# A Multi-Criteria Decision-Making Approach for Selection of Wave Energy Converter Optimal Site

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## Abstract

Ocean wave energy is an essential source of renewable power for coastal communities. Choosing the optimal site for the wave energy converter (WEC) deployment depends on a number of criteria. The characteristics of the WEC must be taken into account in the prediction power supply, whereas the local sea state is connected to elements like wave condition (as a representation of construction budget) and energy output as well as the influence of the exploitable storage of wave energy and its trend. As a result, this research provides a multi-criteria decision-making (MCDM) strategy for considering several factors simultaneously to choose the best possible site. The suggested MCDM technique incorporates two primary factors, i.e., exploitable storage of wave energy and energy production, into a single metric that takes into account both WEC efficiency of a particular type, WEPTOS, and sea state to aid decision-makers in the development of a pilot project. The method was then used to analyse the waves at two locations that had been identified as promising sites for harvesting wave energy along the coast of Oman. To further assess a site's potential upcoming pilot project and select the most efficient WEC, we compared the MCDM results at the stations with certain WEC types. In conclusion, optimal sites for placement of the WEPTOS WEC along the coast of Oman were identified considering the highest annual energy production and exploitable energy storage. Through solving the MCDM technique, 17 sites were pinpointed, and only 6 points were picked up.

**Keywords:** Ocean wave energy; Wave energy converter; Optimal site; Multi-Criteria Decision-Making

## 1 Introduction

The use of fossil fuels has resulted in detrimental climate change and global warming. Due to their scarcity, research and industrial initiatives have shifted their focus toward finding sustainable alternatives, and renewable energy has emerged as a focal point in the recent development plans of the majority of industrialized and some emerging countries. Solar, wind, hydropower, and marine (tide and wave) energy are only a few renewable energy sources that might be used to meet the world's clean energy needs in the future. While solar and wind power are both widely available, marine power is still in the prototyping phase, and advancement in wave energy converter technology (WEC) into economically sustainable accomplishments has been gradual, even in regions with high wave activity. However, research into the criteria for choosing the ideal site for a certain WEC is irreversible. Recently, Portilla et al. (2013) found that it is more effective to gather wave energy in locations with minimum power but temporally stable settings. As described by Dunnet and Wallace (2009), locations with a higher mean annual wave power were chosen for wave energy harvesting and device efficiency analysis.

Existing resource stability and viability must be taken into account while formulating a strategy for long-term growth. When compared to other forms of renewable marine energy, wave power has a higher energy density, making it more practical for large-scale energy extraction in places bordering open sea bodies. WECs have a potential economic benefit due to their relatively cheap capital costs, which are expected to fall further when new, specialized businesses for WEC components and subcomponents arise. WECs are equally visually intrusive to neighbouring homes as wind turbines or solar panels, despite their modest profile. Furthermore, unlike other renewable energy sources such as wind and solar, wave energy can be predicted with greater accuracy. Technically, WEC's key benefit is its predictability, which distinguishes it from other renewable energy sources that might experience abrupt and unpredicted variations in output. WECs may also be utilized as coast protection measures, according to recent research by (Mendoza et al., 2014). Because of these benefits, wave energy is a good fossil fuel replacement for seaside communities where some energy needs are met. Preserving the WECs for the future, particularly in the face of harsh weather, is one of the key technological difficulties that have to be explored, as stated by Leijon et al. (2006), Pontes (1998), Cornett (2009), Arinaga and Cheung (2012). Optimizing the system's efficiency is yet another issue that may be considered in terms of structural and economic considerations. Therefore, for planning and adjusting the WECs, wave power must be accessible and available, as well as an accurate forecast of energy generation, (Shadmani et al., 2022). Additionally, uncertainty surrounding wave energy assessment and site selection, which must consider climatic unpredictability, contributes to the industry's delayed development. Additionally, recent research has shown that regions with a reduced power source but more constant weather are more suitable and trustworthy for harvesting wave energy, (Morim et al., 2014; Monteforte et al., 2015).

Initially, it has been shown that the potential energy output is one of many factors in deciding where to collect wave energy. Second, determining the optimal site to analyse WEC performance has been done using a variety of parameters. Because of this, this research will present a multi-criteria decision-making (MCDM) method based on exploitable energy storage and energy production for selecting the optimal site, one that considers device performance alongside wave condition and resource sustainability. In order to determine the optimal sites for a particular WEC type, WEPTOS, we will use wave power characteristics from two locations, each of them situated in a separate water depth.

