwards through their openings. The turbines are powered by the combined force of compressed and decompressed air. For the turbine to rotate in the same direction, the wind has to pass past it several times. A generator is coupled to a turbine that powers the vehicle.

The generator's power is first distributed to the electrical networks before it reaches demand points and distribution lines that connect individual homes and businesses [11]. When using this wave energy converter, even the minutest of wave movements may generate enough airflow to keep the turbine running and create electricity.

3.4. Benefits and Limitations of Wave Energy

Here are some benefits of wave energy:

The waves arrive in a regular sequence. Unlike other renewable sources, like as wind and the sun, they are available 24 hours a day, 365 days a year. Wind and solar energy, on the other hand, are utterly unpredictable.

Electricity production can be affected by unexpected reductions in wind speed. Cloud cover and nightfall significantly reduce solar energy's exposure to the sun, which reduces its efficiency.

There is no limit to the supply of the renewable resource. It is self-sustaining and does not require human involvement [2]. A future without oceans and seas has never been entertained as a possibility. Humans will continue to make use of it till the end of time. Wave energy is a dependable and efficient energy source because of its characteristics.

Wave energy is a completely renewable form of energy that does not contribute to the emission of damaging greenhouse gases. CO2, CH4, NOx, and ozone are all detrimental greenhouse gases released into the atmosphere as a result of burning fossil fuels like coal and oil [17].

The greatest impact of unemployment and the incapacity of the economy to sustain itself is felt by isolated communities and dying businesses like the shipbuilding industry.

The wave energy industry can offer both remote and urban populations a variety of environmentally friendly alternatives because it can effectively power isolated places that are not serviced by traditional electricity sources.

The ability to channel wave energy results in the emergence of new industries and businesses in remote areas. Moving forward, these isolated communities will experience rapid economic expansion.

A nation can greatly benefit from establishing a robust wave energy infrastructure by reducing its reliance on fossil fuels. The market for fossil fuels is notoriously unstable, and if a shortage emerges, it could harm a nation's economy. Since wave energy is affordable, dependable, and effective, it offers a proven approach to closing this volatility gap.

Offshore locations for wave energy plants can eliminate risks associated with onshore locations, such as soil pollution. Furthermore, unlike the extraction of fossil fuels, which necessitates extensive excavation and severely degrades the soil, the land is left in its natural state.

It's not merely a renewable energy source. There are some limitations as well [2].

Wave energy's location is its main limitation. Only coastal and power plant communities will benefit immediately. Wave energy's source makes it impractical for some. Landlocked nations and far-from-the-sea communities must discover alternative energy sources.

Some adjacent species are at risk even if wave energy is safe. Large equipment must be near the water to gather wave energy.

These devices disturb the seabed, change the habitats of coastal species (such as crabs and starfish), and make noise that disturbs marine life. Wave energy platforms may spill dangerous chemicals and damage adjacent water.

It disrupts private and commercial ships. Wave energy power plants must be near the beach to perform properly and near cities to be useful.

Beachgoers, cruise passengers, freight ships, and RVs use these routes. Wave energy collecting will upset these people and boats. Government officials and enterprises interested in wave energy must consider the needs of those they may disturb.

Wave speed, wavelength, and water density affect wind power. Strong waves are needed to generate a lot of wave power. Inconsistent wave behaviour makes it difficult to predict wave power and unreliable as an energy source.

Wave energy turbines may bother some beachfront residents. They deface the water by looking like huge machines in it. They generate noise pollution, but it's often masked by the much louder waves.

Wave energy provides almost universal benefits, but it's expensive to produce. Wave energy requires large equipment. In many cases, technology's lifespan is uncertain. Wave’s unpredictability Powerful waves can ruin equipment irreparably. Such equipment is expensive to acquire and maintain. Using this energy to create a power mill would be costly. A mill alone won't do. Maintenance is required.

3.5. Recent Developments in Wave Energy

Many of the traditional methods that were employed in the past to produce wave energy in basic forms are no longer used in a professional capacity as a result of the development and application of many more cutting-edge technologies, such as oscillating water columns, attenuators, point absorbers, and oscillating wave surge converters. It is clear how wave energy may be used to generate electricity, pump water, and desalinate salt water. The benefits of wave energy are also unique in that they are a clean, renewable energy source that benefits our society, economy, and environment. Wave energy

power plants also have negative side effects that interfere with the environment of marine life, make it harder to maintain the damaged components, and restrict the movement of ships.

The development of wave energy is still making great strides. Successful deployments have occurred everywhere in the world, from Australia to North America to Asia and Europe. Several large-scale devices are now being manufactured or getting ready for deployment. The industry has been evolving along the TRL scale, and the first farms are being planned. Numerous possible innovations that might have a big influence on prices and energy output have already been researched and incorporated into new prototypes [18].

Due to the various methods in which energy from the waves can be absorbed, as well as depending on location and sea depth, wave energy may stay specialized by concurrently creating a wide range of wave energy technologies. Extensive testing programmes are still needed to evaluate performance and reliability as wave energy projects go from demonstration to their initial pre-commercial arrays of a few units. Strong research and innovation initiatives are still needed to accelerate the development of wave energy to full maturity. A favourable political environment is essential for increasing development.

4. Conclusion

In brief, oceanic energy can be generated in a variety of ways. Using all of these mechanisms, such as the tides, ocean currents, waves, run-of-the-river, and salinity to generate energy from the sea is known as marine energy. Some wave energy converters make use of buoys to harvest energy from the ocean waves, while others rely on tides and currents to drive their turbines. There are only a few places in the world where wave energy can be used on a large scale and profitably while tidal energy offers a significant opportunity for increasing global renewable energy production capacity. To put it another way, tidal energy is the energy that flows from Earth's gravitational rotation to the oceans, while wave energy is the energy that winds provide and is retained by waves. There are several advantages and disadvantages of using tidal and wave energy but as a whole, marine energy has several disadvantages, including environmental impacts on marine life, underwater noise and distorting natural water flow. Energy derived from the sea is one such resource that changes in value depending on the location. Installation and maintenance costs can be high for some technologies that have not yet progressed. The natural flow of water and the marine ecological system are harmed by these projects. Although wave energy has numerous advantages, its production costs are prohibitive. Large machinery is needed to generate wave power. Often, the longevity of technology is unknown. The unpredictability of the Wave Equipment might be permanently damaged by powerful waves. The purchase and upkeep of such equipment are prohibitively expensive. It would be expensive to use this energy to power a mill. A mill by itself is insufficient. Upkeep is a need. On the other hand, over time, the water quality and flow patterns around tidal energy arrays may change. Marine life could be harmed by these submerged turbine blades, which could cause fish and marine animals to lose their capacity to communicate and navigate, as well as disrupt their ecosystems. As a result, some vulnerable animals may avoid electromagnetic fields caused by power lines or changes to their habitat. Despite their drawbacks and advantages, both tidal and wave energy are constantly improving. However, to boost the economic viability of tidal and wave energy, researchers must focus on reducing prices, developing equipment that can withstand ocean forces, and minimizing environmental impacts.

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