IJASRM International Journal of Advanced Scientific Research and Management, Vol. 3 Issue 5, May 2018.
www.ijasrm.com
ISSN 2455-6378

Potential of Wave Power as Source of Electricity in Malaysia

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Abstract
Wave power is one of the most resourceful and a constant-contributed source of energy at the ocean or the shoreline. At the same time, the production of wave energy is bringing new perspective and methodology to renewable and sustainable energy. This paper review the development of wave energy in the other country other than Peninsular Malaysia covering the impact of wave energy from the perspectives of its science, the costs, and its environmental impact of developing wave power devices. Then, this paper presented the actions and solutions that should be taken by the Peninsular Malaysia toward solving the global warming and climate change. Furthermore, this research also covered the potential sea sites for which Peninsular Malaysia to develop the wave power devices, that is the east coast of Peninsular Malaysia and the Malacca Strait. A short review about the environmental impact of developing wave power plants at both the shoreline, as well as the coastline respectively were presented in the paper. Although wave energy is a reliable source of energy, the costs of development and maintenance of the wave power devices is far too expensive to be practical.

Keywords: *Wave power; Renewable and Sustainable Energy; Energy; Economic; Environment.*

1. Introduction

As the world emerging into a more advanced technological generation, many daily consumptions are indeed needed – one of the consumptions is energy. Energy is one of the most highly demanded “food” for operating almost all living things or running objects or substances, let alone, human. In Peninsular Malaysia alone, this has no exception. Peninsular Malaysia has many renewable resources that has been working on for the past recent years. There were many studies conducted in the area of renewable energy in Malaysia [1-7]. However, the main focus of this paper is solely depending upon four intentions, which are (1) the potential sites of wave power devices development in Malaysia at the east coast of Peninsular Malaysia and the Malacca Strait (2) the review about the science of wave energy and its development (3) the costs of developing and maintaining wave power farms and (4) the environmental impacts toward the marine life while operating wave power devices at the ocean.

1.1 Malaysia Background Research of Renewable Energy Production

Peninsular Malaysia energy supplies are based solely on the production and sales of crude oil and natural gas and has a Reserves-to-Production R/P ratio of 38.2 years. According to data, Malaysia has its natural gas reserved as many as 83 trillion standard cubic feet (tscf) as of 2010. But, the production has been declining at about 10% on average per annum [8]. Coal is also another example of Malaysian energy production, with as high R/P ratio of 285 years, Malaysia′s production of coal reserves of over 1938 million ton [8]. The *Suruhanjaya Tenaga* (ST) Malaysia has awarded some new licenses for the two 1-GW units of supercritical coal-fired power plants at both *Tanjung Bin* and *Manjung*. Meanwhile, ST has also called for bids for the new coal or the gas fired power plants in view of the expected expiry of some of the original Independent Power Producers (IPP) licenses from 2015 onwards; ST is still renegotiating the existing IPP power purchase agreements for possible extension of 5 to 10 years. On the other hand, hydroelectric power is also considered as one of many of Malaysia energy sources. Malaysia does possesses some substantial hydroelectric resources. Unfortunately, to develop a hydroelectric power plant is capital intensive and overwhelmingly complex. The dam involves not only the design, the construction, and the operation of the water dams, but it also substantially affected the Malaysia's environmental, social, and political considerations. Lastly, Malaysia also have taken the nuclear energy into consideration, however, only a handful of research and actions has been contributed and carried out due to many objections from the Malaysian themselves [8].

1.2 Malaysia's Approach to Solve Global Disasters

As the issues of energy consumptions are striking right into the world, Malaysia energy sector has been seeking for more reliable, green, efficient, and cost-effective energy solutions and resources to continue the supplies for the highly demanding local energy consumptions. By doing that, those energy sectors promote efficient utilization, advocating its supply diversification, and discouraging wastage on many aspects – like foods, drinks, electricity usage, etc. Moreover, Peninsular Malaysia is also trying to adopt renewable and sustainable energy solutions – research alone showed that, the issues of global warming and climate change had dramatically increased globally over time; as Peninsular Malaysia is still one of the largest contributors of carbon dioxide gas into the air [8].