## 2 Methodology

Several criteria and circumstances determine the optimal site for harvesting wave energy. Key criteria in WEC installation include the features of exploitable and total wave energy storage, accessibility, availability, monthly and yearly energy output, monthly variability index, and design wave height, (Kamranzad et al., 2020). Evaluating the aforementioned factors will reveal the optimal site and best equipment to use under certain circumstances. To take into account all relevant factors, we propose a multi-criteria decision-making (MCDM) technique based on the above parameters.

On the basis of the authors' prior research in the seas near the borders of Oman, namely the Gulf of Oman, we will make estimates of the relevant parameters at two regional sites to examine the efficacy of the suggested technique. This research provides a useful application for the findings of prior research and reaches a judgement that can be used by decision-makers regarding which of the stations as far discussed is best situated to provide some of the energy needs through wave power. The dataset is briefly explained in the next section, followed by a description of the selected stations.

### 2.1 Wave Energy Resource

Incorporating a large-scale collection of waves modelled numerically across time, wave energy resources have been explored in the waters around Oman, the Gulf of Oman border. The potential of wave energy in the Gulf of Oman has been assessed for two stations using the wave data collected from the offshore buoys, as shown in Figure 1. The present study's major criteria for selecting hotspots were the availability of energy and the suggested criteria for taking into account the sustainable and long-term consistency of the resources. While this paper proposes a technique for evaluating WEC performance, such evaluation has not yet been conducted thoroughly.

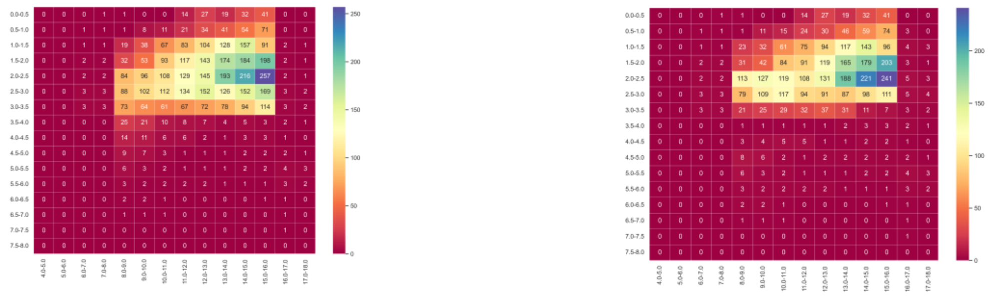
The wind and wave conditions in each of these water bodies vary seasonally and annually. For instance, the fall is when the Gulf of Oman's wave environment is at its peak. Due to its proximity to the Indian Ocean, the Gulf of Oman has summer monsoons that significantly influence the wave environment, causing southern waves to predominate throughout the monsoon season. For further information on wave modelling and wave energy estimate in the Gulf of Oman. SWAN (Simulating Waves Nearshore) model has been used to simulate the wave field. The ECMWF's modified ERA5 product, localized and adjusted in each research region, served as the forcing. Each wind component has had its wind field modified to accommodate changes in the wind's direction and magnitude. Mazaheri et al. (2013) provides further information regarding the influential variables derived from the used wind domain. The wave strength was then determined, and its spatiotemporal fluctuation in each location was assessed using the dataset of wave characteristics in long-term that had been created. The equation ($P = 0.49H_s^2 \times T_e$) was used to determine the wave power ($P$) for deep sea circumstances, where $H_s$ is significant wave height and $T_e$ is the energy period ($T_e = m_{-1}/m_0$).

In order to generate the wave features in the more promising places, noticeably higher-resolution local models were constructed using the boundary condition generated from the master versions. The spatio-temporal wave energy variability was then investigated using refined wave data, and the best position was chosen while considering the local resources' sustainability. Last but not least, the best position within each body of water was chosen based on various variables, such as the amount of energy, unpredictability, and frequency of wave power over a specific threshold, and the depth at which WECs may be deployed. Figure 1 displays the chosen sites in the Gulf of Oman (Barka and Quriyat). According to a regional assessment of wave energy capacity, the aforementioned two stations not only have the greatest promise, but also are the best fit in terms of sustainability.


