Device Selection of the Potential Wave Energy Site in Indonesian Seas

B Triasdian\textsuperscript{1,2}, Y S Indartono\textsuperscript{1,2}, N S Ningsih\textsuperscript{3} and D Novitasari\textsuperscript{4}

\textsuperscript{1}Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung
\textsuperscript{2}New and Renewable Energy Research Center, Institut Teknologi Bandung
\textsuperscript{3}Faculty of Earth Sciences and Technology, Institut Teknologi Bandung,
\textsuperscript{4}Center for Energy Studies, Universitas Gadjah Mada

Abstract. Ocean wave energy (OWE) is one of many promising renewable energy sources with a high energy density. By using the average wave energy data of 21-year WAVEWATCH-III (WW3) model, some areas were discovered to have a great potential for the wave energy generation. This present study was evaluating the selected Wave Energy Converters (WEC) and determining their capability to do the energy capture in the potential site of the Indonesian seas. The data of WW3 indicate the energy flux of OWE in Indonesia reached to 74.65 kW/m. The case study was conducted in the present research placed in an area of the Java Island called Cidaun, with energy flux about 42.41 kW/m. One of the Heaving Device type was used for assessing the practical energy and to analyze its development in Indonesia with certain limitations; a single round float and diameter device about two meters. The annual energy extracted from the designated WEC was approximately reached 119 GWh. Furthermore, the levelized cost of energy (LCOE) was assessed for the particular device in the selected site, resulted about 25.13 $cent/kWh or four times higher than a standard of minimum feed in tariff given by the Indonesian government.

1. Introduction

Indonesia is an archipelagic country that 70\% of the area is filled with water. The area reaches to 5.8 million km\textsuperscript{2} and elongated shoreline about 95.181 km\textsuperscript{1}. The vast potential of the Indonesian seas can give a huge advantage to utilize ocean energy for their alternative energy resource. There are three major energy from the ocean that are potential in Indonesia; namely tidal, ocean thermal and wave. Ocean wave energy (OWE) has a high power density and consistent propagation that made them as a promising renewable energy in Indonesian seas\textsuperscript{2}. Wave energy presents a number of advantages with respect to other CO\textsubscript{2}-free energy sources – resource predictability, high power density, relatively high utilization factor and low impact of environmental and visual\textsuperscript{3}. As the tropical country, the waves propagated wind in Indonesia are not locally generate in their near-shore. However, some of places are found have an abundant energy generated by the wind waves called the swell. The west region of the Indonesian water is exposed to swells from the South Indian Ocean and affected by the predominant monsoons, especially the South West monsoon\textsuperscript{4}. The utilization of renewable energy (RE) is not limited to the feasibility study, but also have to consider the technical requirement, environmental impact and socio-economic study. There is recorded that more than 1,000 wave energy converters (WEC) are existed worldwide that are classified by dimension, arrangement with respect to the main wave direction, distance to the shore, the principal of operation\textsuperscript{5}\textsuperscript{6}.
As an archipelagic country with more than 17,500 islands, RE utilization in Indonesia will benefit the remote. The small islands in Indonesia rarely have the local energy source that all the energy supply comes from the main island, makes the cost of energy relatively high. Based on National Energy Policy, the target of New Renewable Energy (NRE) of Indonesia is 23% of the national energy mix by 2025[7]. Bioenergy will share 10%, hydro 3%, geothermal 7% and other NRE of 3%. Ocean renewable energy considered as one of the options of NRE to be developed in Indonesia.

In the present paper, we are emphasizing on the device-matched and financial aspects related to wave power. The device selection process will be vary by the region, due to a different society and environment. Some aspects were selected by considering on the installation process, size and the maintenance requirement of five main variants of WEC. The financial assessment of the selected design can be used to analyze the possibility of the ocean wave development in the future. These matters are also expected to become the consideration of the blue energy issue for the government related questions are likely appearing between the scientist, engineer and investors.