The Intergovernmental Panel on Climate Change (IPCC) stated that, the total anthropogenic greenhouse gas (GHG) emissions continued to increase between 1970 and 2010 [9]. Despite a growing number of climate change mitigation policies have been realised and some actions have been carried out, annual GHG emissions are still growing with an average of 1.0 Gt carbon dioxide equivalents ($GtCO_2eq$) or 2.2% per year from 2000 to 2010 – Compared with 0.4 $GtCO_2eq$ or 1.3% per year from 1970 to 2000 [9]. The IPCC also reported a possible increase in global temperatures from 1.1 °C to 6.4 °C [8] and the rise of the sea levels from 16.5 cm to 53.8 cm by 2100 [9]. Although these data are global, however Peninsular Malaysia have the similar issues.

1.3 Wave Energy Potential Sites at Peninsular Malaysia

Energy comes from various type of forms, as one of them is from the ocean waves. To understand this, considering during the days, the sunlight would heat up the Earth, and winds are massively generated and so as its energy. Ocean waves are basically being generated by those winds that swipe through and passing by the surface of the ocean, and this constant process causes the ocean surface to move at the parallel direction as the winds; along the process, thousands of kilometers of stored energy are being transferred without noticeable or any significant loss. Meanwhile, this wave energy is considered a very useful and efficient renewable and natural energy form to be used [10].

As those waves travel from the offshore toward the coast, its averagely collected energy is reduced due to the bottom topography friction. However, at the nearshore, wave energy is influenced by several factors including the coastal refraction and diffraction, wave breaking, and the sea bottom roughness. So, there may be some locations that both nearshore and offshore can be considered as a potential site for a wave farm [10]. Since then, numerous of wave power devices has been invented to capture this amazing amount of energy at the ocean [11], whereas these technologies are still yet to be consistently developed in the Peninsular Malaysia.

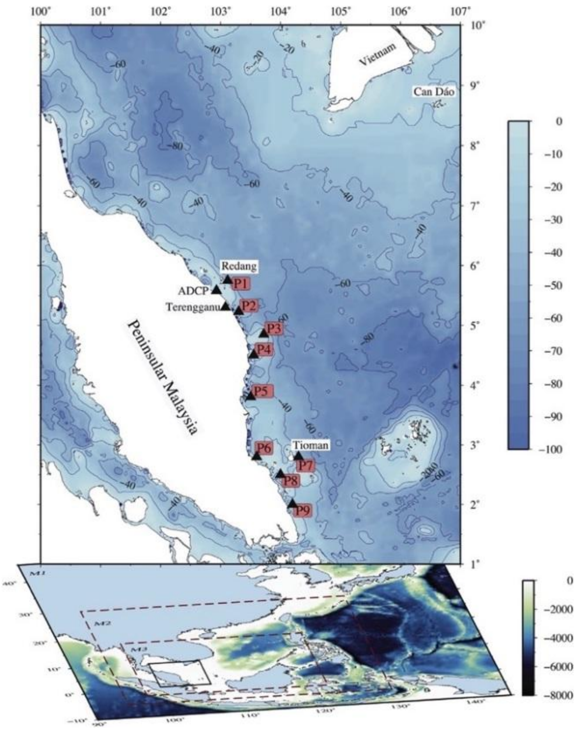

Fig. 1 The potential site at the east coast of Peninsular Malaysia. The red marks represent the nine different sites with different sea level.

The east coast of Peninsular Malaysia, which have a direct exposure from the South China Sea, is a potential site for Peninsular Malaysia to build a wave plant, where the wave power devices can be placed on. The reason is that, at this region of the sea, the east coast of Peninsular Malaysia forms the sea waves that travel from the far north area of the ocean; it could generate a massive amount of wave energy that might be stored and captured by the wave plant. The wave conditions at the east coast are also mainly influenced by its surrounding seasonal and inter-annual changes of the climate [10]. Moreover, due to the presence of the nearshore islands at the east coast site, the wave energy that can be generated is also depending on the site's conditions, which almost nine sites with different depths of sea level, as shown in **Fig. 1**, were selected to investigate the temporary distribution of wave power at the coastal area of Peninsular Malaysia.

Other than the east coast, among the South East Asia, the sea regions in between the Bay of Benyal (BoB) and the Malacca Strait (MS) has also potentially shown to become a wave farm site for the wave power devices development [12]. Generally, the system needed a minimum of 10 years of generated data for the wave energy resource assessment – this is to avoid the years of variations that may massively influence the estimated results. The domain covered in this study and the area of focus in between BoB and MS are shown in **Fig. 2** [12].

