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Review Paper

A Review of Ocean Wave Power Extraction; the primary interface

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Abstract

This paper aims to describe the importance of data, data collection methods, parameters to estimate the potential of wave energy and environmental impacts. The technical and economical status in wave energy conversion is outlined. Power and energy efficiency relationships are discussed. Many different types of wave-energy converters have been detailed. The progress in wave energy conversion in Malaysia is reviewed.

Keywords: Wave energy, Wave parameters, Wave data sources, Energy conversion, Environmental impact

1. Introduction

Renewable energy resources need to be explored to maintain and meet energy demand and replace the slowly depleting fossil fuels. The need for energy resources for future is recognized by all countries as their economic growth and self-reliance will depend mainly on vital field of energy. The increase in oil prices, the depletion of coal resources, the possible threat to the environment due to effluents from fossil fuels and nuclear power plants has prompted the technological developments in the utilization of renewable sources of energy such as solar, wind, biological and ocean energy programs. The sources of energy from the seas are waves, tides, currents and salinity gradients and natural thermal differences in the oceanic water. The idea of converting the energy of ocean surface waves into useful energy forms is not new.

The wave energy is suited for countries with vast coast line and high waves approaching the shore. It is free from environmental pollution and continuous as waves are never going to cease. The extraction of energy from the waves can be a viable solution to the enormous power requirements of a country like Malaysia having a vast coastline. The present technology of wave energy conversion may be economically not encouraging when compared to the conventional energy sources like fossil and hydro power. However wave power, could be economically viable for remote islands and main land.

Ocean wave power is a more promising resource, because waves originate from storms far out to sea and can travel long distances without significant energy loss, power produced from them is much steadier and more predictable, both day to day and season to season. Wave power production is much smoother and more consistent than wind or solar, resulting in higher overall capacity factors. Wave energy varies as the square of wave height, whereas wind power varies with the cube of air speed. Water being 850 times as dense as air, these results in much higher power production from waves averaged over time. Wave energy needs only 1/200 the land area of wind and requires no access roads and infrastructure costs are less.

Wave energy has long been considered one of the most promising renewable technologies. Not only is the energy resource, but it is more dependable than most renewable energy resources wave power at a given site is available up to 90 % of the time, while solar and wind availability tend to be available just 20–30 % of the time [1]. There are more than 1000 different patented proposals for wave energy devices, and several have demonstrated the potential for commercially viable electricity generation.

The greatest potential for wave energy exists where the strongest winds are found at the temperate latitudes between 40^0 and 60^0 north and south; on the eastern boundaries of oceans. Worldwide, wave energy could potentially provide up to 2TW of electricity, according to the World Energy Council, approximately 1/5 of current global energy demand [1]. The economics of wave energy power, though not yet competitive with fossil fuels, are promising, and the situation is improving with more advanced technology.

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In Malaysia research and development study of wave energy conversion began, after the 8th Malaysian National plan in early 2000. Malaysia with exploitable wave power resources considered wave energy as a possible source of power supply and introduced support measures and related programmes for wave energy. Several research programmes with government support started recently, mainly in Universities, aiming at developing proto type wave power conversion technologies in the medium and long term [2-5]. University Malaysia Terengganu (UMT) has initiated research work in renewable energy including wave to find a suitable renewable energy from Malaysian sources.

2. Wave Data Sources

There are various categories of wave data available such as instrumental measurement, visual observations, wave hindcasting and remote sensing to fulfill the purposes.

2.1 Instrumentals Measurement

Wave instrumentals measurement or direct observation was the most accurate way to measure the wave height concerning the area of each particular study. However this method needs a highest cost, expose to the vandalism and unfortunately scarce limitary point data in the fields of wide areas. This measured wave data can only be used to calibrate the other measurement. There are four main categories of instruments to measuring the wave, which are known as wave staff, sub-surface sensor, buoys and ship borne systems.

