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Wave Energy Resource Evaluation and Characterisation for the Libyan Sea

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Abstract

The study focuses on a high resolution coastal assessment for the Libyan Sea at the South-West Mediterranean. To date majority of information for the area, are based on large scale oceanic models with coarse resolutions not adequate for nearshore assessments. This dataset and analysis provides an in–depth wave energy resource assessment and detail dissemination of sites according to their metocean characteristics. Identification for wave energy is based on the database constructed, allowing the quantification of energy levels and resource implications at sites.

Mean values of wave heights around the coastlines are $\approx 1m$, though high storm events exceed $5m$ at several areas. Highest wave energy resource are located at open coastal areas, with energetic months reaching up to 10 kW/m. Low energy seasons are throughout summer months, where energy content is reduced threefold. The resource can be classified as low, however coefficient of variation suggests a predictable resource with extreme events not expected to surpass 10m.

Although, resource is not as energetic as open oceanic regions the low variations may assist wave energy as a supporting renewable energy option. Assessing the wave climate around the coasts for a long period of time, also provides confident and robust suggestions on the selection for wave energy converters. In addition, the lower extreme events are expected to reduce potential installations costs by lowering structural expenditure and strengthen-

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ing works to facilitate operation at milder environments.

Keywords: Wave Energy, Numerical Wave Modelling, Wave Power, Extreme Value Analysis

1. Introduction

Countries world–wide are exploring increased adaptation of renewable energy in order to achieve energy independence and fiscal benefits [1, 2, 3]. South Mediterranean countries are exposed to high levels of wind and solar resource, wave energy is a renewable high density resource that is often overlooked.

North African countries have been increasing their interest into renewable energy, this study presents an extensive wave power assessment, investigating for the first time the opportunities that may arise from wave energy. The 35 years nearshore database hindcast allows to present long–term evolution of wave conditions, climate variability, and extremes given for the areas. Such information are important for future wave energy deployment but can also be used in coastal defences, and environmental studies.

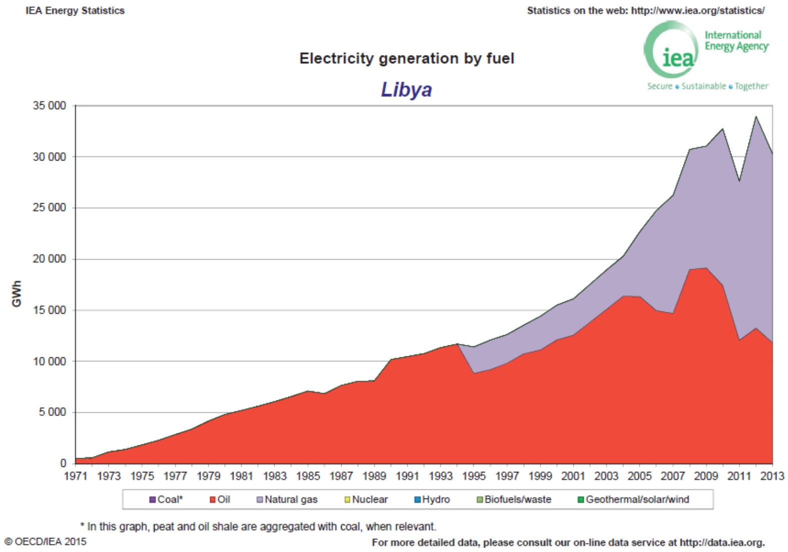


Figure 1: Libyan energy mix electricity contribution per fuel as given by the International Energy Agency as in 2013 [4]

Libya is a developing country whose production is dominated by fossil fuels. Lately steps were introduced for integration of renewable technologies in the electricity mix, mostly onshore wind and photovoltaics, both though at infancy levels. Due to the structure of electrical grids opportunities exist for renewable energy (RE) development through a localized de–centralised approach, reducing infrastructure necessities [5]. The increasing trend of energy imports has underlined the necessity for supply diversification and renewable energy deployment consideration. Nowadays, financial schemes are provided by European Development Bank (EDB) and World Bank Group (WBG) for development of clean energy projects.

As seen in Fig. 1 Libya is completely dependent in electricity by fossil fuels. More specifically, for the year 2013 Libyas electrical consumption was at 24.58 TWh with the majority of electrical supply originating from oil (11.8 TWh) and gas (18.4 TWh) products. This dependency is based on other countries that are oil producers and underline the necessity for energy diversification. Future plans include the interconnection of neighbouring countries (Libya, Algeria, Tunisia and Italy) in an attempt to maximise commercial and geopolitical cooperation of energy exchange (see Fig.2). This provides potential opportunities for the exchange of surplus electricity by renewable energies.

Figure 2: Plans for connection lines between the North African counties as found in [5]

Libya is a country recovering from internal conflicts and major geopolitical events, while the level of maturity for energy technologies and companies is not as competitive as in Europe. Several African countries are considering the interconnection of the electricity grids in the continent, as a way to reduce external dependencies and assist to the development of the region [6]. Thus, significant opportunities arise by the ever-rising energy consumption in the emerging countries of the African continent.

Libya has an open dialogue and discussion of potential development of different renewable technologies as discussed in Mohamed et.al. [7, 8]. In that discussion immediate usable technologies identified are solar, photovoltaic and wind. From an extensive interview with policy makers, energy companies and public awareness/acceptance, Mohamed et.al. [8] concluded that applicability and acceptance of RE is at high levels. Concerning wave and tidal energies, Libyan policy official consider them viable at 23%, and company generators at 18%. Furthermore, above 80% of both industry and government official admit that RE can satisfy the increasing energy consumption and assist the financial developments, more information on the interviews can be found in Mohamed et.al. [8].

The inter–dependent nature of wind and wave resources, allow further RE integration and ability to for the electrical grids to absorb higher levels of renewable electricity [9, 10, 11]. Allowing development of decentralized grids that have lower cost of energy and can act as a viable solution for economic growth.

The study aims to contribute and underline the opportunities that exist for wave energy production in Libya. Long–term data produced by a validated coastal numerical model, which run over 35 years are subsequently used for extensive climate, resource and a site classification analysis. Information on model set–up, calibration, boundaries, can be found in Lavidas et.al. [12, 13].

This study is separated in the following sections: Section 2 presents in brief the wave model used and the information extracted, and discusses gap of knowledge in the region. Section 3 provides the wave climate and power variations. Several extracted locations are examined in terms of wave characteristics and power. Annual and monthly variations are presented, alongside a detail site characterisation based on the joint distributions of metocean characteristics. The extreme value analysis is based on the dataset and provides return periods that may affect wave energy deployments and offshore activities. Section 4 discusses the findings, and addresses the opportunities within the region, based on results of the analysis.