**Fig. 1:** Selected sites along coast of Oman

## 2.2 Wave Energy Converter Type

Since the wave characteristics significantly influence the WEC's efficiency, it is different from several forms of renewable energy because there are several proven technologies to produce energy. As a result, the most suitable WECs are often most effective within the typical parameters of the considerable wave heights and times. A power wave resource evaluation is necessary to calculate the amount of usable electricity produced by a certain WEC device at a given location. The total electric output may be obtained towards this end when the device's power matrix is multiplied by the wave resource matrix (the probability of occurrences), a more accurate prediction may be made (i.e., the electric production for various sea conditions) (Margheritini et al., 2009). Figure 2 depicts the wave resource matrix at two considered stations, Barka and Quriyat.



**(a)** **(b)**

**Fig. 2:** Probability of occurrence of different wave conditions at **(a)** Barka station and **(b)** Quriyat station

Despite the numerous devices for collecting wave energy, WEPTOS WEC, a new and innovative one, is considered in this research, presented by (Pecher et al., 2012). With a smart structure that can adjust the amount of incoming wave energy and minimize loads in harsh wave environments, the WEPTOS WEC is a unique device that combines a well-known and influential wave energy absorption mechanism. This novel WEC type, as seen in Figure 3, might be deployed strategically to maximize wave energy extraction. Through various rotor modes, this movable A-shaped, slack-moored, floating structure absorbs the energy of the waves. The rotors on each leg pivot around a single axle, which allows them to send the absorbed power to a single power take-off (PTO) mechanism. In order to capture wave energy in a brand-new and creative way, the WEPTOS WEC uses an established technique. The WEPTOS structure's survival capacity has been crucial since its conception.

**Fig. 3:** WEPTOS WEC structure

The primary features of the devices under consideration are listed in Table 1 after being compiled from the appropriate sources. Energy output will be studied annually and monthly timescales to account for the effects of climatic variability on the devices' operation.

**Table 1:** Main characteristics of WEPTOS WEC

| Technology | Rated Power (kW) | Classification | Matrix resolution $(H_s \times T_e)$ |
|---|---|---|---|
| WEPTOS | 3587 | Attenuator | $0.5\ m\ \times 1.0\ s$ |

## 2.3 Total Exploitable Storage and Energy Production

Total and exploitable wave energy per unit area ($E_t$ and $E_e$, respectively) were determined as part of an effort to look at the viability of using WECs in various stations:

$$E_t = P_{mean} \times t \tag{1}$$

$$E_e = P_{mean} \times t_e \tag{2}$$

Where, $t$ is the sum of all hours in a year (=8760 h), $t_e$ is the sum of all hours that correspond to wave power higher than a threshold (2 kW/m) and $P_{mean}$ represents the mean wave power. Energy output ($E_0$) was determined using the following equations to compare the effectiveness of each WEC at various sites:

$$E_0 = \sum_{i=1}^{n_T} \sum_{j=1}^{n_H} p_{ij} P_{ij} \tag{3}$$

where $\boldsymbol{p_{ij}}$ is the proportion of periods a certain sea state occurs, as specified by significant wave height ($\boldsymbol{H_s}$) and energy period ($\boldsymbol{T_e = m_{-1}/m_0}$). WEC's electrical power output, denoted by $\boldsymbol{P_{ij}}$, corresponds to an identical energy bin. Monthly energy output was computed using the power matrix of the WEPTOS WEC, as illustrated in Figure 4.

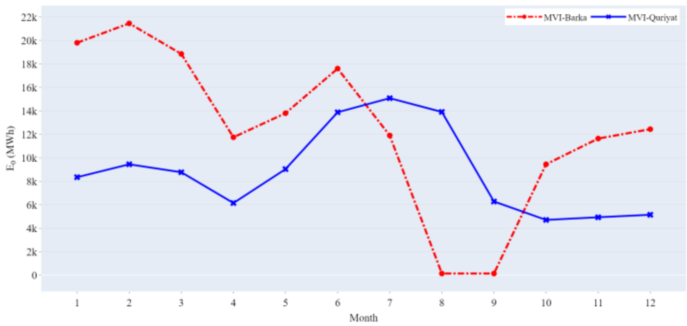



**Fig. 4:** Monthly variability of energy output at two considered stations

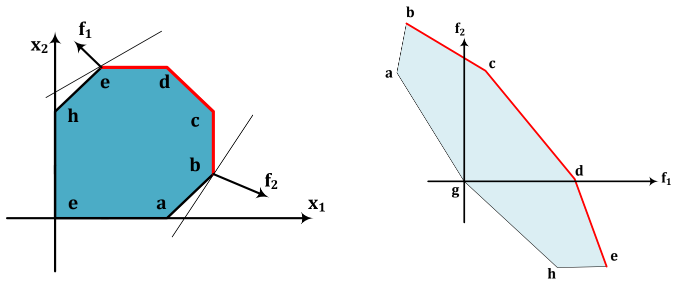
## 2.4 Multi-criteria Decision-making Approach

Multi-criteria decision-making (MCDM), often referred to as multiple criteria decision analysis (MCDA), is a study topic that examines numerous options in a circumstance or research subject that encompasses ordinary activities, social sciences, engineering, medicine, and many other disciplines. MCDM is one of the most prominent decision-making strategies applied in numerous domains (Bruno & Genovese, 2018).