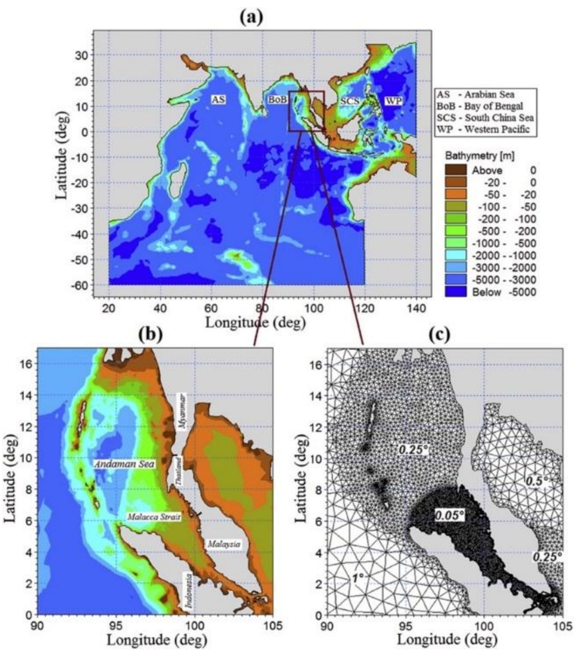

Fig. 2 (a) Domain and bathymetry covering Indian Ocean, South China Sea and part of Western Pacific, (b) Andaman Sea and Malacca Strait (c) west coasts of Malaysia and Thailand, and north coast of Sumatra region of Indonesia are marked by thin black lines

2. The Science of Wave Energy and the Development of Wave Power Devices

Wave energy is being considered as one of most natural and renewable energy that almost occurs anytime and anywhere around the ocean sites or coasts. As a matter of fact, wave energy could possibly cause some dramatic hazard to life or even damaging the ocean or marine property [13]. Therefore, the first ever computer-generated based wave forecast were built during the 1956s, and these early development of wave forecasts computers were to be used to determine the single wave height and the period of waves at each grid point – these grid points are the direct location between the local wind speed and wave height and period. Besides that, these computer-generated wave forecasts computers can minimize the risk of the loss of those marine life and property.

Back in time, when these computer-generated wave forecasts models were implemented at the National Weather Service, it's been found out that the representative wave approach did not go orderly to the inherent complexity of the wave field on the ocean surface. With that, forecast skills of such models were limited. The complexity of the sea conditions indicate that it consists of the randomness of the superposition of waves of different wavelengths, propagating in different directions, and that the only logical way to describe it is through a statistical description of the inherent spectrum [13].
A more complete description of the sea conditions, as well as the potential for a much better forecast though, can be realized or showed by predicting the so-called energy spectrum $F(f, \theta)$. This spectrum describes the distribution of wave energy over wave frequency f and wave propagation direction [10]. From such a spectrum, the wave height H_s can be calculated as

$$H_s = 4\left[\iint F(f,\theta)\, df\, d\theta\right]^{\frac{1}{2}}, \qquad (1)$$

$$m_0 = \iint F(f,\theta)\, df\, d\theta, \qquad (2)$$

where m_n represent the spectral moment of order n,

$$m_n = \int_0^{2\pi}\int_0^{\infty} f^n F(f,\theta) df\, d\theta, \qquad (3)$$

where f is the wave frequency, and θ is wave direction and $F(f,\theta)$ is the spectral density.
The energy period T_e is also defined as,

$$T_e = \frac{m_{-1}}{m_0}, \qquad (4)$$

where m_{-1} and m_0 both are minus the first and the zeroth moments of the wave spectrum respectively [10]. By using the peak wave period T_p, the T_e was defined. Yet, the relationship between both T_p and T_e are depending on the shape of the wave spectrum and which the equation can be derived as,

$$T_e = \alpha T_p, \qquad (5)$$

International Journal of Advanced Scientific Research and Management, Vol. 3 Issue 5, May 2018.
www.ijasrm.com
ISSN 2455-6378

whereas the coefficient α is depending on the shape of the wave spectrum and it can be obtained by the numerical integration of the wave spectrum [14]. Thus, 0.9 is the value that based upon Goda's experiment [15] .

