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WAVES POWER PLANTS ENVIRONMENTAL & ECONOMICAL IMPACTS

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Abstract

In this work we summarized the concept of wave power plants; with its details of mechanism and types as well as its importance in generating clean safe energy in addition to the environmental and economical impacts.

I. INTRODUCTION

When entering the field of wave energy utilization it is relevant to ask why is it important to start utilizing this resource. The reasons for this are shared with other renewable energy sources, such as hydro, wind, solar, biomass and other ocean energy forms such as tidal, currents, thermal and salinity driven systems. The key issues that the use of renewable energy sources can help to overcome includes environmental problems, depletion of the fossil fuels, security of supply and job csreation[1].The environmental problems relates to both local effects such as pollution but also the production of CO_2, which is related to energy production using fossil fuels, with the now well established negative effects on climate change as a consequence .The depletion of fossil fuels was already highlighted in publications in the 1950s. and it is well established that the fossil fuels are finite and that the time horizon before they are depleted are counted in 10'ths, maybe 100'ths, of years. Thus, it is also obvious that the current level of energy consumption, which is by far majority based on fossil fuels, cannot continue unless alternative sources are developed. And here the renewable energy sources are the most obvious answers, as these resources will be available as long as the sun is shining. But even still while there currently are reasonable amounts of fossil fuels available, the uneven distribution of the resource around the globe is giving rise to conflicts. It can only be expected that this tendency will be worsened as the fossil resources are getting more and more depleted. Thus, for most nations it is of great interest to decrease their dependency on fuel supply from other countries to maintain their sovereignty and political stability. As an answer to that renewable energy sources are very diverse and to a much larger extent scattered and well distributed around the globe [7].

II. PHYSICAL CONCEPT

Wave power is the capture of energy of wind waves to do useful work – for example, electricity generation, water desalination, or pumping water. A machine that exploits wave power is a wave energy converter (WEC).Wave power is distinct from tidal power, which captures the energy of the current caused by the gravitational pull of the Sun and Moon. Waves and tides are also distinct from ocean currents which are caused by other forces including breaking waves, wind, the Carioles effect, cobbling, and differences in temperature and salinity. Wave-power generation is not a widely employed commercial technology, although there have been attempts to use it since at least 1890[8]. In 2008, the first experimental wave farm was opened in Portugal at the Aguçadoura Wave Park[9] .Waves are generated by wind passing over the surface of the sea. As long as the waves propagate slower than the wind speed just above the waves, there is an energy transfer from the wind to the waves. Both air pressure differences between the upwind and the lee side of a wave crest, as well as friction on the water surface by the wind, making the water to go into the shear stress causes the growth of the waves. Wave height is determined by wind speed, the duration of time the wind has been blowing, fetch (the distance over which the wind excites the waves) and by the depth and topography of the seafloor (which can focus or disperse the energy of the waves). A given

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wind speed has a matching practical limit over which time or distance will not produce larger waves. When this limit has been reached the sea is said to be "fully developed". In general, larger waves are more powerful but wave power is also determined by wave speed, wavelength, and water density [10]. Oscillatory motion is highest at the surface and diminishes exponentially with depth. However, for standing waves (clapotis) near a reflecting coast, wave energy is also present as pressure oscillations at great depth, producing microseisms. These pressure fluctuations at greater depth are too small to be interesting from the point of view of wave power. The waves propagate on the ocean surface, and the wave energy is also transported horizontally with the group velocity. The mean transport rate of the wave energy through a vertical plane of unit width, parallel to a wave crest, is called the wave energy flux (or wave power, which must not be confused with the actual power generated by a wave power device)[11].

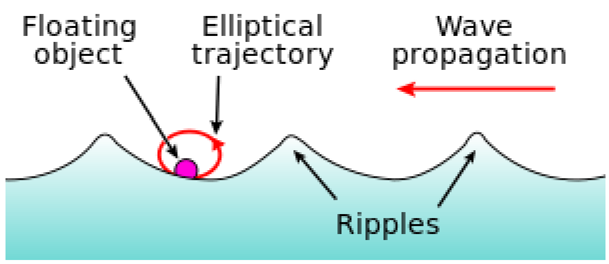

Fig (1) When an object bobs up and down on a ripple in a pond, it follows approximately an elliptical trajectory.