MCDM assesses the criteria to evaluate if each criterion is a desirable or undesirable decision for a given application. It also tries to evaluate this criterion, depending on the specified criteria, against every other accessible choice in an effort to aid the decision maker in picking an alternative with the lowest tradeoff and greatest benefits. The factors utilized in assessing these criteria might be either deductive or inductive. There are many methods available for solving MCDM problems, such as Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarities to Ideal Solution (TOPSIS), Elimination Et Choix Traduisant la Realite (ELECTRE), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), ViseKriterijumska Optimizcija i Kaompromisno Resenje (VIKOR), and Data Envelopment Analysis (DEA). In this study, a TOPSIS method is used to evaluate the model.

TOPSIS is a valuable MCDM technique. This is an alternate method that uses parameter weights to normalize score distributions and identify the best possible solution, which meets all criteria. For best results, it employs a straightforward mathematical technique. TOPSIS's guiding principle is to choose the option that is geometrically closest to the positive ideal solution and farthest from the negative ideal solution, as measured by the Euclidean distance. By adding together, the greatest possible results for each option, we get the positive ideal solution ($X_+$). The negative ideal solution ($X_-$) incorporates all the lowest possible values for each feasible choice. Both answers are speculative and derived from this procedure. This approach does this by determining how close a given value is to the positive ideal solution. In light of the evaluation and computation, we decide on a different priority ($\gamma$), as shown in Figure 4. This MCDM approach is often used to address practical issues. It is a simple method that can efficiently compute and evaluate the relative merits of several possibilities for making a decision.

Therefore, our proposed approach for locating optimal sites for deployment of WECs is illustrated in Figure 5, which is integrated with the wave generation model, SWAN.




**(a)** **(b)**

**Fig. 4:** Demonstration of **(a)** decision space and **(b)** solutions in the criterion space

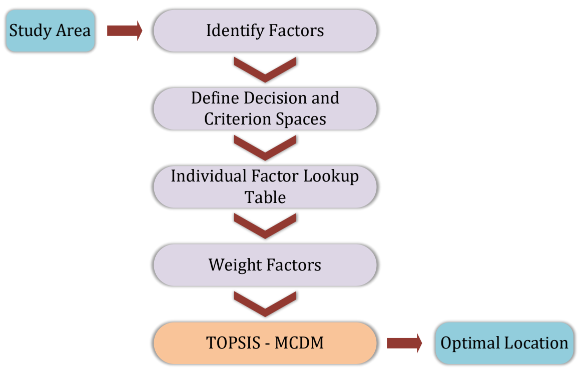



**Fig. 5:** Proposed methodology

## 3 Results

In summary, this study performs an MCDM approach to locate the optimal sites along the coast of Oman for emplacing the WECs. Two primary factors have been employed in this approach: exploitable energy storage of wave energy and energy production, which carry out the decision-making process through the TOPSIS-based MCDM approach. In addition, the best locations are found on the basis of WEPTOS WEC deployment, which is a novel WEC type. As a result of examining these two items, it is possible to quickly and easily evaluate the relative merits of several stations.

Comparing the chosen stations revealed that, while being shallower, the Barka station had larger exploitable storage of wave energy ($E_e$), reaching around 3212 kWh/m. where wave heights are greater, and the environment is harsh in certain seasons, with monsoon predominating in summer. Quriyat, which is east of Muscat, has the second-highest wave energy storage that may be used. This region is subject to swells in pre-monsoon and locally produced high waves during the monsoon. $E_e/E_t$, a measure of the exploitable storage of wave energy, shows that Barka has the highest value (19.8%). The percentage at Quriyat, where 13.1% of the total wave energy ($E_t$) storages are exploitable, is the second highest. Accordingly, Quriyat seems to be the greatest place for wave energy extraction despite Barka having a large ratio of wave energy that may be exploited for overall wave energy storage.

