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Wave energy potential assessment for Riva and Foça, Turkey

Riva ve Foça, Türkiye için dalga enerji potansiyeli değerlendirmesi

***Yazar(lar) (Author(s))**: Egemen SULUKAN*

ORCID: 0000-0003-1138-2465

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. Wave Energy Potential Assessment for Riva and Foça, Turkey

Araştırma Makalesi / ResearchArticle

Egemen SULUKAN[*]
National Defense University, Turkish Naval Academy, Mechanical Engineering Department, İstanbul, Turkey
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ABSTRACT

Humankind has been looking for alternative energy supply options. This search has always been a big challenge. Renewable energy sources blossom the most possibly nature-harmonized options with no harmful propagation or emissions. Turkey, as a developing country and a highly experienced candidate to European Union membership, determines relevant energy policies by assessing domestic energy potentials. However, no official target for energy utilization from the seas is officially set so far. Wave energy can be one of the alternatives that can contribute to the energy mix of Turkey. This contribution would also positively affect the fossil fuel import rates of the country while the wave energy conversion technologies mature and penetrate the energy markets. With this in mind, wave energy potentials have been calculated for two locations, Riva and Foça; based on the data measured and obtained from the Office of Navigation, Hydrography and Oceanography of Turkish Navy. Comparatively low wave energy level results are obtained, mainly caused by the measurement sites are not on the shores of open sea or oceans, but inner seas. These results would hopefully help the respective engineers to reach the most suitable designs for these wave characteristics.

Keywords: Wave energy, wave energy potential, significant wave height, wave period.

Riva ve Foça, Türkiye için Dalga Enerji Potansiyeli Değerlendirmesi

ÖZ

İnsanoğlu alternatif enerji arz seçenekleri arayagelmektedir. Bu arayış her zaman büyük bir mücadele olmuştur. Yenilenebilir enerji kaynakları, doğaya en uyumlu olası seçenekleri, zararlı bir yayılım veya emisyon olmadan sunar. Türkiye, gelişmekte olan bir ülke ve Avrupa Birliği üyeliğine oldukça deneyimli bir aday olarak, yerli enerji potansiyellerini değerlendirerek ilgili enerji politikaları belirlemektedir. Bununla birlikte, bugüne kadar denizlerden enerji kullanımı için resmi bir hedef belirlenmemiştir. Dalga enerjisi Türkiye'nin enerji karışımına katkıda bulunabilecek alternatiflerden biri olabilir. Dalga enerji çevrim teknolojileri olgunlaşarak enerji piyasalarına nüfuz ederken, bu katkı ülkenin fosil yakıt ithalat oranlarını da olumlu yönde etkiler. Bu düşünceyle, Türk Deniz Kuvvetleri Seyir, Hidrografi ve Oşinografi Dairesinden alınan ve elde edilen verilere dayanılarak, Riva ve Foça olmak üzere iki konum için dalga enerjisi potansiyeli hesaplanmıştır. Ölçüm sahalarının açık deniz veya okyanus kıyılarında değil, iç sahillerde olması sebebiyle nispeten düşük dalga enerji seviyesi sonuçları elde edilmiştir. Bu sonuçların bu alanda çalışacak mühendislerin bu dalga karakteristikleri için en uygun tasarımlara ulaşmalarına yardımcı olması umulmaktadır.

Anahtar Kelimeler: Dalga enerjisi, dalga enerjisi potansiyeli, belirgin dalga yüksekliği, dalga periyodu.

1. INTRODUCTION

Turkey, as a country highly dependent on energy imports, has been seeking alternative energy resource options in order to alleviate the budgetary burden mainly arising from its energy imports. As a developing country, Turkey is still suffering from high energy imports. Meanwhile, it is aimed to increase the installed renewable energy systems and reach 600 MW installed capacity in solar power plants, 600 MW in geothermal power plants, 20000 MW in wind power plants and 36000 MW of hydroelectric potential until the year 2023 to be transformed into a more domestic resource-supplied country profile.