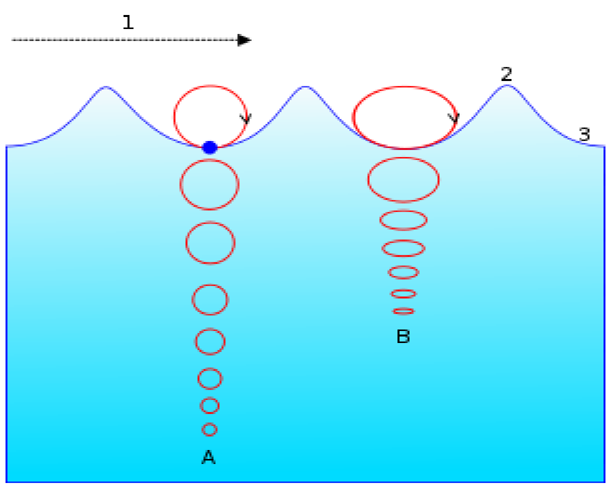

Fig. (2)Motion of a particle in an ocean wave.

A = At deep water. The elliptical motion of fluid particles decreases rapidly with increasing depth below the surface.

B = At shallow water (ocean floor is now at B). The elliptical movement of a fluid particle flattens with decreasing depth.

1 = Propagation direction.

2 = Wave crest.

3 = Wave trough.

III. WAVE POWER MECHANISM

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In 2001, more than 1000 different methods of utilization of wave energy had been patented by many different wave energy companies, most of which never even made it past the first few stages. Only a few of these projects have been shown to work in reality. The following are the three main methods that look most promising [12]:

Oscillating Water Column (OWC): An oscillating water column is partially lowered into water. It is open below the surface line with a hollow upper part filled with air. The water level within the water column increases and decreases with waves coming in resulting in compression and decompression of air. Wells-turbines are ideal for the purpose of converting this into energy, because the turbines rotate the same way independent of the direction of the airflow. A generator converts this mechanical energy into useful electricity.

Surface-following attenuator (Line Absorber): The point absorber consists of a series of long unit, floating on the surface of the water following the movements of the wave. It is this movement that is harnessed and converted to electricity in the point absorber. A Scottish company, Pelamis Wave Power (previously known as Ocean Power Delivery), has installed a successful 2.5 MW wave farm Aguçadoura of the coast of Portugal. This wave power plant was opened in September 2008. Below is a picture of one of the Pelamis Wave Energy Converters that is the foundation of Aguçadoura, maybe the most promising device to harness wave energy so far.

Fig. (2)This device looks like a sea snake in the water. It consists of a series of joints that generate power as the waves move them up and down through hydraulic rams and a generator. An underwater cable moves the electricity to the shore.

Buoyancy Unit/Point Absorber: The buoyancy unit is floating on the waves or below the water surface, fixed to the bottom, following the vertical movements of the waves up and down. These waves drive a pump that generates electricity. The power generation of a typical ocean wave energy unit is about 1 MW, but we expect this output to get better along with the wave energy technology. After several years with low activity around marine energy technologies, the need for renewable energy has pushed the interest for these technologies forward. Some countries have invested more than others when it comes to developing these methods. Britain and Portugal are currently the leading nations when it comes to ocean wave energy conversion, but several other countries are starting to grasp the potential of harnessing wave energy as well.