2.2 Visual Observations

There is a huge volume of observations of waves from ships in normal service all over the world, and these are held in data banks of various meteorological offices. A major source of visual wave data is the compilation made by Hogben and Lumb [6], which cover most of the ship routes to and from Europe. The Pacific Ocean is not so well documented but this can be supplemented with the data from Yamanouchi and Ogawa [7], which covers that ocean in detail. Another important compilation is due to Walden [8] containing visual observations performed in the North Atlantic Ocean Weather Stations during a period of 10 years. The observations are divided into subsets for each combination of area, season and wave direction. In particular, the distribution of the wave periods conditional on the wave height was corrected by an analytical modeling of the joint probability distribution of heights and periods, avoiding use of visual observations. Afterwards, this distribution together with the marginal distribution of visually observed wave heights was used to reconstruct the scatter diagram of wave heights and periods by a computer analysis program.

2.3 Wave Hindcasts

Hindcast wave data could be an alternative to visual wave observation. Compared with data from instrumental measurements, hindcast data cover a much wider sea area and do not miss storms due to instrument malfunction. Hindcast techniques use records of wind speed to estimate corresponding wave conditions. This is achieved by modeling the process of generation and propagation of waves by wind [9]. The hindcast data is a good means of interpolating wave statistics between instrumental sites. They give data over longer periods and also give directional information, which is available from very few instrumental sites.

2.4 Wave Remote Sensing

Remote sensing is one of the indirect observations and it is defined as making measurement by using electromagnetic waves, so that no mechanical disturbance of the sea-surface is caused. This indirect observation is not so sensitive comparing with the direct observation but we can get the data easily and cheaply in wide areas with the same instrument in short time of period. Remote sensing is widely applied to research of the ocean. At present the space-borne radars allow us to realize a global overview of the state upper layer of the ocean surface and to obtain information on its characteristics, such as significant wave height (altimeter), and wind speed (altimeter and scatterometer). Electronic wave scattered by the ocean surface contain the information on its characteristics. A wide range of electromagnetic wavelengths has been successfully used, from infrared pulsed lasers to high frequency radio waves traveling horizontally over the sea surface and being reflected back by sea waves of half their wavelength. There are two classes of remote sensors for waves; direct and indirect sensors. Direct sensors measure directly some relevant parameter of the wave system.

3. Currently Available Wave Data Collection in Malaysia

Presently, sources for wave data especially on wave height and wave period available in Malaysia for engineering purposes are limited [3]. Researchers rely on the visual observation data and the wave spectrum, which are based on western sea conditions and parameters for engineering applications.

British Maritime Technology (BMT) provides the data that contains statistics of ocean wave climate for whole globe generally known as Global Wave Statistics atlas. The data are presented in terms of probability distributions of wave heights, periods and directions for global selection of sea areas. The data have been derived by a quality enhancing analysis of a massive number of visual observations of both waves and winds reported from ships in normal service all over the world using computer program called NMIMET [3].

Malaysian Meteorological Service (MMS) provides monthly statistics of marine meteorological observation information such as wind waves and swells. The wave and wind data collected are derived from marine surface observations reported by ships operating in the Malaysian waters which participated in the World Meteorological Organization Voluntary Observation Ships Scheme, oilrigs and lighthouses. MMS also provides the forecasting wave data and buoy data. MMS also uses a wave-forecasting model called WAM. The data provided by the MMS is presented on monthly charts with individual values in squares of 2^0 latitude by 2^0 longitude and with forcing by MMS 6-hourly wind field [3].

4. Wave Energy Resource Characterization

Assessing the performance of a Wave Energy Converter that is, predicting the effective amount of energy converted from the incident wave field over certain period of time in nominal operation conditions necessarily requires a precise knowledge of the local wave climate. The developers, indeed, need to optimize their devices in order to fit them to actual wave conditions at the envisioned zone of deployment. The main wave characteristics are commonly given in terms wave height, period, direction of propagation and power.