2. Data and methodology

The selection process of the site for the WEC model design mainly considered by the environmental effects and the energy cost assessment. Wave energy was reckoned to the result of WAVEWATCH-III (WW3) numerical model that is provided the hind-cast of wave conditions in the Indonesian seas from 1991 to 2011. The 21 years data were processed to get the seasonal data of wind and waves, therefore the pattern and character of the OWE in the Indonesian seas can be defined.

The wave energy assessment using WW3 indicated that wave energy resources in the Indonesian seas reached to 74.65 kW/m[8]. The most prominent energy is placed in the national sanctuary in Sumatra Island named Lampung. However, there are areas along the south-coast of Java that are potential to be utilized for the WEC. Thus, the research was focused to assess the utilization and recommend for one study in Java Island.

A field observation was undertaken along the south side of the West Java province to validate the selected locations from the model. There are some specifications of the area selected to be observed as follows:

- Energy above 20 kW/m
- The distance from the nearest coastline is less than 5 km
- The site is nearby the public facility
- No rocky reefs
- No sea-grass or coral reefs ecosystem

Those considerations were made to decide the most applicable site to be used as the study case. All large-scale RE conversions are an area demanding and therefore in a potential conflict with other interests[9]. Thus, all the specifications were needed to determine the optimum value between the potential sources, economics and the impact to the environment without offending any conflict in the community. One of the areas that fulfil all the specifications in Java Island, called Cidaun that shown in Figure 1. The selected area has a potential source with energy flux reached to 42.41 kW/m.
Figure 1. The selected area for the WEC development location

2.1 Wave energy converter

Babarit in 2015 specifically distinguished the WEC group and arranged all of them as five main variants; oscillating water column (OWC), Overtopping, Heaving Devices, Fixed and Floating Oscillating Wave Surge Converters (OWSC)[6]. Those specifications are extracting the energy differed one another. The OWC generates the electricity from the rise and fall of the water by a wave in a cylindrical pipe with holes[10], while Overtopping device catch the energy by elevating waves into a reservoir above sea level from which the water passes back to the sea via low head Kaplan hydro turbines[11]. Heaving device utilizes the horizontal movement, while OWSC will adapt the vertical movement to generate power. The illustration of the energy captured by five variants of WEC is presented in the Figure 2.

Figure 2. Illustration of the archetypal five category wave energy devices by Babarit[6]

The wave energy resource development become a priority in some countries in the world due the high energy density and minor potential impact on the environment [12]. However, the location of WEC device installations could give a significant effect to the ocean processes or environmental damage due to a different requirement of installation. The performance measure used of WEC was vary greatly from one source to another, and can be applied depending on the water depth and on the location (shoreline, nearshore, offshore)[13][14]. According to the distance of the location of installation from the shore, WEC is categorized to shoreline, near shore and offshore devices. The environmental impacts of wave energy conversion technologies as depicted in the Table 1 below.

Table 1. Environment impact related to the WEC instalment[1]

| Environmental Effects          | Shoreline | Nearshore | Offshore |
|-------------------------------|-----------|-----------|----------|
| Land use/sterilization        | L         | L         | L-M      |
| Construction/maintenance sites| L         | L         | L-M      |
| Recreation                    | L         | L         | L-M      |
| Coastal erosion               | L         | L-M       | L-M      |
| Sedimentary flow patterns     | L         | L         | L-M      |
| Navigation hazard             | L         | L         | L-M      |
| Fish & marine biota           | L         | L         | L-M      |
| Acoustic noise                | L         | L         | L-M      |
| Working fluid losses          | L         | L         | L-M      |
| Endangered species            | L         | L         | L-M      |
| Device/mooring damage         | L-M       | L-M       | L-M      |

(L: Low, M: medium)
In this research, the design of WEC is made by some deliberation on environmental issues. Due to the high cost of material and maintenance for the seawater instrument, the design is limited using no submerged utilities. The selected site will be adjusted by a particular WEC size to a specific environment.