Wave Power Formula

In deep water where the water depth is larger than half the wavelength, the wave energy flux is[15]

$$P = \frac{\rho g^2}{64\pi} H_{m_0}^2 T_e \approx 0.5 \left(\frac{Kw}{m^3.S}\right) \quad (1)$$

with P the wave energy flux per unit of wave-crest length, H_{m0} the significant wave height, T_e the wave energy period, ρ the water density and g the acceleration by gravity. The above formula states that wave power is proportional to the wave energy period and to the square of the wave height. When the significant wave height is given in meters, and the wave period in seconds, the result is the wave power in kilowatts (kW) per meter of wave front length. Example: Consider moderate ocean swells, in deep water, a few km off a coastline, with a wave height of 3 m and a wave energy period of 8 seconds. Using the formula to solve for power, we get [15]

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$$P \approx 0.5\frac{kw}{m^3.S}(3.m)^2(8.S) \approx 36\frac{kw}{m} \quad (2)$$

meaning there are 36 kilowatts of power potential per meter of wave crest. In major storms, the largest waves offshore are about 15 meters high and have a period of about 15 seconds. According to the above formula, such waves carry about 1.7 MW of power across each meter of wave front. An effective wave power device captures as much as possible of the wave energy flux. As a result, the waves will be of lower height in the region behind the wave power device[16].

Wave Energy and Wave-Energy Flux

In a sea state, the average (mean) energy density per unit area of gravity waves on the water surface is proportional to the wave height squared, according to linear wave theory [17]:

$$E = \frac{1}{16}\rho g H_{m_0}^2 \quad (3)$$

Where E is the mean wave energy density per unit horizontal area (J/m^2), the sum of kinetic and potential energy density per unit horizontal area. The potential energy density is equal to the kinetic energy, both contributing half to the wave energy density E, as can be expected from the equipartition theorem. In ocean waves, surface tension effects are negligible for wavelengths above a few decimeters. As the waves propagate, their energy is transported. The energy transport velocity is the group velocity. As a result, the wave energy flux, through a vertical plane of unit width perpendicular to the wave propagation direction, is equal to[18]:

$$P = Ec_g \quad (4)$$

with c_g the group velocity (m/s). Due to the dispersion relation for water waves under the action of gravity, the group velocity depends on the wavelength λ, or equivalently, on the wave period T. Further, the dispersion relation is a function of the water depth h. As a result, the group velocity behaves differently in the limits of deep and shallow water, and at intermediate depths.

Hydrodynamic Design of a Wave Energy Converter *a body must have a shape, size, placement and motion that gives considerable outgoing waves when moved.*

Size and Shape: The first rule of thumb for wave-absorbing bodies and water columns is that corners should be rounded. Sharp edges will induce drag and viscous losses that normally subtracts directly from the power available for conversion. If corners can be made with radius of curvature larger than or about equal to the stroke of local water particle motion, the viscous losses are usually negligible [80]. The design should be such that this is the case for average waves at the site of operation. When we talk about the size of buoys in general, it should be understood as their horizontal extension relative to the predominant wavelength k unless otherwise specified. The following differentiation may be applied[19]:

- Less than k=6: small body
- Between k=6 and k=2: medium-sized body
- Larger than k=2: large body

For small buoys the shape does not matter much as long as viscous losses are avoided: In terms of wave radiation pattern, small buoys will behave similar to an ax symmetric body whatever the shape. This is because its wave radiation may be approximated by that of a point source, or pair of point sources. What matters for such buoys is the available volume stroke. In average, the power that can be absorbed will roughly be proportional to the available volume stroke. The size of the buoy should then preferably be chosen large enough to absorb a substantial part of the available power, but small enough to work on full stroke in normal-sized waves. if the body is so large and deep that it reflects most of the incident waves, its motion should induce waves travelling upstream to cancel the reflected waves. On the other side for bodies that are almost transparent to the incident waves, only waves travelling in the downstream direction need to be generated in order to absorb energy. In practice, we usually have a combination of these two cases[20].For ax symmetric bodies, the wave excitation typically increases strongly with width up to an extension of around k=2. For bodies beyond this size the increase in size is not paid off by an increase in excitation. This is due to opposing forces over the body surface, making such large bodies less hydrodynamically efficient than smaller bodies. In principle, the same wave radiation pattern as generated by large bodies may be achieved with a number of small bodies placed in a matrix layout, or in a line layout where the each body oscillates in heave and (at least) on more mode of motion. Whether small or large, the part of the body that is to give the excitation must be found close to the sea surface. Bodies that are placed deep in the water, or which do not have considerable body surface area close to the sea surface, will not be able to absorb much wave energy. This follows directly from how the water moves in a passing wave, with orbital motion (and corresponding dynamic pressure [21].