The variability of wave conditions in coastal waters is generally very large compared to offshore waters. Near-shore variation in the wave climate is compounded by shallow-water physical processes such as wave refraction, which may cause local "hot spots" of high energy due to wave focusing particularly at headlands and areas of low energy in bays due to defocusing. In addition, other coastal wave processes such as wave reflection, diffraction, bottom friction and depth-induced breaking effects may have some influence. As averaged over years, offshore wave-power levels in the range of 30–100kW/m are found at latitudes 400–500, and less power levels further south and north. In most tropical waters, the average wave-power level is below 20 kW/m. Offshore wave-power levels may vary from a few kW/m during calm weather to several MW/m during storms. Wave-power levels will vary over time, on many different time scales: hours, days, weeks, months, seasons and years. There are also important wave variations on shorter time scales: wave periods and duration and intervals between wave groups. In spite of their importance, information on wave groups are not always taken care of by wave spectra obtained from wave records. Availability of time series, in addition to wave spectra, from wave records, is also very desirable, concerning practical wave-energy conversion. The variation in offshore wave-power levels is quite large. The average wave energy for a winter month can be 5–10 times the mean value for a summer month. The wave energy can vary 10 times from one week to the next. The wave energy during one storm can be 5 times higher than the mean value for the week the storm occurs. Wave energy in wave groups can be up to 50 times the wave energy between wave groups. Extreme storm seas contain very much wave energy and contribute significantly to yearly mean values of wave-power level [10].

The wave power estimation using the altimeter wave data will give an account of the distribution of wave energy in space and time. Since the last few decades, the hydrodynamics of ocean waves have been thoroughly studied and now it is possible to determine the energy content of the sea with the help of large amount of wave data collected. The power (P) in wave can be expressed by the formula [11],

$$P = 0.55\ H2s\ T, \quad \text{kW per meter of crest length,} \qquad (1)$$

where H_s, is the significant wave height in meter and T is wave energy period in seconds.

The term wind sea is used for waves that are actively growing due to forcing from local wind. These waves travel in or close to the local wind direction. Swell is the term used to describe long-period waves that have moved out from the storm area where they were generated. Swells spread out over the ocean with little energy loss. They are somehow analogous to waves spreading out from the splash of a stone thrown into a pond. Swells in deep water will typically have wavelengths of 100–500m depending on the wind speed. In this context, deep water is understood to mean that the water depth exceeds about one third of the wavelength. Then the seabed has a negligible influence on the wave. An instantaneous picture of the ocean offshore will generally reveal several wave trains with different wavelengths and directions. Swells may coexist with Wind Sea. In contrast to a single-frequency sinusoidal wave propagating in a particular direction, a real sea wave may be considered as composed of many elementary waves of different frequencies and directions. Per unit area of sea surface a stored energy (E) amounting to an average of

$$E = \rho g H2s / 16 \qquad (2)$$

is associated with the wave, where ρ is the mass density of sea water, and g is the acceleration of gravity, whereas Hs is the significant wave height for the actual sea state [12]. This stored energy is equally partitioned between kinetic energy, due to the motion of the water, and potential energy. The potential energy is due to mechanical work performed when the flat water surface is being deformed to a wavy. This work corresponds to water lifted against the gravity force from wave troughs to wave crests. For wavelengths exceeding a few centimeters, the capillary force has a negligible contribution to the potential energy.

The wave climate and energy resource can be presented by the long-term statistics presented in Table 1 below, which were mostly proposed in WERATLAS [13].

Table 1 Long-term wave data statistics [13]

Distribution of wave and wave-energy parameters	
Tables	**Plots**
Frequency table of Hs Exceedance table of P Bivariate frequency table of (Hs,Te) Bivariate frequency table of (Hs,Tp)	Probability density of Hs Exceedance distribution of P Bivariate probability density of (Hs,Te) Bivariate probability density of (Hs,Tp)
Seasonal and Inter-annual Variability	
Plots and table of monthly mean value and confidence limits for Hs Plots and table of monthly mean value and confidence limits for P	

5. Design Approach

The design and construction of the structure are the most critical issues in WEC technology, and the most influential on the economics of energy produced from the waves. In the present situation, the construction dominates the cost of the WEC plant. So, in the preliminary studies of a WEC plant, the first step usually consists in defining the sitting and basic geometry of the plant's structure. This is established, taking into account geo-morphological constraints and local wave climate, from the wave energy absorption hydrodynamics, with the aid of numerical modeling and of wave basin model testing. Such modeling provides the information required for the specification of the power take-off equipment. The standard approach to appraising WEC output and economics is described by Thorpe [14]. To easy understanding the simplified approach is shown in Figure 1.