Furthermore, the wave energy propagation during the travelled pathway depends on the group velocity C_G , since the energy transport velocity equals the group velocity. Hence, the wave energy flux (E_f), through a vertical plane of unit width perpendicular to the wave propagation direction [16] is,

$$E_f = EC_G , \tag{6}$$

where E is the wave energy and C_G is the group velocity, which is described as a function of wave frequency f and water depth d,

$$C_G(f,d) = \frac{g}{4\pi f}\left(1 + \frac{2kd}{\sinh(2kd)\tanh(kd)}\right), \tag{7}$$

And $k = 2\pi/L$ is the wave number and L is the wave length. In deep ocean conditions, $(d > 0.5L)$ the group velocity is defined as,

$$C_G = \frac{g}{4\pi f} . \tag{8}$$

For a sinusoidal wave of height H_s , the average energy stored on a horizontal square meter of the water surface is,

$$E = \rho g \int_0^\infty F(f)\, df = \frac{1}{16}\rho g H_s^2, \tag{9}$$

Half of this is potential energy due to the weight of the water lifted from the wave troughs to the wave crest. The remaining half is kinetic energy residing in the motion of the water. Therefore Eq. (6) can be rewritten as,

$$E_f = \frac{\rho g^2}{64\pi} H_s^2 T_e \approx (0.49) H_s^2 T_e \frac{\text{kW}}{\text{m}}, \tag{10}$$

where ρ and g are seawater mass density (1025 kg/m^2) and gravity acceleration (9.8 m/s^2), respectively. The above formula states the wave power is proportional to the wave period and to the square of the wave height. Moreover, when a significant wave height is given in meters and the wave period in seconds, the result is power in kilowatts (kW) per meter of the wave front length. In deep water, the group velocity equals half of the phase velocity and hence it is independent of water depth in Eq. (8).

However, as the waves propagate toward the coastal shallow waters, group velocity changes according to the water depth and wave length to the point where it becomes equal to phase speed in a given region where $(d < 0.5L)$. In this instance, Eq. (10) requires adjustment to take into account the energy fluctuations due to bathymetric changes. Following [17] the adjusted wave power is given as,

$$E_f^* = \beta E_f , \tag{11}$$

where β is the proposed correction factor based on the cross-correlation between the energy wave period T_e and significant wave height H_s:

$$\beta = 1 + \frac{\text{COV}\,(T_e\,, H_s^2)}{\bar{T}_e \cdot \bar{H}_s^2} , \tag{12}$$

Due to many uncertainties in computing the correction factors, a much smaller value of the second term on the right hand side may indicate how applying the correction factor is at times unnecessary. On the other hand, large values imply an underestimation of wave energy flux [10].

2.1 Development of Wave Power Devices

Peninsular Malaysia has not yet consistently developed a wave power devices to produce its energy supplies, however, this section was about to compare and contrast the development of wave power plants from other countries and relate it to Malaysia. Based on Khan, Kalair [18], there is about $8000 - 80000$ TWh of wave source being produced annually, which already more than half of the global electricity demand. To generate these amount of energy, numerous technologies had been invented such as the oscillating water column (OWC) device, nodding duck, wave energy raft, wave energy pendulum, overtopping device and pointing absorber [11].

These devices can be narrowly classified into two categories: the fixed position devices and the floating devices [11]. The fixed positional wave power devices are mainly located at the sea bottom or some rocky cliff sites, and the floating devices are usually being floated at around the coasts with sea waves. As a matter of fact, the construction of fixed devices are frequently influenced by the marine environments, like wind, wave, tide, and the sea water depth. Whereas the floating devices can always be constructed elsewhere the factory before operating it at the sea sites [19].

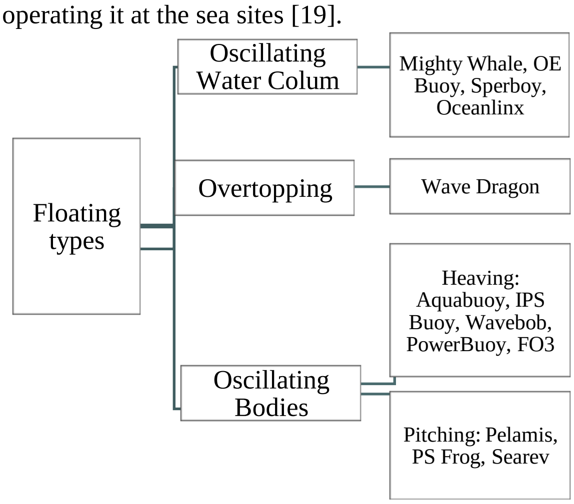

Fig. 3 Examples of devices of floating wave power devices

Besides that, the floating devices also can be classified into three categories: OWC (by using the relative motion between air and the platform), overtopping device (by using the relative motion between seawater and the platform), and oscillating bodies (using the relative motions among several parts of the device and the platform), which shown in **Fig. 3** [11]. Some of the floating wave power devices using the deformations or the piezoelectricity that is caused by the pressure comes beneath the ocean waves and to convert its wave energy. But, the efficiencies rate is less than 5% due to the low wave pressure produced [20].