Heave, Surge / Pitch: Although it is possible to convert energy also through other modes of motion, heave, surge and pitch are usually the modes considered in practice. Heaving buoys and bodies that pitch about an axis close to the mean surface level naturally have high hydrostatic stiffness. Recalling the expression for relative bandwidth given above we see that: Unless provided with some means of reducing the stiffness or controlling the motion, such heaving or pitching systems will have quite narrow response bandwidth, which makes them hydrodynamically inefficient wave absorbers in varying irregular seas. This flaw may be mitigated by active use of the machinery through a proper control strategy, or by including mechanical components to counteract the hydrostatic stiffness[83].Pitching about an axis close to the surface is less volumetric efficient than surging when it comes to absorbing power This is due to the fact that such pitch motion gets its excitation from an area distributed along the direction of propagation for the wave, whereas the surge motion gets its excitation mainly from areas of opposing vertical walls a distance apart. . On the other hand, it may be easier to design a practical machinery for pitching bodies than for surging bodies[22].

Wave Energy Turbine Design

The main characteristics of Wells turbines are that the rotor blade chord lines lie in the plane of turbine rotation, the flow through the turbine is bidirectional and that the turbine is not self starting. The rotor blades resemble a more classic aerofoil shape, often without IGVs (Inlet Guide Vanes).The impulse turbine was originally designed to operate with self-pitch IGV control. IGVs moved in relation to wave frequency (Thakker, 2005). Setoguchi (2003) investigated the operation of a turbine with fixed guide vanes, as the pitching IGVs proved too costly in terms of maintenance, where the fixed IGV configuration was first reported in Maeda (1999). Thakker (2005) investigated the effect of 2D and 3D IGVs finding that 3D IGVs showed a marked improvement to overall efficiency (4.5% in the specific case investigated). Thakker (2005) showed that down-stream guide vanes are less efficient than their upstream counterparts. He ascertained that there was an average of 21% pressure loss due to the down-stream guide vanes[23]Bidirectional turbines tend to have lower efficiencies when compared to normal unidirectional flow turbines. Another issue regarding the performance of these turbines are the so called tip gap leakage losses; one of the most influential features that affect turbo-machine design. Thakker (2005) showed that tip gap losses can reduce the efficiency of the specific impulse turbine investigated by as much as 4%. Tagori (1987) and Raghunathan (1995) found that Wells turbines are sensitive to the tip gap effect than conventional turbines. He found that if the tip gap is decreased, stall is promoted, while cyclic efficiency is improved. It was also noted that a large tip clearance enabled the turbine to operate through a large range of flow rates before stalling [24].

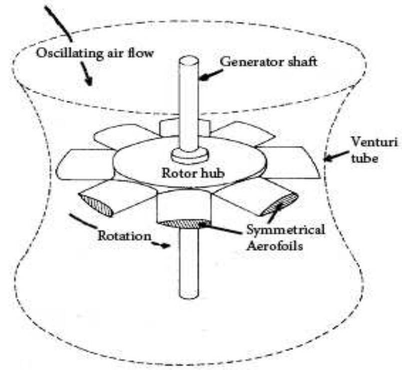

Fig. (4): Wells turbine (Raghunathan, 1982).

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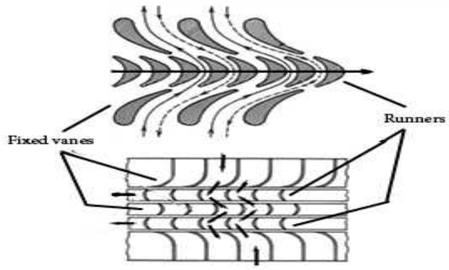

Fig. (5) : Impulse blade row layout.