**Table 2:** Wave energy properties in each station along the coast of Oman

| Station: | $P_{mean}$ $(kW/m)$ | $t_e$ $(hr)$ | $E_t$ $(kWh/m)$ | $E_e$ $(kWh/m)$ | $E_e/E_t$ (%) |
|---|---|---|---|---|---|
| Barka | 1.85 | 1736.4 | 16206 | 3212.3 | 19.8% |
| Quriyat | 1.2 | 1149.3 | 10512 | 1379.2 | 13.1% |

Based on the results presented in Table 3, Barka provides higher annual mean energy production, while Quriyat produce the least energy. The concentration of optimal sites is near the Barka station, where WEPTOS can generate the highest annual mean energy production with considerable amounts.

In the wave energy map, 17 sites (PO1, …, PO17) were positioned as shoreline sites based on the most relevant patterns for the spatial variability of the wave energy, which correspond to the energy conditions in an average year (Figure 6). The reddish colours dominating the colour scale show that the average wave energy is comparable for all the nearshore places shown, with values around 23460 MWh. Finding the optimal site to deploy the WEC is not simple at first glance. It will depend on each sea state's contribution to each research site. The existence of two further offshore locations (PO11 and PO12) can be seen on the wave energy map and would be useful for future energy studies about the potential building of an offshore wave farm.

**Table 3:** Annual mean energy production in each station

| | Barka<br>$E_0$ $(MWh)$ | Quriyat<br>$E_0$ $(MWh)$ |
|---|---|---|
| WEPTOS | 3248 | 2135 |

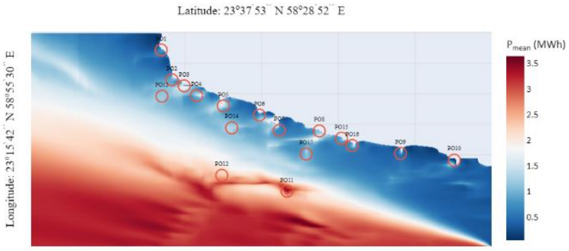



**Fig. 6:** Optimal sites selected based on the MCDM approach

Figure 7 shows a map of the predicted energy production from a WEPTOS WEC pilot project along the shore. The nearshore zone, which includes sea depths between 9 and 15 m, is shown on this map with its geographic variations. By mapping the wave energy map with the wave energy of WEPTOS, a reduction in the number of potential sites for the WEC installation from the previously specified 17 points to only six (PO3, PO5, PO6, PO7, PO8, PO16) has been determined. The six locations pinpointed in Figure 7 produce energy at yearly production levels of around 34868 MWh. It is essential to note the emergence of additional exploitation-prone regions that were not initially anticipated as locations that would produce energy at levels near 26770 MWh. The aforementioned situations cause the incidence of sea states relapsing inside the ranges of greater efficiency.

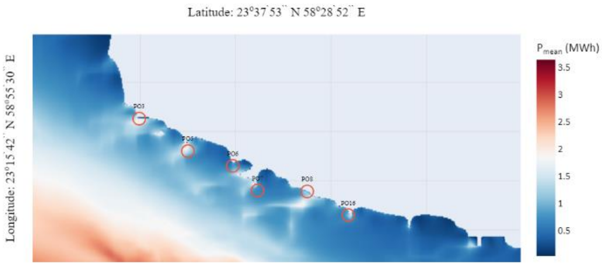



**Fig. 7:** Mapped wave energy from WEC along the coast of Oman between 9 and 15 m water depth

## 4 Conclusion

Finding the coastal regions where the process of refraction or shoaling focuses solely on the wave energy into the so-called spots or locations with the most energy is one of the main goals of any evaluation of the wave resource. In terms of where wave farms may be located, these nearshore areas are particularly intriguing. In this research, wind data from the ECMWF were combined with wave data from offshore buoys. In addition, two key criteria—exploitable energy storage and energy production for a specific WEC type, WEPTOS—were taken into account for determining the best locations using a TOPSIS-based MCDM technique. 17 sites were identified as a consequence of the propagation of these instances using a wave model from offshore conditions to the shoreline. Given that Oman's coastline is devoid of any other WEC plants and that the study zone is one of the most active ones, the locations spotted here seem to be valuable sites that may be tapped in future.

Conclusively, it should be noted that these two components are not the only ones that should be taken into consideration. The location of a future wave farm installation may be influenced by other components, such as the effects of local and national development, availability, accessibility, and the monthly variability index. Even in such situation, MCDM may be used to rank the possibilities since it gives the necessary details about the viability of various device-station combinations for future sustainable growth based not only on the amount of electricity generated but also on the unpredictability of the output.

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