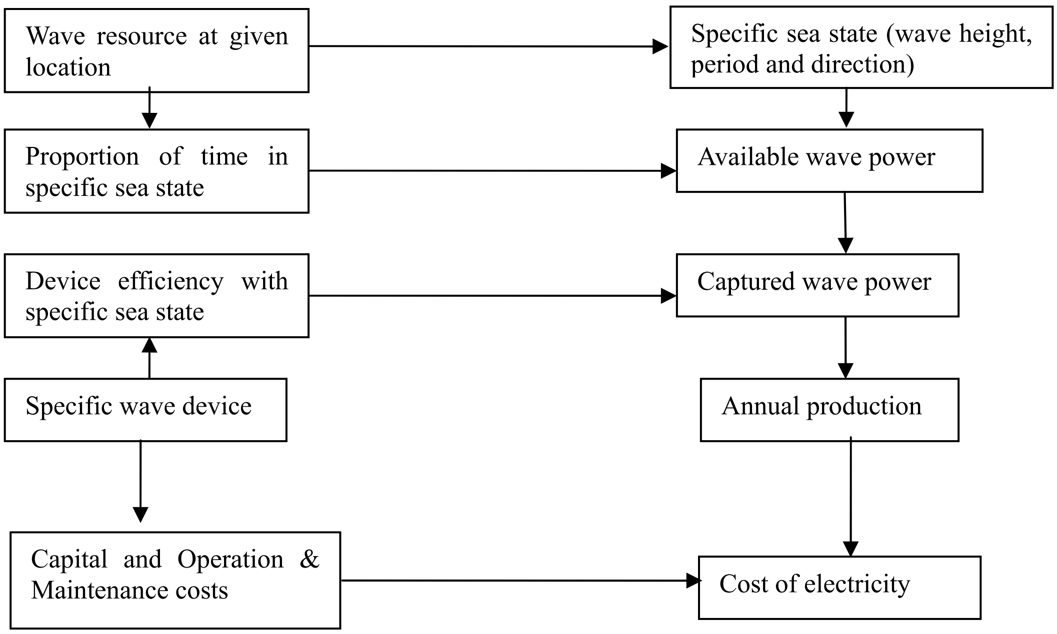

Fig. 1 Methodology for appraising WECs [14]

6. Wave Energy Converters

The physical law of conservation of energy requires that the energy-extracting device must interact with the waves such as to reduce the amount of wave energy that is otherwise present in the sea. The device must generate a wave, which interferes destructively with the sea waves [13, 15]. Wave energy has not yet converged to a single and unique technology. So far many different concepts of devices have been proposed by inventors for more than two centuries [16-20]. Of these some have achieved the prototype state and already having faced real sea conditions. In fact it might be more than one converter type that reaches the stage of large-scale implementation. Generally, the existing devices are classified according to the distance between the location of the installation and the shore. Shoreline devices do not require long underwater electrical cables or deep-water moorings. However, they have limitations regarding the potential sites to be installed because they are fixed or embedded in the shoreline, typically water depths do not exceed 10m, therefore subject to a much less powerful wave regime. The near shore devices, typical depth range 10-25m, enjoy a more energetic wave climate than the shoreline devices. However, they require suitable seabed conditions for installation. There are many types of offshore devices, typical depth around 50m. This class of devices explores the more powerful wave regimes available in deep water before energy dissipation mechanisms have had a significant effect on wave power levels.

Worldwide economically recoverable wave energy resources are in the range of 140 to 750 TWh/yr. With projected long-term technical improvements, this could be increased by a factor of 2 to 3. WEC devices have the greatest potential for applications at some part of the coastline of the countries because of the combination of the relatively high ratio of available shoreline per unit energy requirement, availability of greater unit wave energies due to trade winds, and the relatively high costs of other local energy sources. At present the following devices are used to convert the wave energy.