2. Material and Methods

Simulating WAves nearshore (SWAN) is a third generation spectral phased-average model used for wave studies [14]. The wind input is provided by NCEP and the Re-Analysis package of the CFSR dataset, 1-hour time intervals [15]. The model was initiated for the Mediterranean Sea and for subsequent meshes for a duration of 35 years from 1980-2014. A two way nested scheme was used, the Mediterranean domain had a spatial resolution 0.1^o, Libya domain was examined under a finer mesh with resolution 0.025^o. A detail validation has been presented in Lavidas et.al. [12, 13]. The calibration and coefficient tuning took into account the higher temporal resolution of the wind product. The calibration results tested two different formulations for wind growth, with the selected scheme providing good correlations, low biases and reduced scattering.

The wind scheme is based on formulations by Komen [16] with a linear growth coefficient activated [17]. Bottom friction, depth breaking, refraction, diffraction processes all are used to account for wave interactions. Triads are solved with the Eldeberky method [18], and quadruplets are activated in a semi-implicit way.

Direction has been subdivided into 25 intervals while the frequency is discretised in 30 bins, the lowest initial wave frequency used is set to 2 seconds while the highest is 28 seconds and they is distributed logarithmically ($\Delta f = 0.1f$). The selection and range of frequency and directional bins, has a direct effect on the computational resources, while often times an increase in the parameters does not translate into improved performance [19]. The coordinates are Spherical and have been extracted by ETOPO-1 [20] and bathymetry domains were constructed using bi-linear interpolation.

The final database was compared with buoys measurements and other state–or–the–art models run in the region, that also shared same buoy data. The resulted dataset found improvements over a compared oceanic models, with lower root–mean–square–error (rmse) values and biases for our dataset. However our model also recorded over–estimation of wave parameters for very low resource levels, something that is expected in numerical wave models [21]. In addition, our datasets spatial wave energy distribution was also compared to a high resolution unstructured model for the Aegan, finding similar ”hot-spot” distribution and obtaining similar generation correlation coefficients for same buoy locations [13].

Numerical wave models have been used for the Mediterranean Sea, with oceanic models whose resolution is not often adequate to resolve coastal areas, see Table 1. Majority of studies are based on oceanic models with spatial resolution hindering extrapolation of results to coastal areas, as discussed in Canellas et.al. [22]. For the Libyan Sea no high resolution coastal information exist.

Table 1: Implementation of Mediterranean Models

Region	Study	Model	Period (years)	Spatial Resolution	Parameters
Mediterranean	[23]	WAM	10	$0.5^o x 0.5^o$ & $0.25^o x 0.25^o$	Waves, Wave Climate
Mediterranean	[24]	WAM	44	$0.5^o x 0.5^o$	Waves, Wave Power
Mediterranean	[25]	WAM	10	$0.1^o x 0.1^o$	Waves
Mediterranean	[26]	WAM	2	$0.1^o x 0.1^o$	Waves
Mediterranean	[27]	WAM	10	$0.625^o x 0.625^o$	Wave Power
Mediterranean	[28]	WW3	35	$0.12^o x 0.09^o$	Wave Power
Mediterranean	[12]	SWAN	35	$0.1^o x 0.1^o$	Waves, Wave Power

Majority of initial studies in the Mediterranean including [24, 25], delivered wave parameter data. Since 2010 though examination of the wave energy resource, usefulness and opportunities within have spurred dedicated studies for wave power [27, 28, 12]. With models both large and coastal scale, at high resolution and delivering long-term records with usual range of data $\approx 10 - 35$ years.

Wave energy is derived by the wave height (H_{m0}) and so-called period energy (T_e) and/or peak period (T_p) that the local resource offers. The energy contained within waves expressed in W/m, corresponds to the energy per crest unit length. In SWAN energy components are computed with a formulation appropriate for the realist representation of resource. Over the summation of very different wave frequencies (f) and directions (θ).

$$P_x = \rho g \int \int C_{gx} E(f, \theta) df d\theta \tag{1}$$

$$P_y = \rho g \int \int C_{gy} E(f, \theta) df d\theta \tag{2}$$

where $E(f, \theta)$ the energy density spectrum over an x (longitude) y (latitude) system. C_g are the components of absolute group velocities, water density (ρ), g gravitational acceleration. Total wave power is estimated in kW/m:

$$P_{wave} = \sqrt{P_x^2 + P_y^2} \tag{3}$$

The study contributes to the offshore community, with a high resolution wave database and analysis. All extracted locations represent easily accessible site, enhancing analysis outreach since no information from buoys or regional models exists for such a long period in Libya. With most model data being hindered by non-adequate resolution at these depths and distances from shores, the locations considered and their respective origins are presented in Table 2.

Table 2: Coordinates and depth information of the extracted locations

Location	Longitude	Latitude	Depth (≈m)
Libya1	14^o20”	32^o75”	30-35
Libya2	21^o77”	33^o00”	130-150
Libya3	22^o45”	32^o90”	30-45
Libya4	25^o05”	32^o00”	40-50
Libya5	17^o85”	30^o90”	20-30