This official vision clearly appeared in the "Electricity Energy Market and Supply Security Strategy Paper" published under coordination of Under-secretariat of State Planning Organization of Turkey in 2009; which has been the backbone and foundation of the policy and strategies shortly expressed as "Our primary target is to ensure that the share of renewable resources in electricity generation is increased up to at least 30% by 2023. This target will be subject to revision based on potential developments in the technology market, and resource potential" by the Ministry of Natural Resources and Energy of Turkey [1].

Even though it is aimed to maximize the renewable energy utilization by the year 2023, 100th anniversary of the founding of the Republic of Turkey, no targets are set for wave energy utilization in this strategy paper. However, this issue could be assessed under the title

**Sorumlu Yazar (Corresponding Author)*
e-posta : esulukan@dho.edu.tr, egemensulukan@gmail.com

"other renewables" of this strategy paper, depending on the maturing technologies and its proven technical and economic potential in time. Wave energy is evaluated by previously conducted studies as a yearly potential of 18.5 TWh [2] and 10 TWh [3] as one of the alternative energy resources of the country. Wave energy can obviously contribute to the energy mix with its potential, as well as resource security and diversification dimensions of this issue.

The energy policies of Turkey have been evaluated by various studies so far. An outlook is given by Yılmaz and Uslu for the period 1923-2003, investigating the implemented policies in the energy field during different periods since the foundation of the Republic of Turkey in 1923 [4]. Kiliç and Kaya gave a general outlook about the energy reserves, energy demand, energy production, energy consumption, energy policies, and relevant developments in their study [5]. From the renewable energy potentials perspective, Benli conducted a study on the potential of renewable energy resources in Turkey and the magnitude of their current and future contributions to the national energy consumption considering energy politics [6]. Ozgur also investigated the present state of world renewable energy sources and then looked in detail at the potential resources available in Turkey [7].

Some other analyses reported the energy production and policy status in Turkey [8-10]. Kabak and Dağdeviren analyzed and prioritized the renewable energy sources for Turkey by using a hybrid multi-criteria decision-making methodology [11]. Nevertheless; as one of the primary studies conducted in Turkey in wave energy context, Taşdemir has analyzed the wave power potential along the coast of Turkey in 1991 [12]. Özdamar, et al investigated the wind-wave potential of Çeşme-Turkey [13]. In another comprehensive study, Ayat published the wave power atlas of Eastern Mediterranean and Aegean Seas [14], and Aydoğan et al produced the wave energy atlas of the Black Sea from 13-years hindcasted wave data [15]. Akpınar et al assessed wave energy resource of the Black Sea based on 15-year numerical hindcast data [16]. Citiroglu and Okur studied on wave energy converter (WEC) applications in Ereğli on the western Black Sea coast of Turkey [17].

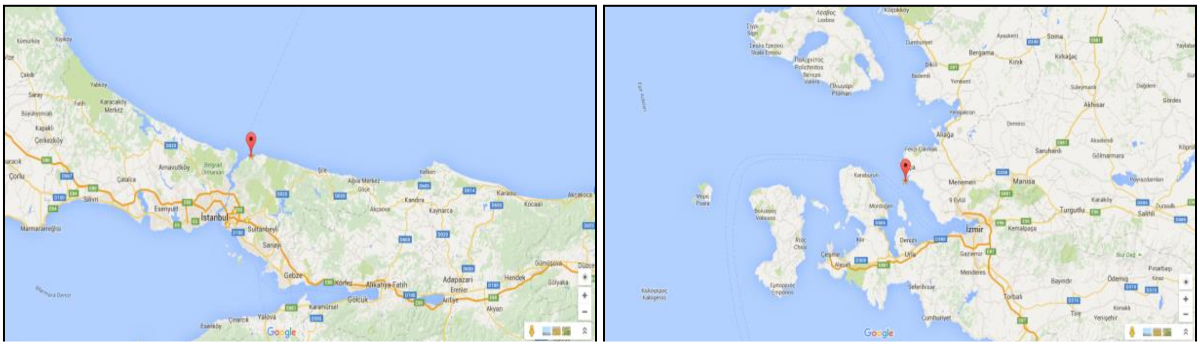
Even though the wave energy potential of Turkish coasts has been evaluated many times, no commercial wave energy conversion system implemented so far. Nevertheless, a recent application to the Energy Market Regulatory Authority (EMRA) for energy production license has been accepted as a breakthrough in this area. This project, namely "Gelemiş Wave Power Plant" reportedly will be located in Kaş, Antalya with an installed capacity of 4.5 MW.