6.1 Attenuators

Attenuators are long multi segment floating structures oriented parallel to the direction of the wave travel. The differing heights of waves along the length of the device causes flexing where the segments connect, and this flexing is connected to hydraulic pumps or other converters. The attenuators with the most advanced development are the McCabe wave pump and the Pelamis (Figure 2).

The McCabe wave pump (Figure 3) has three pontoons linearly hinged together and pointed parallel to the wave direction. The center pontoon is attached to a submerged damper plate, which causes it to remain still relative to fore and aft pontoons. Hydraulic pumps attached between the center and end pontoons are activated as the waves force the end pontoons up and down. The pressurized hydraulic fluid can be used to drive a motor generator or to pressurize water for desalinization.

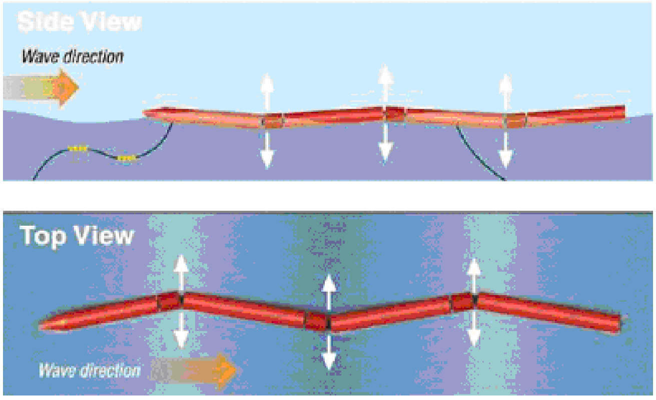

Fig. 2 Pelamis [21]

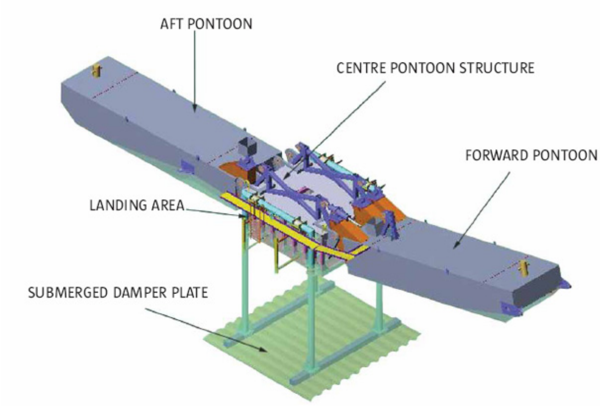

Fig. 3 McCabe Wave Pump [21]

6.2 Point Absorbers

Point absorbers have a small horizontal dimension compared with the vertical dimension and utilize the rise and fall of the wave height at a single point for WEC (Figure 4). The construction involves a floating structure with one component relatively immobile, and a second component with movement driven by wave motion (a floating buoy inside a fixed cylinder). The relative motion is used to drive electromechanical or hydraulic energy converters. Float or buoy systems that use the rise and fall of ocean swells to drive hydraulic pumps. The object can be mounted to a floating raft or to a device fixed on the ocean floor. A series of anchored buoys rise and fall with the wave. The movement "strokes" an electrical generator and makes electricity that is then shipped ashore by underwater power cable.


Fig. 4 Point Absorber Energy Converter [22]


Fig. 5 AquaBuOY Wave Energy Converter [23]

Figure 5 is another type of point absorber that is the third generation that utilizes the wave energy to pressurize a fluid that is then used to drive a turbine generator. The vertical movement of the buoy drives a broad, neutrally buoyant disk acting as a water piston contained in a long tube beneath the buoy. The water piston motion in turn elongates and relaxes a hose containing seawater, and the change in hose volume acts as a pump to pressurize the seawater.