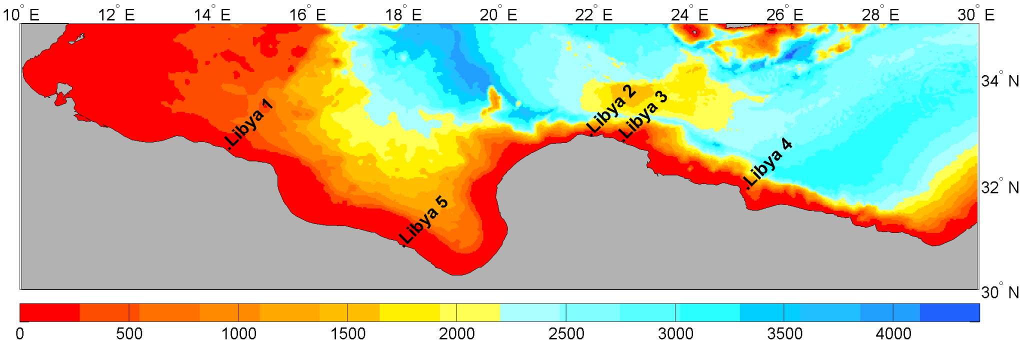
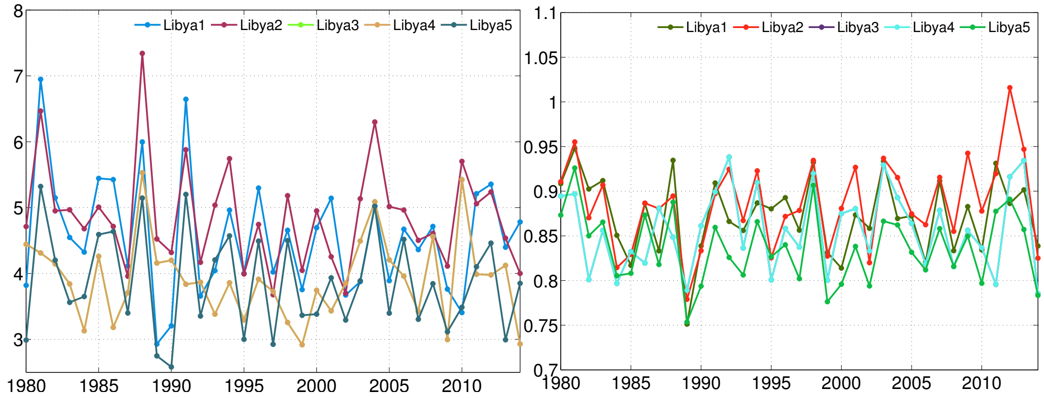


Figure 3: Locations and Depth of domain in meters

3. Results

Libyan points examined are located in both the West and East Side of the coastlines, providing a representation of expected resource and fluctuations along the coasts. Point selection was based on H_{m0} and wave energy maps of previous hindcast studies by the authors. Libya 1 is located at the East coasts near the city of Al-Khums, Libya 2 is between the city of Al Hamamah and Susah, Libya 3 is on the North West of the city of Dernah. Libya 4 is on the far east side of the Libya coasts on the East of Tubruq and Libya 5 is at the located at the Gulf of Sidra East off the town of Surt.

Highest values of mean and maximum H_{m0} are recorded in Libya 2-4, followed by Libya 1. Lowest levels of both mean and maxima are encountered in Libya 5. This was expected since Libya 5 is located at an encapsulated area at shallow depths, with surrounding land masses reducing incoming resource. Interestingly Libya 1, placed at an exposed region receives significant levels of wave height, eastern location are exposed similar trends in magnitude and trend annually. Maximum values differ significantly for locations, mean exposed resources remain the same for all areas within the range of 0.75-0.85 meters (see Fig. 4).



(a) Max H_{m0} (b) Mean H_{m0}

Figure 4: Wave characteristics of locations

Greater differences in mean and maximum values of H_{m0} exist between records from the hindcast. Libya 2 has an average difference of wave height around 2.5 meters (maxima) and 0.30 m (mean) (see Fig. 4). While this suggests the energy content will not be as high at the first location, conditions that potential wave farms are exposed will be significantly less reducing the capital expenditure.

Wave resource while milder in South Mediterranean it can still play an important role in both the production and coverage of renewable variability. Wave energy is directly correlated to wind for wave generation and propagation, and indirectly to solar through environmental interactions of precipitation.

Furthermore, winds blowing over the area affect locally generated waves. Waves can act as "storage" carrier of energy content which has temporal differences in comparison with wind [29]. This is expected to be an important component since inter-connectivity of resources (wind and waves), can act complementary minimizing discrepancies in expected production, and reducing to some extent the necessity for infrastructure that can accommodate increased renewable energy [30, 31, 32].

Coefficient of Variation (CoV) reveals the level of variability of wave energy across the area, combination with individual locations maxima and means allows identifying potential locations that have high resource and minimum variation of wave energy. This ensures that the potential energy production by WECs will be uninterrupted and deliver smoother operation and energy production throughout their lifetime operation.

$$CoV = \frac{\sigma}{\mu} \tag{4}$$

The CoV in Fig. 5 is based on the estimation of the P_{wave} mean (μ) and standard deviation (σ) values (see Eq. 4), the scale of the figure has been scaled to display the region with the highest levels. This allows examination of seasonal, intra–annual, and decadal variations for both significant wave height and period. Fluctuation annually and overall are adequately resolved over a long-term context, which is suggested by previous protocols and studies that propose at least 10 years data to be used for characterization [33, 34].

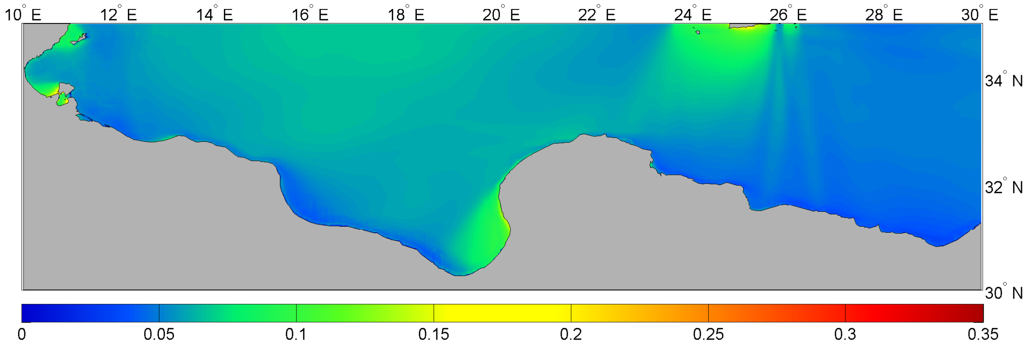


Figure 5: CoV of Wave Energy over 35 years for the Libyan coastlines (scaled down)

Highest CoV levels encountered at Gulf of Sidra (Khali J Surt) with values ranging from 0.1-0.15 (see Fig. 5), since the locations are placed in an encapsulated environment and the propagated resource is reduced by bottom interactions and coastlines. Remainder of coastlines are exposed to low levels of CoV.

In the case of Tunisia, the Southern part in the border with Libya, presents similar levels of CoV and more specifically at the peninsula of Jerba at the Gulf of Gabes. The inner coastlines are affected by refraction, shoaling, and depth breaking effects characterising interactions between sudden changes and areas behind land masses, accounting for higher CoV values. Turning orography from North to South of the Libyan coastline affects the final levels of energy flux that reach the areas, with complex areas being un-desirable for WEC applications. This ensures that WEC farms will be able to deliver predictable amounts of energy in their annual yields. The change and variability of wave power apart from the information that can be extracted from Fig. 5, can also display the CoV expected.