The wave energy area has also attracted a global attention. A number of studies have been conducted for wave energy potential estimations, in Lebanon [18], Lithuanian coast of the Baltic Sea [19], Azore Islands [20], and Sicily (Italy) [21].

Apart from the potential estimations, the energy harvesting technologies have also been an interesting field to be reviewed and improved. Wave energy technologies and the necessary power-equipment are analyzed by López et al [22], Rusu and Onea assessed the performances of various WECs along the European continental coasts [23] and recently, Di Fresco and Traverso analyzed the simulation and test of the Seaspoon WEC [24].

Besides the developments in technology and implementations, allocation of the wave energy converters have recently risen as an important issue. Three wave energy converter arrays located in the Turkish coasts of the Black Sea are analyzed by modeling four sea states observed at each of two locations to investigate the effects of the wave-body interactions on the energy generation within arrays [25], while a test bed study conducted to evaluate best practices in wave modeling to characterize energy resources of Oregon Coast, with its high wave energy and available measured data and two third-generation spectral wave models, SWAN and WWIII, were evaluated to employ a four-level nested-grid approach [26].

Additionally, different studies conducted to determine the optimal size of a cylindrical buoy based on wave characteristics: wave length,amplitude, velocity and other factors. Waves are classified into long-period swell waves and short-period lippers and a bouy design with a skirt is proposed to increase the cylindrical buoy's damping and to decrease the effect of the ripple energy source, which can easily cause instability of the energy system [27]. Zou, et al applied the optimal control theory to compute control for a single-degree-of-freedom heave wave energy converter. In order to maximize the energy extraction per cycle for both constrained and unconstrained optimal control problems considering the periodic and non-periodic excitation forces. Their simulation results show that the proposed optimal control solution matches the solution obtained using the complex conjugate control with the advantage of the proposed control without the need for wave prediction; but only requiring the knowledge of the excitation force and its derivatives at the current time [28]. Bozzi et al focused on hydrodynamic interactions between heaving wave energy converters in wave parks of four devices, simulated in the time domain by a hydrodynamic-electromagnetic model, coupled with a boundary element code for the estimation of hydrodynamic parameters, considering to assess the effect of design parameters on array power production. Then, a site-specific design optimization is carried out for different Italian locations and some key insights on wave farm design in real wave climates are provided show that the effect of wave interactions on energy absorption is not expected to be a main issue, as long as the devices are separated by at least 10 buoy diameters and that the layouts are oriented to achieve the maximum energy absorption for the prevailing wave direction [29].



(a) (b)

Figure 1. Wave buoy locations in Riva (a) and Foça (b)

The wave climate around Turkey and wave prediction studies have been made in previously conducted NATO TU-Waves Project. At the end of this project, a wind and wave atlas with detailed statistical information, including wind and wave climate for the Black Sea and the other Turkish coasts is published [30].

Sağlam et al studied on "Calculating the Technical Potential of Wave Energy in Turkey, Case Studies for Project Feasibility and Design". Wave power assessment was given for most of the sites in Turkish waters [3].

Ferreira and Soarez studied on modelling distributions of significant wave height [31] and Özger et al studied on the general wave energy formula by using perturbation theory and the impact of the standard deviations of the two wave variables in determining the amount of available wave power in a sea site [32].

This paper is structured as follows: Chapter 1 gives a brief review of wave energy studies, Chapter 2 introduces the materials and methodology, including the area of interest of this paper and wave data used in the calculations and information about the wave buoys used for measurements and then gives the theoretical background heading the wave power potential assessment in two selected locations. The calculation results are represented in Chapter 3, with the conclusions given in Chapter 4 and; finally, discussions take place in Chapter 5.

2. MATERIALS AND METHODOLOGY

Even number of studies have been conducted to evaluate the wave energy potential near the shores of Turkey, these above mentioned studies are mostly based on formulae or computer data calculated on a grid system. This gap is a result of the lack of wave measurements along the shores of Turkey. Therefore, the estimations calculated in this paper aims to provide a regional insight near these two locations in the Black Sea and Aegean Sea for future wave energy studies.