6.3 Overtopping Devices

Overtopping devices have reservoirs that are filled by impinging waves to levels above the average surrounding ocean. The released reservoir water is used to drive hydro turbines or other conversion devices. Overtopping devices have been designed and tested for both onshore and floating offshore applications. The offshore devices include the Wave Dragon (Figure 6) [24], whose design includes wave reflectors that concentrate the waves toward it and thus raises the effective wave height. Wave Dragon development includes a 7-MW demonstration project off the coast of Wales and a pre commercial prototype project performing long-term and real sea tests on hydraulic behavior, turbine strategy, and power production to the grid in Denmark. The Wave Dragon design has been scaled to 11 MW [25], but larger systems are feasible since the overtopping devices do not need to be in resonance with the waves as is the case for point absorbing devices.

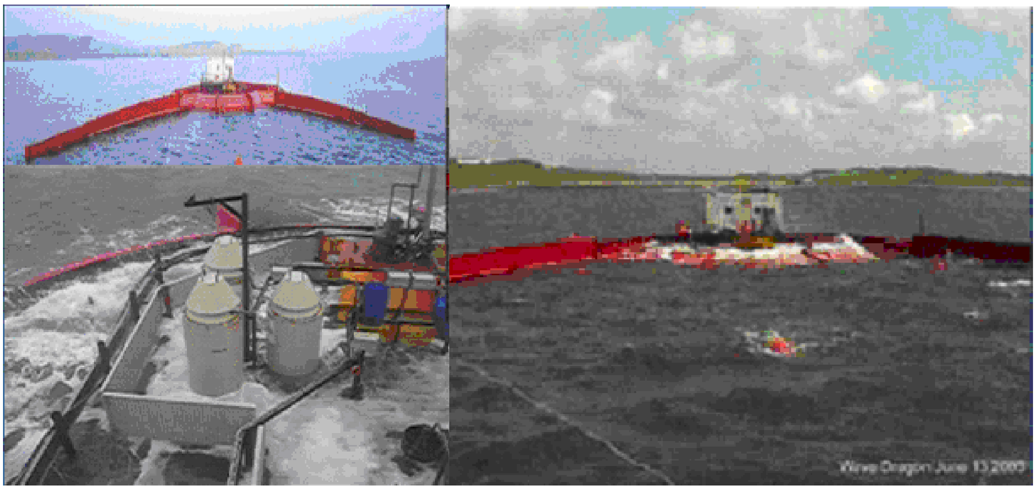

Fig. 6 Wave Dragon Overtopping Device [24]

6.4 Terminators

Terminator devices extend perpendicular to the direction of wave travel and capture or reflect the power of the wave. These devices are typically installed onshore or near shore. However, floating versions have been designed for offshore applications. The oscillating water column (OWC) is a form of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. The wave action causes the captured water column to move up and down like a piston to force the air though an opening connected to a turbine (Figure 7).

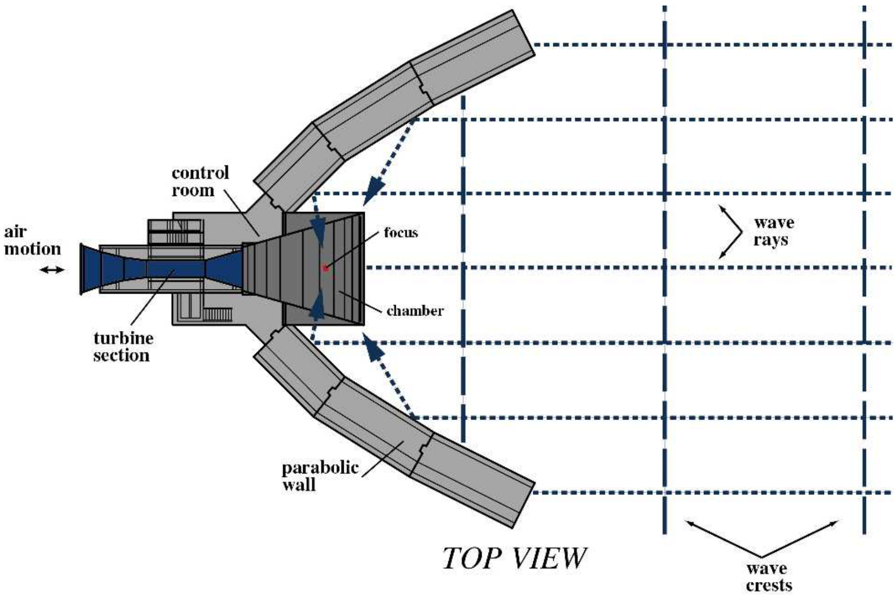

Fig. 7 Oscillating Water Column [26]