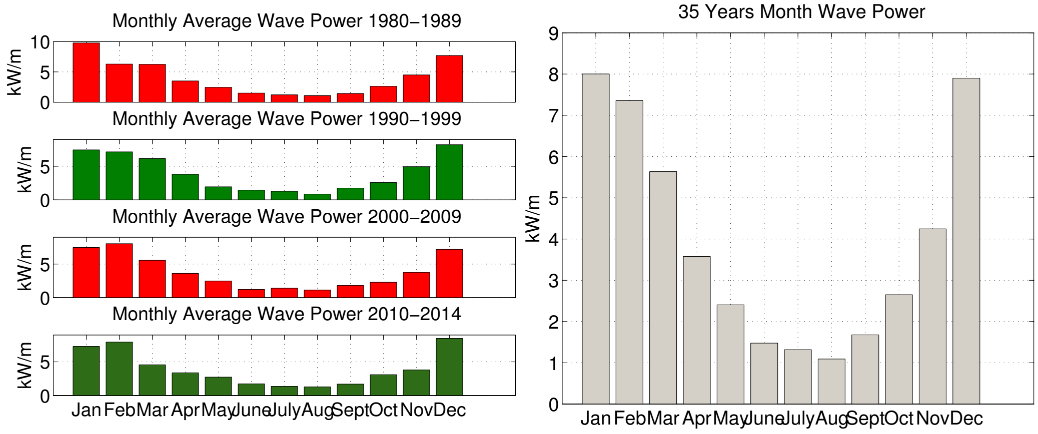
From Figs. 6-7, distribution of monthly wave energy for selected locations as well as overall monthly average are estimated. In all cases summer months present the lowest values, as is to be expected. Highest levels of resource are found in the autumn and winter months with a slow decrease over the spring.

More specifically for locations 1–4 have similar distribution of monthly mean energy, with Libya 1 expressing a maximum value of wave energy of 8 kW/m (overall) and minimum ≈1 kW/m, see Fig. 6. Libya 2-4 have the same levels of magnitude in wave energy with overall maximum resource located at 10 kW/m and the lowest at 1kW/m, see also Fig. 6. Libya 5 as discussed in the wave height analysis has the lowest incoming wave parameters with the highest frequencies thus reducing the incoming flux. This is evident in Fig. 7 where the overall maximum is around 6.5 kW/m while minimum value is 1.5 kW/m. The decadal analysis of the months also exhibit that annual monthly averages deviate as well.

Spatial distribution of wave power for the region is presented in Fig. 8. Following the energy analysis for the locations, highest resources are met on the North-East coast, with intermediate depth wave power close to $8(kW/m)$ (Locations 2-3). The Gulf of Sidra (Khali J Surt), and West areas near the Gulf of Gabes have the lowest resource overall.

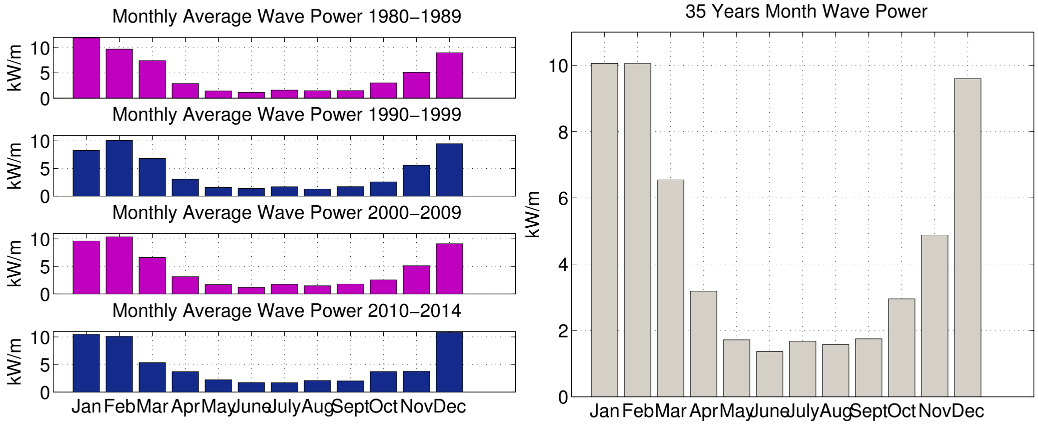
3.1. Wave Energy Development Index (WEDI)

In order to quantify and assess potential sites for future research and WECs application, wave energy distribution must not be the only criterion.