In this study, wave data measured by the Office of Navigation, Hydrography and Oceanography (ONHO) of the Turkish Navy are used to calculate more precise wave energy potentials for different two locations. Two important parameters, the significant wave height (H_s) and the zero up-crossing-period (T_e) values are measured, recorded and processes by ONHO in two different locations around the Anatolian peninsula.

The first buoy is located at Riva site at coordinates 41°13'42.1"N-29°11'24.1"E, just near to northern entrance to Istanbul Straits from the Black Sea, on 18,5 meters depth, as illustrated in Figure 1. The second buoy is located at coordinates 38°36'59.7"N 26°44'24.2"E, near Foça at the mid-region of the Aegean Sea, on a depth of 41 meters.

2.1. Wave Buoys

Figure 2. Waverider DWR-Mk III buoy (Courtesy of Datawell BV)

Datawell Waverider MK-III, as shown in Figure 2, measures wave height per second with a stabilized platform sensor, enabling wave height measurements by a single accelerometer. The wave direction, direct pitch and roll measurements are performed with horizontal accelerometers and a compass, by the sensor unit. The collected data are sent to a computer, linked to the buoy, and then statistical and spectral analyses are held in every 30 minutes, periodically [33].

2.2. Wave Energy Potential Assessment

The movement of water creates the wave power in the marine environment. Wave energy project developers need to find the average resource as the first step. The power E (in kW/m) in a wave is approximately equal to the square of the significant wave height H_s multiplied by the zero up-crossing wave period T_e as follows:

$$E=\frac{\rho g^2 T_e H_s}{64\pi} \quad (1)$$

where ρ is the density of the sea water, and g is the gravitational acceleration. The typical sea state is composed of many individual components, each of which is like the ideal monochromatic wave, with the properties such as period, wave height and direction. The total power, carried by each unit length of the wave is equal to the sum of the powers of each these component. It is a reality that, measuring all the heights and periods is impossible, therefore an averaging process is used to evaluate the total power.

With respective data, both significant wave height (H_s) and the zero up-crossing-period (T_e) measured at Riva and Foça, the power has been estimated using the general expression of wave power (kW/m) for deep-water, (1), in spite of accuracy loss and ignoring detailed directional information.

$$E = \alpha \times T_e \times H_s^2 \quad (2)$$

where, significant wave height, H_s, is the average of the highest one-third of the waves and the zero up-crossing period, T_e, number of how many times the seawater surface crosses upward the mean level in a defined time interval.

Later, the same wave energy potential assessment in these sites executed using the stochastic structure of wave power potential formulation additional to traditional calculations. The general wave power formulation (2) derived by using the perturbation theory that gives the average power at those two points [32].

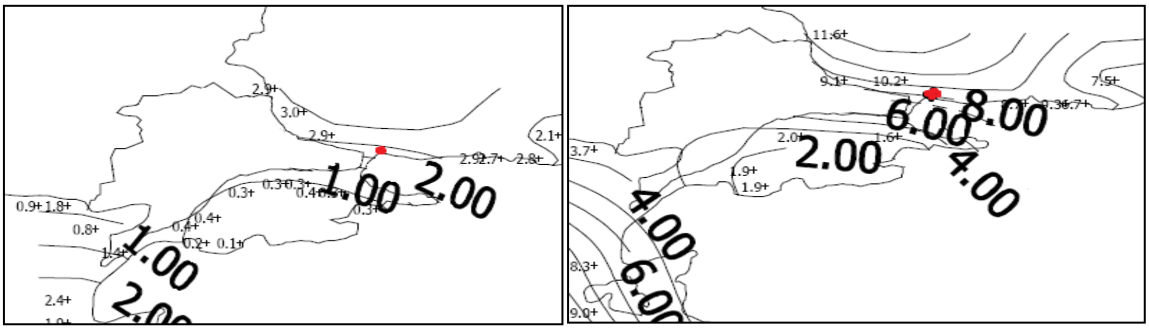
The annual variation in sea states can be expressed by a "sea-state scatter diagram" (e.g. Table 1), which indicates how often a sea state with a particular combination of H_s and T_e occurs annually.