Wave Energy Advantages and Disadvantages

Advantages

1. Renewable: The best thing about wave energy is that it will never run out. There will always be waves crashing upon the shores of nations, near the populated coastal regions. The waves flow back from the shore, but they always return. Unlike fossil fuels, which are running out, in some places in the world, just as quickly as people can discover them. Unlike ethanol, a corn product, waves are not limited by a season. They require no input from man to make their power, and they can always be counted on.
2. Environment Friendly: Also unlike fossil fuels, creating power from waves creates no harmful byproducts such as gas, waste, and pollution. The energy from waves can be taken directly into electricity-producing machinery and used to power generators and power plants nearby. In today's energy-powered world, a source of clean energy is hard to come by.
3. *Abundant and Widely Available* :Another benefit to using this energy is its nearness to places that can use it. Lots of big cities and harbors are next to the ocean and can harness the power of the waves for their use. Coastal cities tend to be well-populated, so lots of people can get use from wave energy plants.
4. *Variety of Ways To Harness* : A final benefit is that there are a variety of ways to gather it. Current gathering methods range from installed power plant with hydro turbines to seafaring vessels equipped with massive structures that are laid into the sea to gather the wave energy.
5. *Easily Predictable* : The biggest advantages of wave power as against most of the other alternative energy sources is that it is easily predictable and can be used to calculate the amount that it can produce. The wave energy is consistent and proves much better than other sources which are dependent on wind or sun exposure.
6. *Less Dependency on Foreign Oil Cos* : Dependence on foreign companies for fossil fuels can be reduced if energy from wave power can be extracted up to its maximum. Not only it will help to curb air pollution but can also provide green jobs to millions of people.
7. *No Damage to Land* : Unlike fossil fuels which cause massive damage to land as they can leave large holes while extracting energy from them , wave power does not cause any damage to earth. It is safe, clean and one of the preferred method to extract energy from ocean.
8.Wave energy has this advantage over solar or wind energy that the energy has been naturally concentrated by accumulation over time and space and transported from the point at which it was originally present in the winds.
9. A much greater amount of power is concentrated in the waves than in the wind. If we compare the power concentrated in a good wind energy to the corresponding area having wave energy then we will find that wave energy is 100 times greater than wind energy.
10. It is a free and renewable energy source.
11. Wave power devices do not need huge land masses like solar energy wind energy.
12. These devices are almost pollution-free. After removing the energy from the waves waters are left in a placid state.
13. No wastes or greenhouse gases are produced in the process. In my opinion this is the most important advantage of wave energy[24].

Disadvantages

1. *Suitable to Certain Locations* : The biggest disadvantage to getting your energy from the waves is location. Only power plants and towns near the ocean will benefit directly from it. Because of its source, wave energy is not a viable power source for everyone. Landlocked nations and cities far from the sea have to find alternate sources of power, so wave energy is not the clean energy solution for everyone.
2. *Effect on marine Ecosystem* : As clean as wave energy is, it still creates hazards for some of the creatures near it. Large machines have to be put near and in the water to gather energy from the waves. These machines disturb the seafloor, change the habitat of near-shore creatures (like crabs and starfish) and create noise that disturbs the sea life around them. There is also a danger of toxic chemicals that are used on wave energy platforms spilling and polluting the water near them.
3. *Source of Disturbance for Private and Commercial Vessels* : Another downside is that it disturbs commercial and private vessels. Power plants that gather wave energy have to be placed by the coastline to do their job, and they have to be near cities and other populated areas to be of much use to anybody. But these are places that are major thoroughfares for cargo ships, cruise ships, recreational vehicles and beach goers. All of these people and vessels will be disrupted by the installation of a wave energy gathering source. This means that government officials and private companies that want to invest in wave energy sources have to take into account and consider the needs of those they may be disturbing.
4. *Wavelength* : Wind power is highly dependent on wavelength i.e. wave speed, wave length, wavelength and water density. They require a consistent flow of powerful waves to generate significant amount of wave power. Some areas experience unreliable wave behavior and it becomes unpredictable to forecast accurate wave power and therefore cannot be trusted as reliable energy source.
5. *Weak Performance in Rough Weather* : The performance of wave power drops significantly during rough weather. They must withstand rough weather.
6. *Noise and Visual pollution* : Wave energy generators may be unpleasant for some who live close to coastal regions. They look like large machines working in the middle of the ocean and destroy the beauty of the ocean. They also generate noise pollution but the noise is often covered by the noise of waves which is much more than that of wave generators.