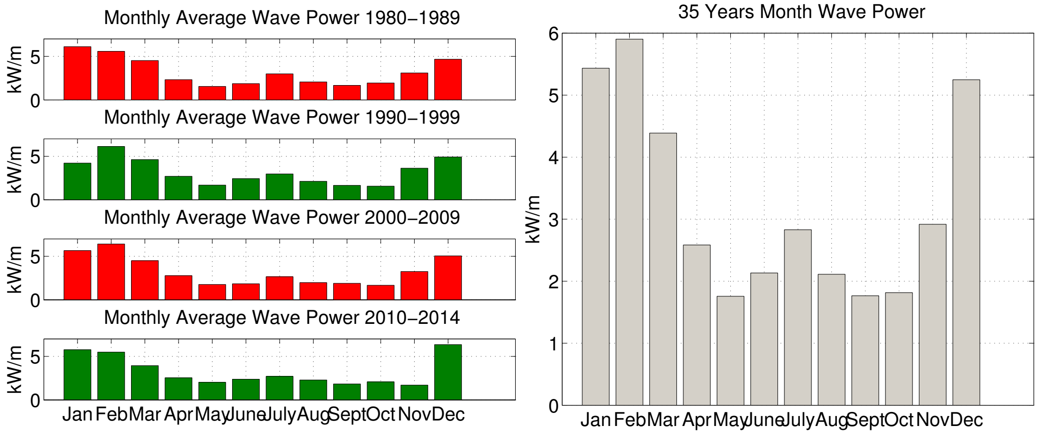
(a) Libya 1 decades

(b) Libya 1



(c) Libya 2 decades

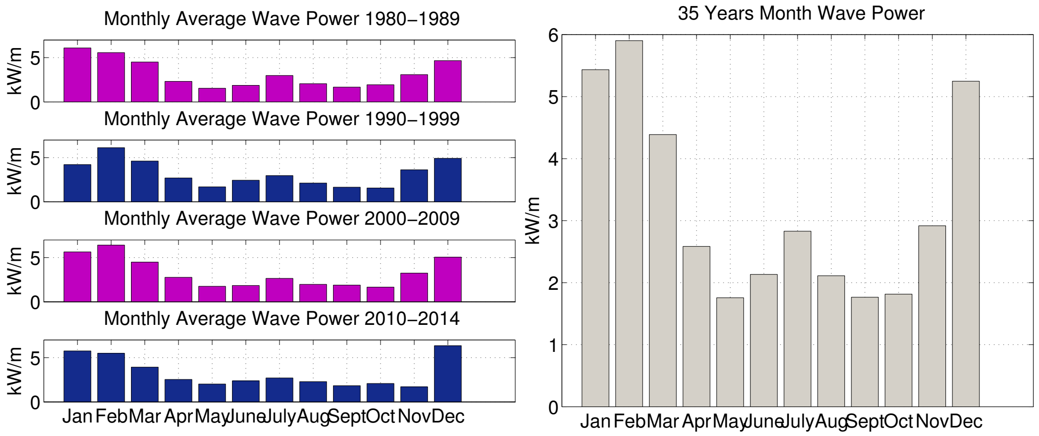
(d) Libya 2



(e) Libya 3 decades

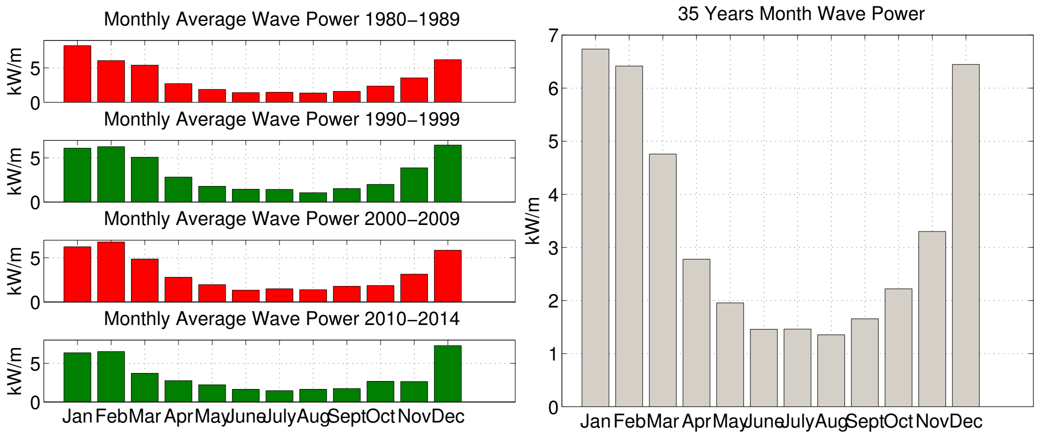
(f) Libya 3

Figure 6: Wave Characteristics of locations 1-3



(a) Libya 4 decades

(b) Libya 4



(c) Libya 5 decades

(d) Libya 5

Figure 7: Wave Characteristics of locations 4-5

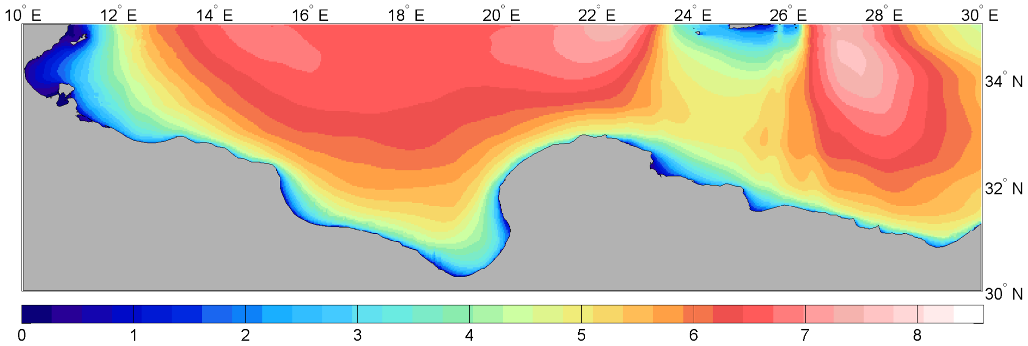


Figure 8: Wave Power content (kW/m) for Libyan Sea through overall hindcast period

Metocean conditions do not only affect wave energy flux but also have direct implications on survivability structures deployed. Wave Energy Development Index (WEDI) as presented by Hagermann [35] and Akpinar et.al. [36], associates effects of mean ($\overline{P_{wave}}$) and maximum wave power (J_{wave}) thus including storm events, see Eq. 5. WEDI provides insight on potential dangers and interactions that harsh events can have on WECs and offshore structures. While, it is not the sole decisive factor, the index in combination with the mean energy content and extreme value analysis can assist in the proper sitting selection for wave energy converters, reduce infrastructure and maintenance costs.

$$WEDI = \frac{\overline{P_{wave}}}{J_{wave}} \tag{5}$$

The Wave Energy Development Index (WEDI) shows the potential of wave energy at a site while also reveals the level of danger for a location (area-region), establishing a "cost–to–benefit" approach taking into account potential risks with the local conditions in regards to energy levels. The index has a range from 0-1, locations with 1 have the harshest events that can affect the survivability.

Spatial distribution of the WEDI index over the 35 years hindcast is presented in Fig. 9, the irregularities of the coastline e.g. small gulf and turning areas have an effect on the way the final energy reaches the shores. Such areas are easily identified, and WEDI acquires values up to 0.08. At shallower locations less than 10m the index acquires higher values, since the max over the mean often mean "harsher" conditions. Areas near shallow