3. RESULTS

Considering that all the heights and periods are dependent for an irregular sea, statistical analysis showed the wave power density at Riva site P_{ave} is 4.8 kW/m with regard to the range of wave heights up to 3.9 m and wave period up to 11 seconds were available at most of the year. The sea state scatter diagram of the site, Riva (the Black Sea) has been prepared using the significant wave height, mean and peak wave periods as shown in Table 1, containing the significant height (H_s), wave period and weighting values corresponding to H_s and T_e. Weighting values describe how many times it occurs in the time period of measurement. Power at Foça Site is calculated comparably as 2 kW/m less than the power calculated for Riva site.

The methodology used in the perturbation method, equation (2) is implemented for the measured data taken from ONHO. Actual wave power potential assessment in both sites was more than the power calculated using the traditional formula as 7.87 kW/m for Riva site and 3.1 kW/m for Foça site. The error ratio of power estimations between average and actual powers for Riva site is 38.9% and 36% for Foça site.

When the assessment is compared to the previous calculated results, Figure 3 (a) and (b) shows that the results occur between the minimum and maximum power levels [3]. The results arrived by using data.



(a) (b)

Figure 3. (a) Minimum and (b) maximum wave power levels at Riva site (kW/m)

$$\overline{E} = 0.49\overline{H}_s^2\overline{T}_e\left(1+\frac{\sigma_H\sigma_H}{\overline{H}_s^2}+2\frac{\tau_{HT}\sigma_H\sigma_T}{\overline{H}_s\overline{T}_e}+\frac{\tau_{H^2T}\sigma_{H^2}\sigma_T}{\overline{H}_s^2\overline{T}_e}\right) \quad (3)$$

Where, $\overline{Hs}$ and $\overline{Te}$ are the arithmetic averages and σH, σT and σH2 are the standard deviations of significant wave height, zero up-crossing period and significant wave height squared, respectively.

measured by ONHO and calculated in NATO TU-Waves project coincide with each other in a great scale.

Figure 4 shows that, the highest wave power occurs mainly in winter and autumn seasons. Especially, the period between January and April gives a power level of 13.8 kW/m; then declining to the least levels of 0.7 to 1.1 kW/m between April to July. After July, it rises to 4.3 kW/m level in August. The power level reaches the highest point to 25.6 kW/m between September-December 2012. Figure 4 may give a general idea about the specification basics of wave energy converter design, which to be built according to sea-wave climate while the dominant wave power level results in 4.3 kW/m at Riva site. Calculations made by these

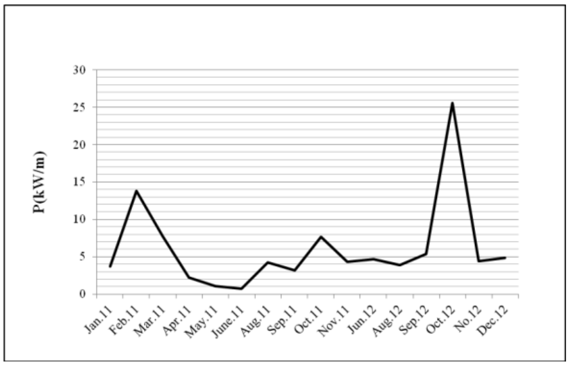
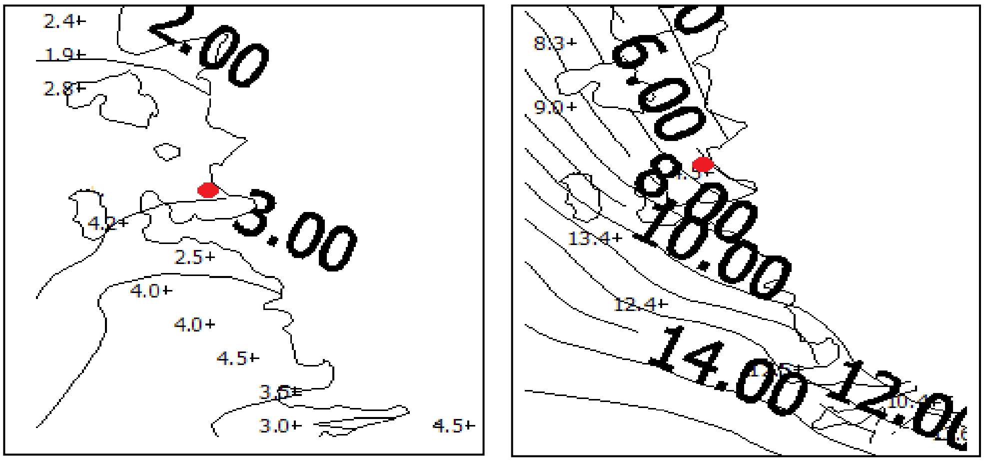