7. Economic Considerations

Unless special conditions arise, wave power will be assessed on the same basis as other renewable energy generating plant, coal, oil, nuclear, gas turbine, etc. The preferred plant will always be that which will enable the generating system to continue to meet a changing demand at the minimum overall cost. Each new plant is therefore assessed for the balance between the cost of installation, operation and maintenance and the overall savings, primarily of expensive fuels, which it would be expected to make in normal operation over its life.

Based on economical consideration two important design objectives can be identified. Firstly, for each site it will be necessary to optimize the scale of the device, which will be determined by the wave climate, and its rating. These will be chosen to balance the improvements in net availability against the increasing specific cost which reducing the device rating will achieve. Secondly, in order that the overall availability can even approach this potential optimum, the system must be as simple, maintainable and reliable as possible.

8. Environmental Considerations

Wave energy devices produce no gaseous, liquid or solid emissions and hence, in normal operation, wave energy is a virtually non-polluting source. However the deployment of wave power schemes could have certain impact on the environment. Some of the effects may be beneficial and some potentially adverse. The most commonly cited potential environmental impacts of wave energy technologies are noise, hydraulic fluid spill, visual effects, hydrodynamics and mammal perturbations. However these have not been studied in detail. It is also worth to look at the similar positive environmental impacts, i.e. wave energy devices could enhance marine life by providing structure, acting in much the same way as artificial reefs. Common and different aspects of the devices should be identified.

Small-scale wave energy plants are likely to have minimal environmental impacts. However, some of the very large-scale projects that have been proposed have the potential for harming ocean ecosystems. Covering very large areas of the surface of the ocean with wave energy devices would harm marine life and could have more widespread effects, by altering the way the ocean interacts with the atmosphere. Wave power plants act as wave breakers, calming the sea. Changes in waves and currents would most directly impact species that spend their lives nearer the surface. Wave energy is promising, holds a huge potential to reduce reliance on fossil fuels, and is considered to be relatively environmentally benign at this time.

The environmental impact assessment will be an essential element for large-scale ocean wave energy permitting. If not approached well in advance before potential park-scale development takes place, a number of acceptance issues and even substantial delays in permitting or rejection by the authorities can be the consequence. Thorpe TW [27] summarizes the environmental impacts of wave energy conversion technologies as follows (Table 2).

Table 2 Environmental impacts of wave energy conversion technologies [27], W: weak effect; M: medium effect

Environmental Effects	Shoreline	Near shore	Offshore
Land use	W		
Construction/Maintenance	W		
Recreation	W	W	
Costal Erosion	W	W-M	W-M
Sedimentary Flow Patton		W	W
Navigation Hazard		W	W
Fish and Marine Biota	W	W	W

9. More Government Support Needed for Wave Energy Research

Government of Malaysia must increase their support for wave energy research because the technologies are a crucial element in achieving a balanced global energy future, wave energy can make major contributions to the diversity and security of energy supply and to economic development. Considerable attention has been drawn to their potential for mitigating climate change. We need to use public funds as effectively as possible in achieving this. Malaysia must improve her market deployment strategies for wave energy technologies and, above all, increase targeted wave energy research and development.

10. Conclusions

The wave energy resource is extremely large and offers the possibility of environmentally benign energy at moderate cost. There are a range of wave energy concepts which could produce modest and substantial amounts of power. Shoreline devices are already viable in certain locations and could be exploited in many others. Further improvement is needed on wave energy data and data collection methods. On the basis of currently available empirical information, the environmental impacts are expected to be small; however, efforts should be made on environmental effects by wave energy projects. This could be essential to sustainable development of wave energy. Government of Malaysia must increase their support for wave energy research in achieving a balanced energy future.

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