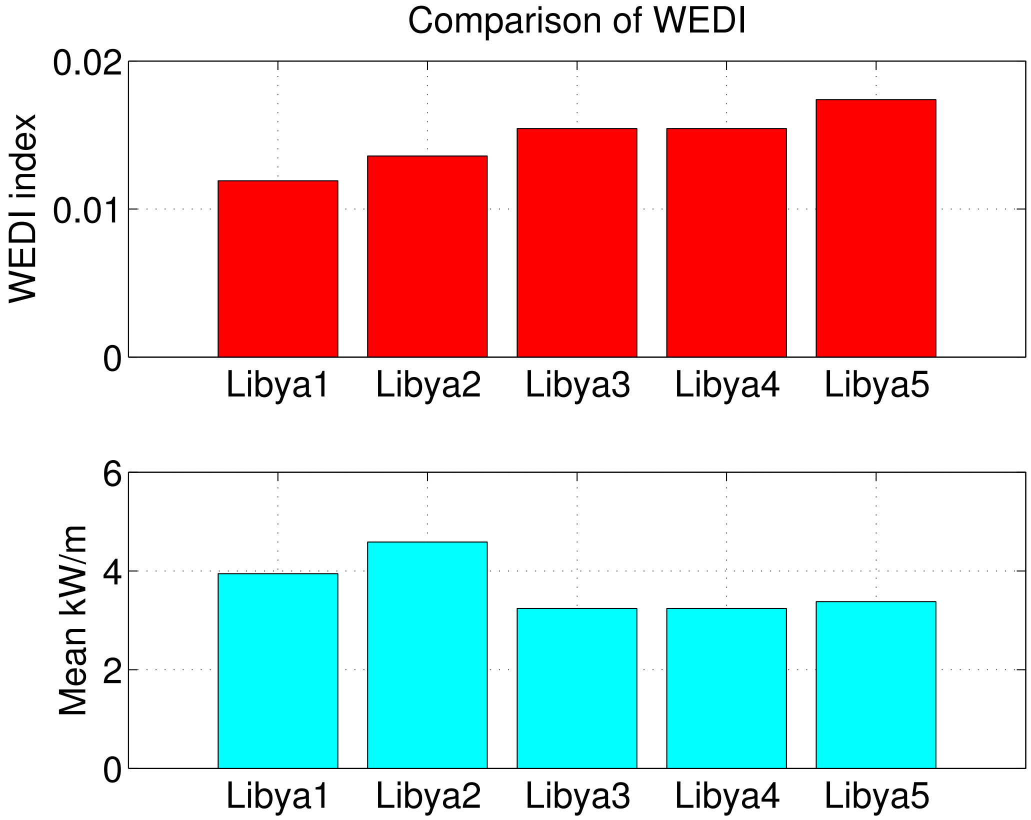


Figure 9: Wave Energy Development Index for the Libyan coastlines for the 35 years hindcast (reduced)

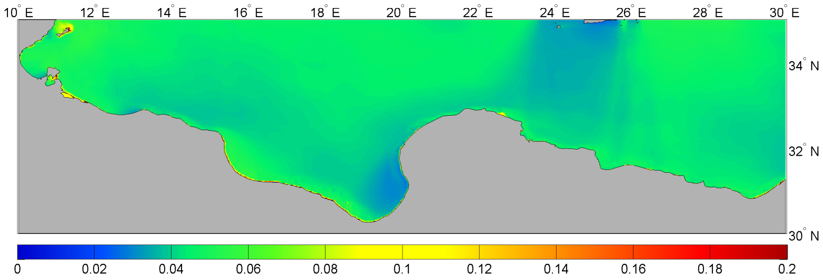


Figure 10: WEDI and mean resource encountered for the Libyan investigated locations over the 35 years hindcast

regions reach values of 0.2 such an example can be easily seen in the North West region of the map, at the Sharqi island.

From the extracted locations Libya 5 obtains the highest index, thus amongst these locations it is the least favourable (see Fig. 10). On the other hand Libya 1-2 are ranked as the most promising sites, with higher levels of resource constant over time and lower WEDI, this ensures predictability. In a sense WEDI provides preliminary information about "harsh" events and helps us consider some initial levels of capital required.

However, when wave farms are be deployed the authors believes that another important element is imperative to quantify. That is the investigation of extreme value events. This ensures that effects of extreme return periods on locations provide complete information about the dangers, potential, infrastructure work required.

3.2. Wave energy site assessment

To assist in the informative decision on site classification, the bivariate (joint) distribution of H_{m0} and period are examined. The wave period taken into account in the classification in the energy period T_e, which is directly used in most WEC power matrices [37]. The number of occurrences of the coupled data provide insights on "dominant" wave characteristics height/frequency for each location.

In Fig. 11, the hindcast is used to provide with an overview of seastate characteristics. Libya 2-3, locations which are fairly close (see Fig. 3) have similar descriptions. Dominant characteristics describing the points express H_{m0} from 0.5-2, T_e ranges from 4-8 sec. Although, higher records over 7 meters for both points are found, they are less than 1% of total time (Libya2) and less 0.5% for Libya 3. Libya 1, also presents similar patterns for wave occurrences, with most common instances of 0.5-2 m H_{m0} and up to 7 sec. It maximum values over 7 m represent less than 0.3%. Libya 4 shows a slighter increase of H_{m0} occurrences, with a good number present to heights from 1.5-3 meters. Libya 5, which as seen is surrounded by land masses, has most common wave periods up to 4-6 sec and H_{m0} mostly from 0.5-1.5m.

Analysis of the bivariate wave distribution indicates that a wave energy converter should have operational characteristics for low magnitude conditions. Operational modes should cover a cut-in (start of production) for H_{m0} between 0.5-1 m and high frequencies (low periods 2-7 sec). Rated power should be reached within 1.5-3m, allowing consistent performance. While,