Figure 4. Monthly variation of wave power at Riva site

measured wave characteristics varying 4.8-7.8 kW/m of power in the Riva site. This result indicates a correlation with the results obtained from the previously conducted studies. The calculated maximum wave energy level is around the previously calculated value (8 kW/m) as given in Figure 3. However, the minimum energy level is around 4.8 kW/m, which is higher than the previous result found around 2 kW/m.

Recent calculation based on measured wave characteristics results 2.0-3.1 kW/m in Foça site. Figure 5 gives the minimum and maximum wave power levels belonging to Foça site, varying 2.26 - 8.40 kW/m.

Wave power levels are illustrated in Figure 5 with the



(a) (b)

Figure 5. (a) Minimum and (b) maximum wave power levels at Foça site (kW/m)

contours at this site. Figure 5(a) shows the minimum wave power levels calculated around 4.2 kW/m for the measurement site, while the maximum level is around 4.5 kW/m. The buoy is located in a position in a very short distance to the shoreline. As the energy level decreases around the shoreline, it is increasing when getting distant from the shore. This region gives a promising situation in terms of mild sea state and wave energy potential.

4. CONCLUSION

This study brings a calculation by using the measured data belonging to two different locations obtained from an official state institution rendered to reach the virtual amount of power intervals.

At the first look, the wave energy potential of Turkey can be assessed as uneconomical for electricity generation under current circumstances and by means of current WEC technologies. However, it is a reality that there is such a potential in the country, which is surrounded seas by the three sides. This potential may currently be ignored as wave energy-based electricity generation targets still does not appear in the official strategy paper. Turkey, as an import-dependent on energy country by 73%, importing almost all oil and natural gas and one fifth of all coal, should make every effort to minimize energy imports by taking all kinds of energy potentials into account.

Even the current evaluations on wave-energy based electricity production may not seem to contribute to higher levels when compared to conventional sources, this level will increase due to the technological developments in time.

As another important issue about the utilization of the current WEC technologies on the seas surrounding Turkey, it is widely known that the larger sized WECs require higher investment costs and bring potential structural problems associated with strength, and corrosive effects on material. For these two sites, it is assessed that, this "mild" sea-wave regime may divert the designer to combine an array of smaller sized WECs to be moored near these locations and harness the wave energy avoiding structural damages with other potential risks associated with large WEC sizes. At the end, implementing the arrays of these WECs would give optimal and determined electricity generation with cost-effective project budgets.

Current energy technologies will remarkably mold the energy mixture of future. It is widely accepted that fossil fuels are widely consumed in transportation, industrial, residential sectors and conversion technologies and appear as the main cause of the environmental contamination. Unless cleaner alternative energy carriers replace the fossil fuels, greenhouse gases will continue to be responsible mainly for the global warming.

Demand technologies used in transportation sector use liquid fuels and electricity mostly. Aviation vehicles use liquid fuels only. In the near future, hydrogen may be one of the convenient fuels as well as it is in the other sectors. One seventh of the world surface is covered by water. Exploiting vast offshore opportunities, wave energy farms for electricity and hydrogen production can be a good mean for the storage systems.

Nevertheless, efforts to generate electricity from wave power can be associated with hydrogen production at the respective electricity production site. Current studies indicate an abundant hydrogen-sulphide potential in the Black Sea. It seems possible to separate these two valuable substances, hydrogen and sulfur using electricity, which is produced by WECs nearby. Thus, it is to cause to decrease the contamination of the Black Sea [35].