2.1.1 The Oscillating Water Column

Oscillating devices of this kind usually are the main carrier to convert wave energy. By using only it's one simple body, its subsequent energy conversion mechanism is comprised of pipes in the body, air turbines, and generators. Moreover, this devices is water-proof and its biofouling and environmental impact are much slighter than the oscillating bodies [19].

2.1.2 Overtopping

Overtopping devices is one of the famous wave power devices that is currently being adopted widely. One of the devices is called Wave Dragon. Wave Dragon bear the weight of the carrier and its size is gigantic. To work in wind, current, or wave, its mooring system is very complex, as well as expensive. It puts its water turbine underneath the seawater [19].

2.1.3 Oscillating Bodies

Oscillating bodies convert wave energy into kinetic energy of the bodies through the relative motions among the bodies and the platform. Its shape of the bodies are usually round pie, long bar, or nodding duck, etc. During the energy conversion, the device converts the wave energy into the mechanical energy of the bodies. The devices themselves consist of a platform and one or more oscillating bodies. And, these type of devices are currently the mainstream of the world development.

3. The "Mighty Whale"

The "Mighty Whale" is one of the prototype of OCW. It's a steel floating structure and whale-like model which shown in **Fig. 4** [21]. The main body of the whole floating structure consists of as more as three air chambers with an area of $80m^2$ each at the front to allow and obtain wave energy. Each of the air chamber has an intake for sea waves underneath the seawater surface. When the sea waves enter the air chamber, the water level inside the air chamber will go up and down over and over again.

When more waves enter the chamber as the conditions of the sea waves are getting messier (with higher waves frequency), then the high-speed reciprocating airflow is formed and it drives the air turbine within the device, as well as its generator. A much more detailed look inside of the "Mighty Whale" can be referred in **Fig. 5**. Moreover, the wave energy is also being transformed into mechanical energy of air in the chambers [19] .

The "Mighty Whale" was installed with Eels turbines, whose conversion efficiency curve is shown in **Fig. 6**, where the horizontal axis denotes the attack angle, and the maximum efficiency of the Well turbine for "Mighty Whale" is about 47% [22]. Apparently, 8° and 12° are the current attack angles of the Wells turbines. If the attack angle is too large, the turbine is easy to stall and its start property is poor. But, when attack angle is optimum, the flow coefficient is low, and the turbine with a bigger diameter or a higher rotational speed is needed, so the turbine makes more noise. According to Masuda's research, when the significant wave period is $6.8s$, the conversion efficiency is the maximum, which is about 15% high. The properties of this wave-to-wire or total conversion of "Mighty Whale" are shown in **Fig. 7**.

"Mighty Whale" was built in Gokasho Bay Nansei Town Watarai District Mie Prefecture, Japan, where averagely, the annual incident wave power density is about 4 kW/m. The operation days is about 548 days, from August 1998 to December 2000 – except for the maintenance days and the system malfunction days. From the data by Wu, Chen [19], the total generated output consumption was 83.65 MWh, which the average output power was 6.36 kW and the average wave-to-power conversion efficiency was 5.3% (6.36 kW/(30 m × 4 kW/m)) [22].