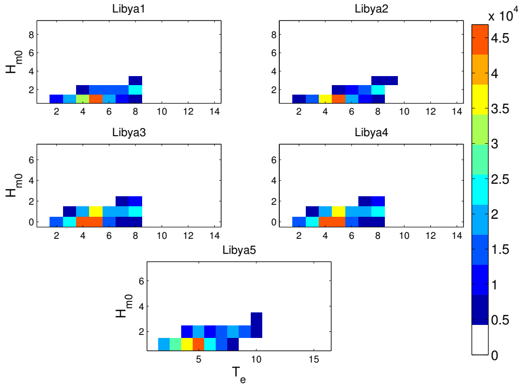


Figure 11: Occurrences

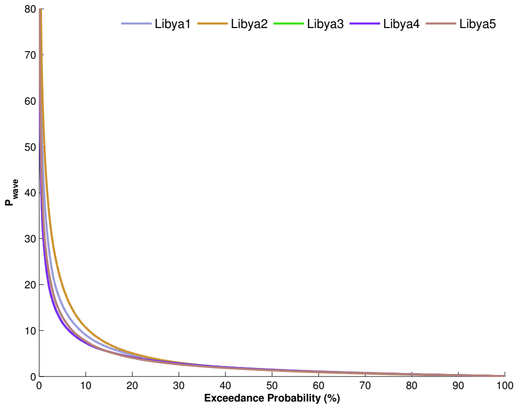
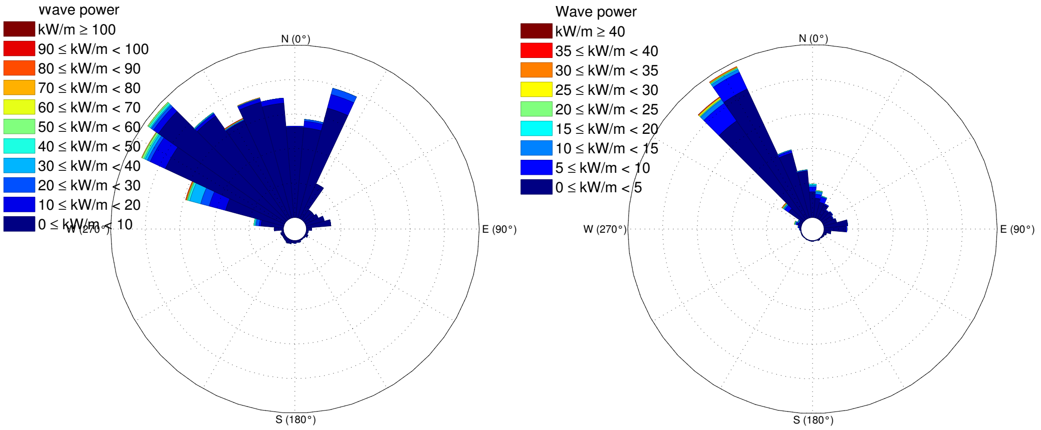


Figure 12: Exceedance probability P_{wave}

higher values of H_{m0} are present in the locations, i.e. over 5m, they represent a small number of occurrences, thus WECs achieving rated production during such intervals are not suitable.

The most commonly found content of wave power for each location, can also be summarised in the exceedance diagram, see Fig. 12. Libya 2 presents the highest resource P_{wave} amongst the locations, while Libya 4 the lowest. The highest probabilities of wave power (kW/m) are under 10 kW/m. The analysis considers only the resource levels of the region. However, it is important to note that in the implementation of WECs in the aformentioned areas, additional information such as directions and spreading are vital. For example in our domain Libya 2 which has been identified as the most promising has a wider range of incoming direction predominately from the North West with higher intensitites. On the other hand, Libya 4 has almost all its wave orginating from the North West, indicating that a perpendicularly North facing device would enhance production.

Wave energy production thus depends not only on the bivariate distribution, but also on the directionality of the resource. In terms of desired direction, this will depend on the selection of the devices. Some WECs favour a perpendicular facing approach to the dominant wave direction, while other devices can utilise a higher number of direction. Such operational characteristics should be taken into account with the bivariate distribution, in order for energy production to be optimised. However, up to now most available information on wave energy production are limited to the bivariate sea states for production [38]. In order to quantify the directional effects additional in-



(a) Libya 2 (b) Libya 4

Figure 13: Characteristic wave roses for P_{wave} and direction

formation have to be shared with the international community. Even with the knowledge of directional effects more specialised analysis are needed.

3.3. Extreme Value Analysis

Asides classification of wave energy content and metocean conditions, another important consideration are the expected extreme return periods. Assessment of extremes adds significantly to structural considerations for WECs and offshore activities. Desirably the length of appropriate datasets, should not be less than 20% of the desired return value. For example if a 50 year period is investigated at least 10 years of data should be available [33, 39]. The hindcast H_{m0} of our model is used for an extreme value analysis (EVA) with use of the Peak-Over-Thresholds (POT) and Generalised Pareto Distribution (GPD) [40].

The data constitute approximately 35 years (420 months), with hourly recording ($> 307,000$hours). The data have been prepared and filtered with threshold ensuring that the final difference of event ensuring data ta identically independently distributed (i.i.d). Common practises suggest a timeframe within 2-4 days to ensure independence, [40, 41].

In order to filter and decluster the current database an appropriate threshold is set, based on the 99^{th} percentile of H_{m0}. The choice took into account the available data and record its effects of the final data size. It is important to note that if a high threshold is set, to a low temporal timeseries the final new dataset may lead to poor statistical fits [42, 43]. Large scale datasets have used a 98^{th} [44] and 99.5^{th} percentile [22]. Length of our dataset suggests that the 99^{th} percentile would be appropriate to reduce the timeseries.

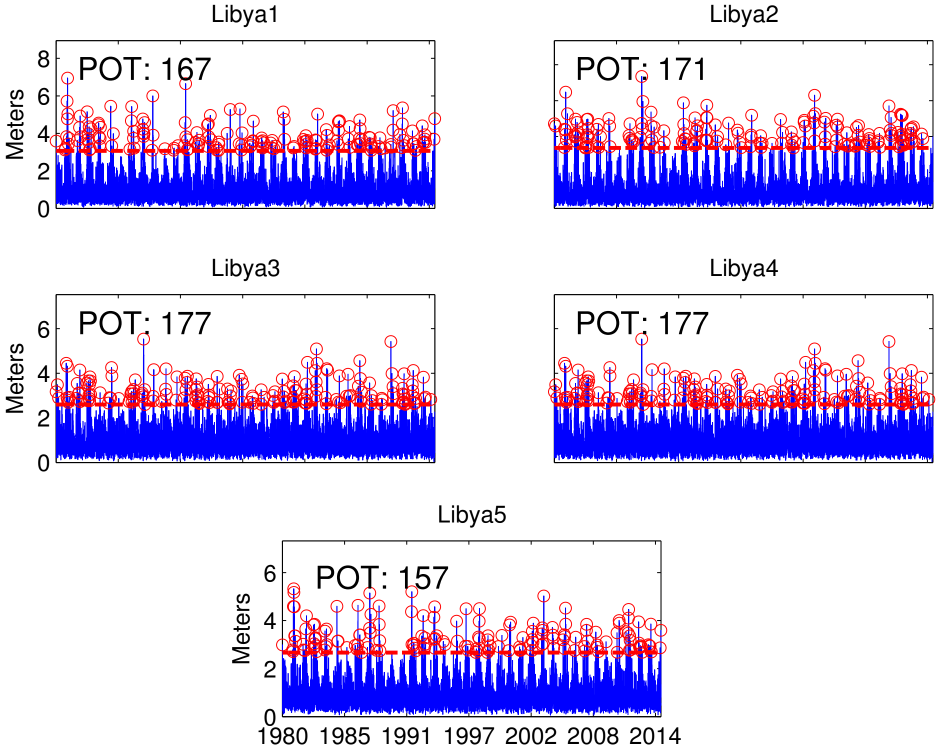


Figure 14: Declustered dataset of H_{m0}

The return levels (return periods) can be calculated by utilizing the fitted GPD parameters of each location and based on the procedure presented in Eq. 7. Since most wave applications are to be installed in a location for at least 20 years, we examined the return periods for H_{10}, H_{20}, H_{50} and H_{100} years, keeping in mind that any potential re-powering and re-use of a site might be possible.

$$\lambda_u = \frac{k}{n_{years}} \tag{6}$$

$$z_p = u + \frac{\hat{\sigma}}{\xi}\left[(N \cdot \lambda_u)^{\xi} - 1\right] \tag{7}$$

with N return value in years, λ_u rate of threshold, u threshold, κ length of dataset by POT, n_{years} sample duration, $\hat{\sigma}$ (scale) and ξ (shape) the GPD parameters.