5. DISCUSSION

The potential life of fossil sources should be elongated by adding every unit of renewable energy to the energy mix since next generations may be in need of them, which are stored in deeper layers of the earth. Wave energy, as the most intense alternative among other solar originated energy resource options, wave energy can be harnessed even from the mild seas by means of appropriately designed WEC farms. Turkey can get the utmost benefit of seas surrounding her three sides, and admire the value of the smallest rocky island in surrounding seas, which will most probably be a natural base for offshore wind and wave energy installations.

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REFERENCES

[1] State Planning Organization of Turkey, ***"Electricity Energy Market and Supply Security Strategy Paper",*** DPT, Ankara, Turkey, (2009).

[2] Hepbasli A., Ozdamar A., Ozalp N., "Present status and potential of renewable energy sources in Turkey", ***Energy Sources***, 23: 631-48, (2001)

[3] Saglam M., Sulukan E., Uyar T.S., "Wave energy and technical potential of Turkey***", Journal of Naval Science and Engineering***, 6(2): 34-50, (2010)

[4] Yılmaz O., Uslu, T., "Energy policies of Turkey during the period 1923-2003", ***Energy Policy***, 35: 258-264, (2007)

[5] Kiliç F.Ç., Kaya D., "Energy production, consumption, policies, and recent developments in Turkey", ***Renewable and Sustainable Energy Reviews***, 11: 1312-1320, (2007)

[6] Benli H., "Potential of renewable energy in electrical energy production and sustainable energy development of Turkey: Performance and policies", *Renewable Energy*, 50: 33-46, (2013)

[7] Ozgur M.A., "Review of Turkey's renewable energy potential", ***Renewable Energy***, 33: 2345-2356, (2008)

[8] Yüksel I., "Energy production and sustainable energy policies in Turkey", ***Renewable Energy,*** 35: 1469-1476, (2010)

[9] Tükenmez M., Demireli E., "Renewable energy policy in Turkey with the new legal regulations", ***Renewable Energy***, 39: 1-9, (2012)

[10] Basaran S.T., Dogru A.O., Balcik F.B., Ulugtekin N.N., Goksel Ç., Sozen S., "Assessment of renewable energy potential and policy in Turkey-toward the acquisition period in European Union", ***Environmental Science and Policy***, 46: 82-94, (2015)

[11] Kabak M., Dağdeviren M., "Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology", ***Energy Conversion and Management***, 79: 25-33, (2014)

[12] Taşdemiroğlu E., "Wave-power potential along the coast of Turkey", ***Energy***, 16: 779-782, (1991)

[13] Ozdamar A., Gursel K.T., Orer G., Pekbey Y., "Investigation of the potential of wind-waves as a renewable energy resource: by the example of Cesme-Turkey", ***Renewable and Sustainable Energy Reviews***, 8(6): 1364-0321, (2004)

[14] Ayat B., "Wave power atlas of Eastern Mediterranean and Aegean Seas", ***Energy***, 54: 251-262, (2013)

[15] Aydoğan B., Ayat B., Yüksel Y., "Black Sea wave energy atlas from 13 years hindcasted wave data", ***Renewable Energy***, 57: 436-447, (2013).

[16] Akpınar A., Kömürcü M.İ., "Assessment of wave energy resource of the Black Sea based on 15-year numerical hindcast data", ***Applied Energy***, 101: 502-512, (2013)

[17] Citiroglu H.K., Okur A., "An approach to wave energy converter applications in Eregli on the western Black Sea coast of Turkey", ***Applied Energy***, 135: 738-747, (2014)

[18] Aoun N.S., Harajli H.A., Queffeulou P., "Preliminary appraisal of wave power prospects in Lebanon", ***Renewable Energy***, 53: 165-173, (2013)

[19] Kasiulis E., Punys P., Kofoed J.P., "Assessment of theoretical near-shore wave power potential along the Lithuanian coast of the Baltic Sea", ***Renewable and Sustainable Energy Reviews***, 41: 134-142, (2015)

[20] Rusu L., Soares C.G., "Wave energy assessments in the Azores islands", Renewable Energy, 45: 183-196, (2012)

[21] Monteforte M., Re C.L., Ferreri G.B., "Wave energy assessment in Sicily (Italy)", ***Renewable Energy***, 78: 276-287, (2015)