Fig. 4 The Japanese “Mighty Whale”

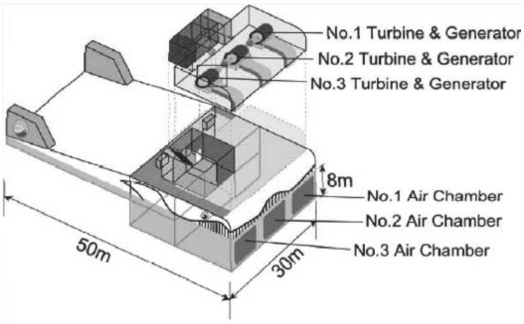

Fig. 5 Detailed Interior of “Mighty Whale” (with Air chambers and Turbines)

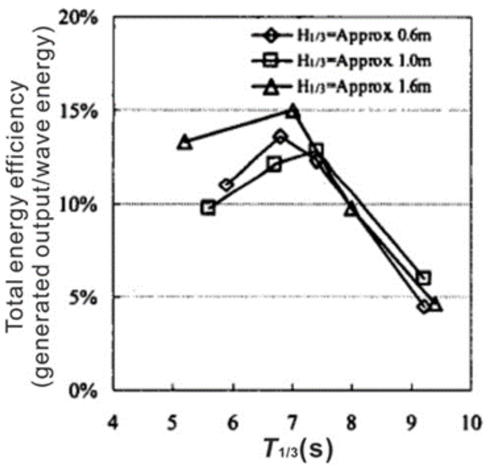

Fig. 6 Energy Output Efficiency of the "Mighty Whale"

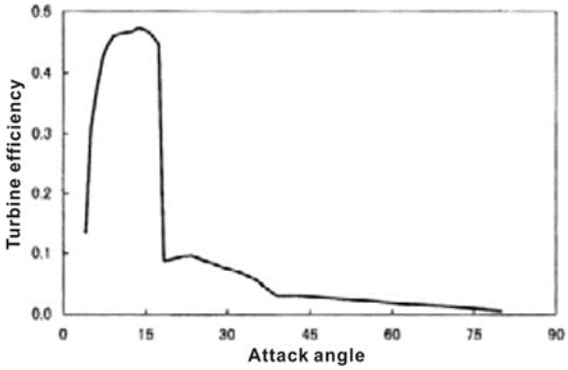

Fig. 7 The Turbine Efficiency for "Mighty Whale"

3. The Costs and Economic Impact of “Mighty Whale” Development

By using the costs of development of the “Mighty Whale” to be a reference as if Peninsular Malaysia is about to build one in the future. First of all, the “Mighty Whale” was developed by the Japan Marine Science and Technology Center (JAMSTEC) since the year 1987. This OCW has experienced almost 3.5 years on sea trials, which from September 10, 1998 until March 2002. The estimated costs of construction of this OCW including the construction in the factory and on the sea site, conversion system such as the air turbines and generators, mooring, cables, and monitoring equipment, etc. Some useful parameters of the “Mighty Whale” is shown in **Table 1** [19].

On the other hand, the “Mighty Whale” was being towed by two tugs, one is rated as 4200 PferdeStarke (PS) and the other 3000 PS and guarded by a 2000 PS boat. To reach the destination, the sea site, they all sailed for about 206 nautical miles, that is, 381.3km. a floating crane rated 1600t was rented to install the mooring [19].

In 2014, the purchasing costs of the “Mighty Whale”, which calculated in Renminbi (RMB), including the costs of equipment and ocean engineering is about 37.3034 million Chinese Yuan Renminbi (CNY) [19]. And the fellow costs can be illustrated in **Table 2**. As General, the service life cycle of a steel boat (which in this case the OCW “Mighty Whale”) is over 20 years. Imagine that the service life cycle of “Mighty Whale” is 15 years. If the technology is mature enough, and it can work 335 days, about 11 month per year, and the predicted total energy output of “Mighty Whale” is 767 MWh. Lastly, the estimated investment is about 37.3 million CNY, not including the costs of repair and maintenance, so as the electricity cost is about 48.64 CNY/kWh.

In order to keep the “Mighty Whale” on stationary, its structure was huge and tight mooring is needed. Although the stability of platform is confirmed, but the cost of those huge structure and tight mooring are more expensive to be considered. Finally, in order for peninsular Malaysia to consider the development of wave power devices, it would need large amount of costs to be invested – even just to build the worldly mainstream technological wave power device, the “Mighty Whale”.