2.2 Cost of energy

The Levelized Cost of Energy (LCOE) is a useful parameter to assess the economic feasibility of a technology. It is defined as the sum of all capital costs and lifetime operation and maintenance costs divided by the electricity generation to grid accumulated throughout the technology’s lifetime [15]. The equations (1) (2) are used to calculate the LCOE as follows[16]:

\[
LCOE = \frac{NPV(CAPEX + OPEX)}{AEP} \quad (1)
\]

\[
AEP = \frac{avl \times CWR \times D \times J \times N \times 24 \times 365 \text{ days}}{1000} \quad (2)
\]

\(NPV\) is the net present value, \(CAPEX\) is the capital expenditures, \(OPEX\) is the operational expenditures and \(AEP\) is the annual electricity production. The equation 2 define \(avl\) as availability, \(CWR\) as Capture Width Ratio, \(D\) as the characteristic dimension of the device and \(J\) as the wave resource of a site. Through a review of the existing data, the cost components for the \(CAPEX\) include the civil and structural costs, plant costs, electrical supply and installation to the development costs [17]. As well as the initial investment, the economic analysis must include the operation and maintenance expenditure \((OPEX)\). Tables 2 and Table 3 show the summaries of the basic costs of wave energy development. The initial cost included the main sector of \(CAPEX\) calculation, while the operation cost related to the \(OPEX\).

Table 2. Summary of initial cost [18]

| Element                        | Cost                  |
|-------------------------------|-----------------------|
| WEC installation             | 2.5 – 6.0 M€/MW       |
| Mooring System                | 0.265 €/day           |
| Mooring Installation          | 50,000 €/day          |
| Underwater Cable              | 10% CAPEX             |
| Cable Installation            | 2.07 €/m              |
| Electrical Substation         | ≈ 1.2 M€              |

Table 3. The annual cost of operation WEC installation

| Cost                          | €/MW h |
|-------------------------------|--------|
| Operation and Maintenance tasks| 20 – 35|
| Public Services               | 3.5    |
| Insurance Cost                | 15     |

OWE is an immature technology in new renewable energy. It is understandable the price of the electricity of the installation still costly compared by other advanced RE technologies. It is expected that wave energy technologies could become more competitive once approximately 2.5–10 GW of cumulative capacity has been installed[17]. World Energy Perspective in 2013 indicates that the cost of energy for existing OWE was about 286 to 1058 ($/MW h). The price was five times higher than any other NRE as general[19]. The convergence of wave energy to the given \(LCOE\) depends not only on resource availability but also on the ability of the sector to identify common solutions and broader design consensus, which will unlock economies of scale.
The government has a role to improve enabling condition and policy framework that could lure public and private investment in renewable energy. The Minister’s Regulation No. 12/2017 insisted some renewable power purchasing prices should be referred to audited regional electricity production price[20], which the national electricity production price approximately 7.39 cents$US/kWh[21]. In order to assist the ocean energy development, especially for OWE, the price would be insufficient to attract investors in this sector. Some countries proposed a higher price to show their support. The highest price feed in tariff (FIT) of ocean energy given by the government of Italy about 34 cents $US/kWh, while the serious commitment for WEC development given by the government of Portugal with FIT price about 33 cents $US/kWh[22][23]. Another assessment was coming from the price of energy by the devices. Andres et al. in 2017 calculated the CAPEX of five different types of WEC from a certain number of LCOE. It shows that the CAPEX from WEC from the lowest cost are Floating OWSC, Heaving Device, Overtopping, OWC and Fixed OWSC, respectively[24].