[22] López I., Andreu J., Ceballos S., Alegría I.M., Kortabarria I., "Review of wave energy technologies and the necessary power-equipment", ***Renewable and Sustainable Energy Reviews***, 27: 413-434, (2013)

[23] Rusu L., Onea F., "Assessment of the performances of various wave energy converters along the European continental coasts", ***Energy***, 82: 889-904, (2015)

[24] Fresco L.D., Traverso A., "Energy conversion of orbital motions in gravitational waves: Simulation and test of the Seaspoon wave energy converter", ***Energy Conversion and Management***, 86: 1164-1172, (2014)

[25] Erselcan İ.Ö., Kükner A., "A numerical analysis of several wave energy converter arrays deployed in the Black Sea", ***Ocean Engineering***, 131: 68-79, (2017

[26] Yang Z., Neary V.S., Wang T., Gunawan B., Dallman A.R., Wu W.C., "A wave model test bed study for wave energy resource characterization", ***Renewable Energy***, (Available online 23 December 2016)

[27] Wang Y.L., "Design of a cylindrical buoy for a wave energy converter", ***Ocean Engineering***, 108: 350-355, (2015)

[28] Zou S., Abdelkhalik O., Robinett R., Bacelli G., Wilson D., "Optimal control of wave energy converters", ***Renewable Energy***, 103: 217-225 (2017)

[29] Bozzi S., Giassi M., Miquel A.M., Antonini A., Bizzozero F., Gruosso G., Archetti R., Passoni G., "Wave energy farm design in real wave climates: the Italian offshore", ***Energy***, 122: 378-389, (2017)

[30] Özhan E., Abdalla S., ***"Türkiye Kıyıları Rüzgar ve Derin Deniz Dalga Atlası"***, Middle East Technical University (MEDCOAST), Ankara, (2002).

[31] Ferreira J.A., Soares C.G., "Modelling distributions of significant wave height", ***Coastal Engineering***, 4: 361-374, (2000)

[32] Özger M., Altunkaynak A., Şen Z., "Statistical investigation of expected wave energy and its reliability", ***Energy Conversion and Management***, 45: 2173-2185, (2004)

[33] Datawell BV., "***Oceanographic Instruments Reference Manual"***, Datawell, Haarlem, (2015)

[34] Tucker M.J., Pitt E.G., ***"Waves in ocean engineering"***, Elsevier Science, Oxford, (2001)

[35] Baykara S.Z., Figen E.H., Kale A., Veziroglu T.N., "Hydrogen from hydrogen sulphide in Black Sea", ***International Journal of Hydrogen Energy***, 32: 1246-1260, (2007

Table 1. Sea state scatter diagram for Riva

Wave period, (Ts), (sec)

Significant wave height, (Hs), (m)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
1.75	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.25	4	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.50	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.75	1	11	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.00	2	11	4	7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.25	1	7	4	7	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.50	5	17	12	9	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.75	2	8	6	2	1	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.00	3	12	10	13	5	4	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.25	1	6	5	8	2	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.50	5	29	21	16	8	11	4	6	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.75	2	9	16	7	4	8	7	4	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.00	1	9	16	6	17	6	4	7	3	2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.25	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.50	2	9	9	5	7	4	8	7	1	5	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.00	1	11	3	5	6	11	11	6	10	7	5	2	0	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.25	1	5	9	4	6	11	6	7	9	7	2	4	8	9	5	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.75	2	5	4	3	3	7	4	7	10	10	9	7	6	2	5	4	0	1	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.00	2	6	2	0	2	2	3	3	6	4	9	5	5	6	3	7	2	4	4	1	2	3	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.75	1	0	0	1	0	0	4	5	4	1	6	5	2	4	4	5	5	2	4	3	3	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.25	0	2	1	0	0	0	1	1	0	1	2	1	1	5	3	2	5	2	1	0	2	0	1	1	0	1	2	1	2	0	1	1	1	0	0	0	0	0	0
8.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.00	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	1	3	2	0	0	0	0	2	1	1	0	1	0	2	1	0	0	1	0	0	0
9.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2	0	0	1	1	1	0	1	2	1	0	1	0	0	1	2
10.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	1	0	0	0	1	0	0	0	0
10.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0