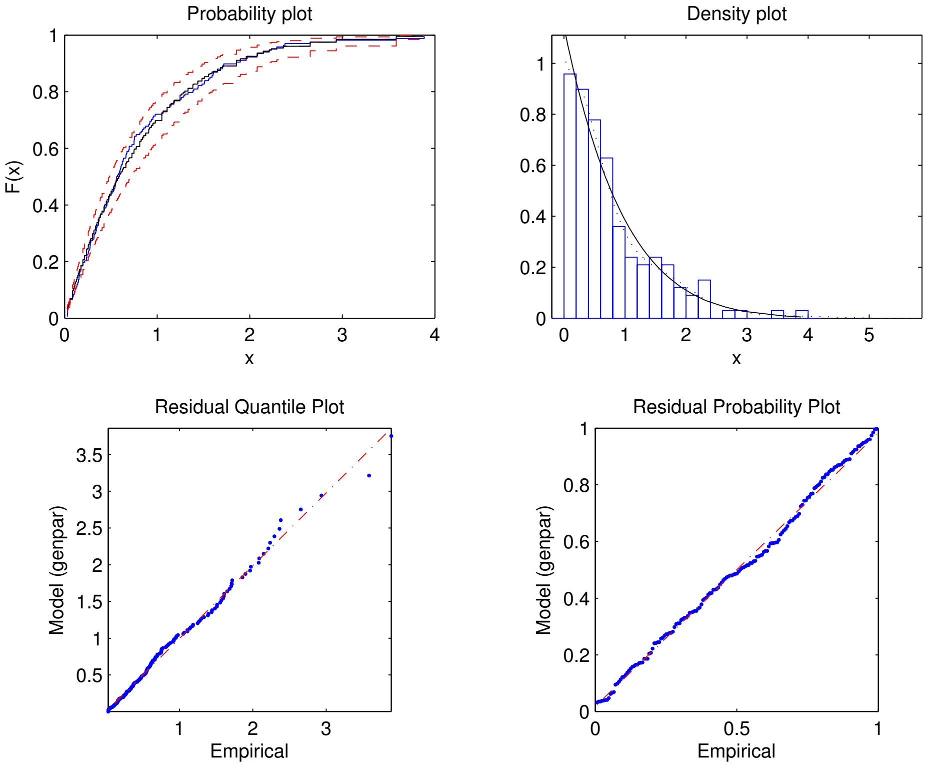


Figure 15: Diagnostics plots for fitter Libya 1

Probability and QQ plots are the bottom two plots in each graph. The GPD through the CDF (upper left plot of each graph), has a good fit while the histogram of the data is given in the upper right plot showing the distribution. The QQ plot (bottom right plot) for all GPD approaches has a good fit, adding confidence in the GPD method. From GPD parameters the return periods can now be estimated and compared with the annual maximum of the each location.

Based on the estimated return periods the most severe condition is met at Libya 2, followed by Libya 5 and 1. Interestingly Libya2 and 3, which exhibit a good wave energy content have lower return values. This indicates that the potential infrastructure costs may be less for the locations, reducing

Table 3: Return H_{m0} in meters

Location	H_{10}	H_{20}	H_{50}	H_{100}	H_{max}
Libya1	7.27	8.24	9.63	10.78	6.94
Libya2	8.62	9.97	12.03	13.82	7.34
Libya3	5.55	6.18	7.06	7.76	5.53
Libya4	5.55	6.18	7.06	7.76	5.53
Libya5	6.81	7.87	9.47	10.84	5.32

the potential capital expenditures required for strengthening works. Our findings show similar trends in extreme return periods with [45], however in that case the model used was an oceanic for a 10 years hindcast. The numerical modelling approach followed by our model allows greater outreach and higher fidelity in nearshore areas. Our return periods, though so good agreement with our H_{10} being over-estimated by $\approx 3\%$. Remaining return periods are higher in Arena et al. [45] in regards to our results from $\approx 1-9\%$.

4. Conclusions

In this study, a third generation wave numerical model was used, fed with high-resolution temporal and spatial data to examine the wave resource and potential wave power at Libyan coast for construction of a comprehensive wave power Atlas. A gap in the awareness of the local metocean conditions is evident by lack of appropriate resource assessment, this study tries to mitigate and provide with valuable information. The hindcast was based on a nested approach the wave numerical model validated [12, 13].

The wave assessment presented annual mean and maximum, quantifying the level of wave energy. The energy content is higher in winter months, with values for 8-10 kW/m. The Western coastlines, for example between 20-24^o East, are exposed to higher resources, while region in encapusalted region such as the Gulf of Surt have almost three times less. However, the lower wave energy resource benefits from low coefficient of variation, enhancing the predictability for energy production. This can provide reliable predictions in energy production, thus reducing uncertainties.

The classification of sites shows that lower resources are encountered, favouring for selection of ”low” operational WECs. Return value analysis shows that the probable severe waves are within $\approx 7-13m$ (depending on location), this may lead to considerations for cost reductions in the installation of WECs. The 35 years Atlas provides a thorough resource assessment and subsequently can be used to quantify potential production by wave converters.

Nearshore waters in Libya are not as energetic as the Atlantic coasts. However, they still hold a significant amount of renewable energy that can be harnessed. With financial support schemes by major banking institutions, developing industrial sectors and potential cooperation in the area, innovative solutions can aid in the energy and financial growth of the countries.

The nature of wave energy and the combination with other local indigenous resources, can lead to the diversification and energy targets set by the respective countries presented. While solar and wind, seem to be the more obvious solution, wave energy can act as an additional production mechanism to enhance RE production and reduce renewable intermittent production. In addition, growth for local coastal populations and industries is also a thing to be expected.

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