3. Result and discussion

Cidaun is selected as the area study of the present research based on analysis of the 21-years data from WW3 model and field observation. Based on the Table 1, either the coastline or nearshore converters considered as a better option than the offshore installation since they have the least environmental impacts. The optimum design of WEC was determined from the limitation lists that is shown in the Table 4 below.

| Consideration                                    | Type of WEC     |
|--------------------------------------------------|-----------------|
|                                                  | OWC | Overtopping | Heaving Device | Fixed OWSC | Floating OWSC |
| Not disturbing the sea floor.                    | v    | v           | v              |           | v             |
| The maintenance could be done out of the water. | v    | v           | v              |           |               |
| The size of the WEC is flexible to the source and environment. | v    | v           | v              |           | v             |

Amongst 5 different converter classifications, the Heaving Device considered as the best WEC type that fulfilled all the requirements of this research. In order to minimize the underwater maintenance and simplifying the operational, trestle was considered to be built for the full design. The overall design of the installation is shown in the Figure 3.

Figure 3. Design of the WEC installation

The WEC design selected is using the work principle of the heaving device with 2-meters diameter and held in a single float (buoy). The assessment of using these design in one of potential site that has an energy flux to 42.41 kW/m can extract the electricity up to 119 GWh per year. The capital expenditure in this research was not only calculate the initial cost, but also the infrastructure requirement using the standard from the Indonesian government like trestle and the...
access road. The capital expenditure of the particular device in the selected site was approximately €19,006,719.44 for 1 MW capacity with more 50% took by the infrastructure cost only. Meanwhile, the operational cost for the 15 years’ instalment for the same capacity was about €6,376,808.23. Using the LCOE equation, the final result of the cost of energy in the particular device in selected area (Cidaun) was approximately 25.13 $ cents/kWh. That price is four times higher than the regional electricity production price, which the standard price for the RE plant by the new energy regulation. It makes the OWE utilization become not feasible to be built in the near future.

There are several ways to cut off the cost of energy to make the development of wave energy technology in Indonesia more competitive:

- Pairing the WEC utility with other coastal project development, for instance: the jetty, harbor, or even tourism (the collaboration of such project could subsidize 46% from all the capital cost).
- Increase the number of WEC installation (For every additional float can suppress cost from 12% - 15%).
- Using the technology in a very remote area with a higher regional electricity price.

The technology will benefit the remote islands like Siberut and Enggano (Sumatra region) with a high energy density, 51 kW/m and 36.70 kW/m, respectively. Using the design and WEC utilities as Cidaun’s case with some modifications, the Siberut Island (using two floats) and Enggano Island (using three floats) will cater the regional electricity price to 12.60 cents/$kWh and 13.68 cents/$/kWh, each. For such remote area like Siberut and Enggano Islands, the development of WEC not only fulfilling the electricity demand, but also will add a significant value for the island if it combines with infrastructure project.

The FIT of wave energy in Indonesia will be more appealing if the government could increase the electricity production price for certain NRE to a reasonable price. The OWE utilization can be set up with a support as we can copy the EU Member States using push and pull mechanism. In some countries, their government is more considerate and set the higher FIT to support the OWE development. Portugal for the instance, has a full support from their government by having FIT for wave energy to 33 $/kWh. The government act can be showed with incentive, investment fund, or regulation convenience.

4. Conclusion

The present study assessed the maximum energy from one of potential sites, called Cidaun which has an average energy flux to 42.41 kW/m using one of type WEC named Heaving Device. The design included a single float with a diameter about two meters. The result depicts that annual energy can be extracted from the source by using the designated device reached approximately 119 GWh. The LCOE for the particular device is approximately 25.13 $/kWh or four times higher than a standard of minimum feed in tariff given by the Indonesian government. There are several ways to optimize the wave energy utilization in Indonesian seas like pairing with the other coastal development or maximizing the capacity of WEC. However, the production price cannot be suppressed without support from the government using investment relief and regulation convenience. We can also encourage the wave energy development by adapting the push and pull mechanism by EU Member States or set the higher FIT like Portugal.

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