Table 1. Parameter of "Mighty Whale" [19]

Geometric dimensions and weight					
Length (m)	Width (m)	Height (m)	Draft (m)	Weight (t)	Tonnage (t)
50	30	12	8	1290	4380
Mooring properties					
Sinker		Mooring chain			Middle sinker
165 t x 4 (net weight in water) 757 t	125 t x 2 (net weight in water) 268.76 t	160 m x 165 x 4 (441.5 kg/m in water) 334.24 t	130 mm x 100m x 4 (323.0 kg/m in water) 148.20 t	81 mm x 207 m x 4 (125.4 kg/m in water) 119.1 t	14 t x 12 (in water) 192.7 t)
Wells turbines: 3 sets					
Rated power	Maximum rpm	Blades	Tip diameter	Hup diameter	Weight
30 kW (900 rpm)	2000 rpm	NACA0021 (8 pieces)	1700 mm	1200 mm	480 kg
Generators: 4 sets					
30 kW x 2, 50 kW x 1, 10 kW x 1					
Power transmission equipment					
Lead-acid cell: 500AH x 132; incerter for loads: 20 kVA x 2; resistive load: 45 kW, 65 kW					

Table 2. Development Costs of "Mighty Whale" [19]

Parts	Constituents	Quantities	Unit price	Cost (in 1 million CNY)	Note
Main structure	Steel	1290 t	15,000 CNY/t	19.35	
Mooring system	Sinker	1043.76 t	6,000 CNY/t	6.2626	Iron scrap
	Mooring chain	601.54 t	8,500 CNY/t	5.113	
	Middle sinker	192.7 t	14,000 CNY/t	2.6978	Manufactured
PTO	Ait turbine	3	200,000 CNY	0.6	
	Generator	4	100,000 CNY	0.4	Rectifying equipment
Ocean engineering	Tug	3	150,000 CNY	0.45	
	Delivery boat	1	100,000 CNY	0.1	
	Small gondola	1	300,000 CNY	0.3	
Power transmission equipment	Cable	1.5 km	800 CNY/m	1.2	
	Inverter equipment	2 (20 kVA)	100,000 CNY	0.2	
	Battery	132 (500AH, 2V)	2500 CNY	0.33	
Else	Monitoring equipment	1	300,000 CNY	0.3	
Overall				37.3034	

4. The Environmental Impact of Developing Wave Power

While wave power is sound as good as the research stated, but, everything has a dark side. Another research has shown that, some of the fixed positional wave power devices that is planted at the shoreline might have some converse effects toward the marine life. Although there are many research about the potential sites for Peninsular Malaysia to develop its own wave power devices, nonetheless, it has no adverse effects just to review some of the disadvantages that the wave power devices might bring to the marine environment and its wild life.

The disadvantage is that, the dampening of the fixed positional wave power devices at the shoreline may cause certain ecological changes. That is, the waves reduction may reduce erosion on the shoreline [23]. To interpret that, the arrays of devices may focus the wave energy on the coastline, thereby increasing the erosion. Another than that, sheltering due to the wave power devices will have a negligible effect on the much largest waves. With that being said, the ecological role of sea waves as a disturbance that maintain the biodiversity will be unencumbered [24] . On the other side, by looking at the marine life or sea wild life, a lot of fish species depending on the sea currents or sea waves to transport their larvae. Therefore, wave power devices might alter the currents between the spawning grounds at the shoreline or coastline and the feeding grounds. Additionally, this also could be harmful to the fish populations, as well as the marine life productions [25]. There is research hypothesized that, the noise produced by the wave power devices might interfere with the ability of some fish species to locate their nursery areas by sound, even though this particular data of the research were not presented apparently.

Finally, breeding vocalizations are also very important for mate attraction for the freshwater goby [26], cod [27], and haddock [28]. The successful settlement of other fish such as coral reef fish also depending on the reef noise and it can be affected by the noise pollution that produced by the wave power devices.

5. Conclusion

Peninsular Malaysia has been searching for many alternative energy solutions to solve as many global issues regarding the eco-system, forest environment, and even the ocean and marine environment as they could. Those concerns which bring back to the question of whether Peninsular Malaysia could adopt or choose wave energy as one of the consistent renewable sources for the country energy supplies. As mentioned above, some potential sites at where the Peninsular Malaysia could possibly plant the wave power devices, either the fixed or floating, which are the east costs of Peninsular Malaysia and the MS. Nonetheless, the costs of development and maintenances of the wave power devices, as referring and comparing with the “Mighty Whale”, are far beyond as what initially expected. As a recommendation, there is no farm at all for Peninsular Malaysia and more data should be collected to keep researching about wave energy and its development of wave power devices. Although Peninsular Malaysia has not yet consistently considering using the wave power devices to generate and to produce its energy supplies, but Peninsular Malaysia has taken a very important and useful first step towards solving the renewable and sustainable energy problems.

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