None of this is to say that wave energy cannot be useful, but those interested in using it to create power have to look at both sides of the equation. They should consider the positives and negatives of this new energy source and consider who and what they may be disturbing. Who knows what the future holds for this newly-discovered energy source.

7. The major demerit of wave energy, in comparison to wind, is that the energy is available in the ocean. So the equipment needed for the extraction of wave energy must operate in a marine environment. The lifetime and reliability is a great factor which should be taken care while constructing the equipment. The transportation of energy is a great factor because the energy produced needed to be transferred to a great distance from the shore.
8. Wave energy converters must be capable of withstanding very severe peak stresses in storms.
9. Finding a proper site for the extraction of energy from the wave is pretty tough because wave energy is totally related to ocean!
10. Devices needed for the harnessing of the wave energy are very complicated.
11. Many economic factors are important in the installation of a wave energy based power plant. These factors are capital, maintenance cost, repair cost as well as replacement cost. For the power generation companies economic factors can play as the major disadvantage of wave energy.

For a better and green house effect free world, renewable energy sources are the most preferable option. So after going through the advantages and disadvantages of wave energy the leaders of the world, power generation companies along with engineers should take some initiative to make the best use of wave energy[24].

IV. ENVIRONMENTAL EFFECTS

Wave Energy is perceived to be a non-polluting and renewable source of energy, especially in relation to harmful emissions as during their normal operation, wave energy devices produce none of the atmospheric greenhouse gas type pollutants and emissions such as carbon dioxide and nitrogen oxides commonly associated with burning fossil fuels to generate electricity. However, virtually all forms of electrical generation whether renewable or conventional will have an impact upon the environment in some way shape or form, but it is generally thought that *Wave Energy*, being a clean energy source which can replenish itself naturally over a short period of time, is less environmentally degrading than some other forms of renewable power generation. We all know that there are several major benefits of using renewable energy sources, such as wind, solar, hydro, wave, tidal and biomass in terms of their impact on energy efficiency and climate change, as well as the security of having a long term energy supply. These renewable energy sources are also important because they reduce our dependence on carbon based fossil fuels, enhances energy efficiency, and reduce harmful greenhouse gas emissions[25].But there are draw backs to any form of energy generation scheme and wave energy is no exception. Any time you convert one form of energy into another you inadvertently disturb other things and as such there will be side effects. For example, with fossil fuels we know that there are atmospheric pollution issues when they are combusted, or with nuclear power there are issues with the waste and spent fuel-rods, as well as the potential for radiation leakage if not handled properly. The deployment and use of wave energy devices and schemes can also have an impact on the environment in terms of the local shipping and fishing industries as well as on the local environment. Some of the **environmental impacts of wave energy** may be beneficial while some others could be potentially harmful. Although little is known at the moment about the potential environmental impact from wave energy devices and other ocean based technologies due to the fact that many are still in their experimental or early stages of deployment and as such there is very little or no direct operational experience, many wave energy schemes are building on the lessons learned from more mature ocean based oil drilling platforms and offshore wind power industries. Because wave energy generation occurs on the ocean's surface either shoreline, near-shore, or located far out at sea, the possible environmental effects of wave energy generation are similar in many ways to those of offshore wind power generation. Although none of these environmental issues are considered to be critical, the following list helps provides a generalized summary of the most common environmental impacts, both positive and negative, of wave energy devices. So this could be summarized as follow[26]:

- Coastal Erosion – Onshore and near-shore schemes may have an effect on coastal erosion due to alteration of currents and waves. Tidal velocities, wave amplitude and water flow maybe altered in proportion to the scale of the array.
- Device Construction – Possible impact during installation from anchoring these devices. Many wave energy devices are secured or tethered to the ocean floor using pilings, concrete blocks, anchors and chains. Site preparation may involve dredging and scouring of the sea bed to install electrical cables. The amount of ocean bottom disturbance would depend on the number of devices installed and the mooring systems employed.
- Environmental – While wave energy produces no greenhouse gases or other atmospheric pollutants whilst generating electricity, emissions do arise from other stages of its construction, transportation and life cycle. Also potential impacts associated with the release and leakage of hydraulic fluids for hydraulic rams, power trains, lubricating oils and fluids, anti-corrosion and biofouling paints and coatings into the surrounding seas.
- Fishing Industry – Exclusion zones around offshore devices could impact on local fishing areas. Anchor lines, tethers and power cables restrict the use of nets while floating devices can create sheltered conditions providing benefits to some marine species and habitats by limiting access and fishing at the site. However, as with marine reserves, fishing activity may increase directly outside the boundary of the installation.
- Marine Eco-system – Marine mammals may be vulnerable to the floating structures or they may act as barriers to marine movement and migration affecting the fauna and flora on the seabed. Most offshore wave energy devices are moored directly to the sea floor and mooring lines could pose a threat of entanglement for some animals, especially larger whales. Floating wave energy devices could entice sea birds to use the structures as temporary roosts.

  • Navigational Hazards – Possible navigational hazards to shipping as their low profile could result in them being difficult to detect visually or by a ships radar. Potential impact on shipping if wave energy devices are not illuminated at night or if their moorings break away during storms. Also, water quality may be affected due to potential oil spills from increased boat traffic in the area for maintenance and repair.
- Noise Pollution – The constant noise from wave capture devices especially in rough conditions may have an impact on whales and dolphins that use echo location to hunt. For shoreline and nearshore devices, the levels of operational noise may constitute a noise nuisance locally on the beach or shoreline. However,

when fully operational any device generated noise will probably be masked by the natural noise coming from the wind and waves.

- Recreational Activities – Offshore and nearshore devices could have an effect on some forms of recreational swimming and of water sports around the floating devices. Sub-aqua diving and water skiing might benefit from the shelter provided by these devices but sailing and wind surfing may suffer. Also, visual impact of large scale installations on tourism as the water depth required by near shore devices might only be a few hundred yards offshore.
- Sedimentary Flow – The placement of onshore and nearshore wave energy installations such as device platforms, anchors, and cables could change the flow of the water and sands immediately around the structures. Changes in water velocities will impact on sediment transport, coastal erosion, and the deposition of coarse sediments such as pebbles or rocks. Slower or restricted water currents will increase the depositing of sediment.

Then the generation of electricity using wave energy devices is a promising prospect and another alternative way to help reduce our current dependency on non-renewable energy fuels. But technological challenges and our lack of understanding of the associated **environmental impacts of wave energy** compared to the more traditional energy sources needs to be better understood. In general for wave energy devices some of these environmental impacts mentioned above will reduce for floating offshore devices and increase for near and shore-based devices. There are real advantages to developing wave energy and ocean based technologies. Emissions-free electricity is, of course, the principal advantage, but another important advantage is energy security. Wave energy is considered a clean energy which replenishes itself naturally over a short time or is in some sense is inexhaustible (such as solar energy) as there are enormous amounts of energy in the oceans waves, but there is not much energy at any given location [26].

V. THE ECONOMIC IMPACT

Total cost of all marine technologies consist of investment and operation cost. Although they are relatively new and actually the total cost is not established. However the cost relation between each technology is visible. The highest investment cost has barrage technology (620 million Francs). The most expansive part is barrage. It depends from the dam length and height. Planned The Severn Barrage power plant will has 214 with total capacity about 8,6GW (40MW each turbine). The generation covers 4% of Brittany houses. The total cost of 10 mile long barrage with all required equipment is about 30 billion of US$. The Race power plant annual generation equals 600 million kWh (7200 hours) and planned the Sever power plant 17 billion kWh. However the operational cost is relatively low, about €0,02 per kWh. It is related with inexpensive maintenance. One constructed power plant does not generate additional costs. Moreover the barrage technology has long operational life time, even to 200 years [27]. The TSG technology is still in experimental stage and the final cost of the TSG power plant is not established. An investment cost depends from location. For installation at shoreline it is about 5650 €/kW, for near-shore 6825 €/kW and for offshore (in relatively long distance from shore) 8000 €/kW. Estimate components of the TSG project costs consist of:

- mechanical and electrical components (about 30% of total cost),
- material and structure (about 20% of total cost),
- sitting, environmental monitoring and permitting (about 20% of total cost),
- mooring and foundation (about 15% of total cost),
- installation and decommissioning (about 10% of total cost),
- transmission and grid connection (about 5% of total cost)

The last one point does not encompass cases when the grid is not strong enough. If the electrical network is weak there are additional cost related with grid development. Operation and maintenance costs are also depends from the location however it is not the only one factor which has influence on that costs. For power plants located in shoreline it is about 145 €/(kW*year), for near-shore power plants 150 €/(kW*year) and 160 €/(kW*year) for devices deployed in long distance. Average lifetime of the TSG is about 25 years. The economical side of the WEC technologies is not established yet. The price limitation of prototype projects is between €6450 and €13500 per kW. Initial capital investment costs of first production devices are between €2500 and €7000 per kW. At present average operation and maintenance costs are about 140 €/(kW*year) for power plants located in shoreline, 145 €/(kW*year) for devices deployed near shore and 155 €/(kW*year) in case of offshore in long distance from shore. Therefore the WEC technologies are not competitive however high energy price is forecast to decrease. Average performance of the WEC devices is between 3000h to 4000h (depends from technology). Average life time of the WEC power plants is about 25 years. The UK is the country which would like to use the marine energy as a source of a clean energy to achieve resolution of the Kyoto agreement. The UK government plans to spend £ 130 million for capital investment to deploy 60MW pre-commercial arrays. The marine energy industry development is planed to realized in three stages [27]:

The first stage consists in support for small power plants up to 1MW capacity. Technologies are mature enough to deploy prototypes on the open sea, in first step of the first stage and to deploy full-scale grid connected farms. The estimate cost of the first stage is about £ 30 million.

The second stage is a period of first competitive marine power plants. Planned for farm with from 2 to 10MW capacity. However upfront capital grand will be still required due to unpredictable first farms production. The estimate cost of the second stage is between £ 42 to £ 84 million for investment support and from £ 0.9 to £ 4.2 per annum for operating support.

The third stage establish over 10MW capacity farms development. It is a period when the expected cost of continuous and uninterrupted energy generation is between £ 75 and £ 125 for MWh.

VI. CONCLUSION

With 2/3 of the earth's surface covered in water, ocean waves represent our planet's last untapped natural renewable energy resource. The waves hold tremendous amounts of energy – we only need to tap into it.

According to the IEA-OES, Annual report in 2017, it is estimated that 80,000TWh of electricity per year can potentially be captured from ocean waves – sufficient to meet our global energy demand five times over. If we can use only a minor part of this potential, it would be a great leap for mankind, especially considering that the vast majority of the world population lives in close proximity to coastlines.

Waves are not created equal along all coastlines. The combination of the Earth's rotation and prevailing winds from the west means that regions with high wave energy resources are typically located along the western coasts of the continents. This is especially true of locations where the trade winds act – above latitude 40 degrees north and below about 25 degrees south – and where the waves can travel without any obstacles for thousands of nautical miles. Wave climates close to the equator are normally not the most cost effective.

The potential for efficient wave power utilization around the globe is high, with many wave-power rich areas of the world close to large population concentrations including Scotland, Ireland, Norway, France, Spain, and Portugal. In North America; Canada, the US West coast and Hawaii have ideal steady wave climates and in South America, Chile in particular has the same. Finally, southern Africa, Australia, and New Zealand have promising potential as well.

The energy resource in waves is quoted as the average annual power per meter wave front [kW/m], which is to say – that if the number 25 kW/m is quoted – the waves at that site have been recorded to have an average of 25kW/m power content over a year or whatever length the recording represents. As this is an average there will be days with next to no power in the waves but also times when the wave power is orders of magnitude greater. This large variation between extremes puts great strain on any wave power device to be efficient in the small waves and survive in the large ones[28].

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