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# Wave Power Variation near the Romanian Coastal Waters

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**Abstract.** In the present work, the relationship between Romanian wave power and the distance to the shoreline is evaluated, by taking also into account the performances of some wave energy converters. Several reference sites located on northern, centre and southern part of this area were taken into account, the wave energy being assessed at 5 km, 15 km and 30 km from the shore. More important resources were noticed close to the Vama Veche (in south) were an average of 4.27 kW/m is reported offshore. As we go from shore to offshore, the wave variations may reach a maximum of 7.7% in the case of the Navodari site (centre), while a 3.3% is expected for Vama Veche. In the case of the wave generators, three types of systems (Seabased, Pelamis and Wave Dragon) were considered, that cover a rated capacity ranging from 15 kW to 7000 kW. For the Saint George site (north), the power production is insignificant being located close to zero, while in terms of the capacity factor a maximum of 0.12% may be expected from the Seabased system. The capacity factor significantly increases as we go to south, being reported during winter time values close to 3% for Pelamis system or 6% in the case of Seabased, respectively.

## 1 Introduction

The wave energy represents one of the most promising sources, capable to cover the energy demand from the coastal areas. It is well known that a significant percentage of the world population lives in such regions, being estimated that almost 44% reside within 150 km of the coastline [1].

In 1799, was registered the first patent involving a Wave Energy Converter (WEC) and since then hundreds of concepts were developed. Almost 150 projects (concept or tested) are reported on a global scale, and from them, almost 50% are being implemented in Europe [2]. Compared to the offshore wind industry, the wave sector is still in an infancy stage, and several technical-economic aspects will need to be solved in order to become a competitive market. The EU strategy also aims to accelerate the development of this marine sector, being predicted that a successful project will report a Levelized Cost of Energy (LCOE) of 15ct€/kWh by 2030 which needs to be reduced to 10ct€/kWh by 2035 [3].

The sites located between 30 and 60 degree latitude in both hemispheres reveal the best wave energy resources, especially the ones located on the western coasts of the continents and islands [4,5]. We may expect average wave power flux of 50 kW/m close to southern regions of Australia, Africa or South America, while a lower value of 25 kW/m seems to define the northern coasts of Madagascar [6]. As for the Black Sea, during the recent years, various studies were implemented, most of them being focused on the calibration of the wave models or on the characterisation of these resources from a meteorological point of view [7–9]. In Rusu and Onea [10] was performed a long-term assessment of the Black Sea by using numerical models and satellite data. According to these results, more important wave resources were noticed on the western part of this basin. A similar conclusion was reached in Rusu *et al* [11] and Rusu and Butunoiu [12]. In Diaconu and Rusu [13] was proposed the implementation of a wave farm project for the Romanian nearshore, in order to reduce the coastal erosion caused by the wave action. According to these findings, such project seems to provide effective protection, especially during the winter time when the storm conditions are more frequent. Several studies focused on the hybrid/mixed wind-wave projects emerge, this type of project being considered more suitable for the enclosed seas. This approach was considered in Rusu and Onea [14] for Sardinia Island, or in Astariz *et al* [15] for some offshore sites located close to the Wave Hub location, United Kingdom.

## 2 Methods and materials

Figure 1 presents the distribution of the reference sites, which were grouped around three reference lines, namely A (north), B (centre) and C (south). The relation between the distance from the shoreline and wave resources will be also investigated, by taking into account several distances (5 km, 15 km and 30 km).

For the present work, the information provided by the ERA-Interim dataset [16] with a spatial resolution of 0.75°×0.75° was processed, obtaing results for a 20-year time interval (from January 1998 to August 2017). The wave parameters considered for evaluation are the

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significant wave height (*Hs* in meters) and the wave period (*Te* in seconds).

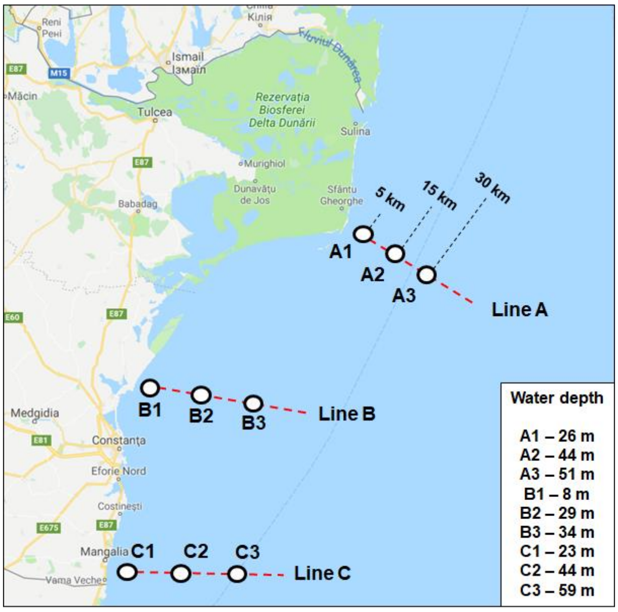


**Fig. 1.** The target area and the reference sites considered for evaluation.

The wave energy flux (*Jwave* in W/m), of a particular site can be expressed as [17]:

$$J_{wave} = \frac{\rho_{water} g^2}{64\pi} T_e H_s^2, \qquad (1)$$

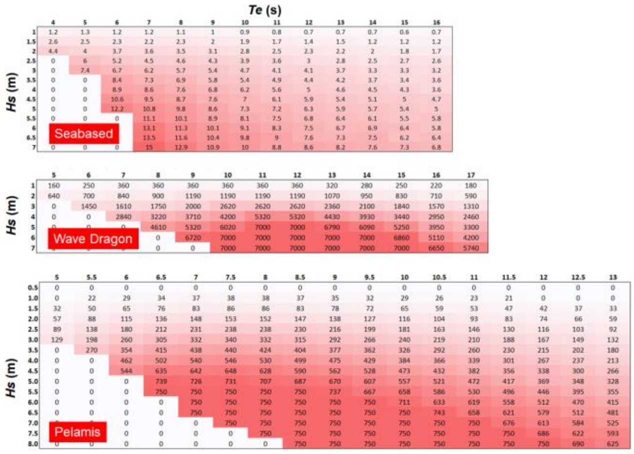
where $\rho_{water}$ (kg/m$^3$) – seawater density and $g$ (m/s) – gravitational acceleration.

The expected electric power output of a WEC generator can be determined by combining the bivariate distributions (*Hs* × *Te*) with the power matrix of each WEC, as follows [2]:

$$P_E = \frac{1}{100} \cdot \sum_{i=1}^{n_T} \sum_{j=1}^{n_H} p_{ij} \cdot P_{ij}, \qquad (2)$$

where $p_{ij}$ is related to the energy percentage associated to the bin defined by the line $i$ and column $j$, where as $P_{ij}$ is the expected electric power output defined in the power matrix of each WEC for the same bin (defined by line $i$ and column $j$).

For the present work, three WECs (Seabased, Pelamis and Wave Dragon) are considered, their power matrices being presented in Figure 2. By using these systems was possible to cover a full range of rated powers, which start from 15 kW and reaching a maximum of 7000 kW in the case of the Wave Dragon system [2,18,19]. The wave energy exploitation has many difficulties and it is possible that some wave project will no longer be operational. This is the case of the Pelamis project, which for the moment is shut down due to some financial issues. Nevertheless, this system was used in the world's first commercial wave energy project located in the vicinity of Agucadoura coast, Portugal [20].


*Te* (s)

Seabased

| *Hs* (m) | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.2 | 1.3 | 1.2 | 1.2 | 1.1 | 1 | 0.9 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | 0.7 |
| 1.5 | 2.6 | 2.5 | 2.3 | 2.2 | 2.3 | 2 | 1.9 | 1.7 | 1.4 | 1.5 | 1.2 | 1.2 | 1.2 |
| 2 | 4.4 | 4 | 3.7 | 3.6 | 3.5 | 3.1 | 2.8 | 2.5 | 2.3 | 2.2 | 2 | 1.8 | 1.7 |
| 2.5 | 0 | 6 | 5.2 | 4.5 | 4.6 | 4.3 | 3.9 | 3.6 | 3 | 2.8 | 2.5 | 2.7 | 2.6 |
| 3 | 0 | 7.4 | 6.7 | 6.2 | 5.7 | 5.4 | 4.7 | 4.1 | 4.1 | 3.7 | 3.3 | 3.3 | 3.2 |
| 3.5 | 0 | 0 | 8.4 | 7.3 | 6.9 | 5.8 | 5.4 | 4.9 | 4.4 | 4.2 | 3.7 | 3.4 | 3.6 |
| 4 | 0 | 0 | 8.9 | 8.6 | 7.6 | 6.8 | 6.2 | 5.6 | 5 | 4.6 | 4.5 | 4.3 | 3.6 |
| 4.5 | 0 | 0 | 10.6 | 9.5 | 8.7 | 7.6 | 7 | 6.1 | 5.9 | 5.4 | 5.1 | 5 | 4.7 |
| 5 | 0 | 0 | 12.2 | 10.8 | 9.8 | 8.6 | 7.3 | 7.2 | 6.3 | 5.9 | 5.7 | 5.4 | 5 |
| 5.5 | 0 | 0 | 0 | 11.1 | 10.1 | 8.9 | 8.1 | 7.5 | 6.8 | 6.4 | 6.1 | 5.5 | 5.8 |
| 6 |  |  |  | 13.1 | 11.3 | 10.1 | 9.1 | 8.3 | 7.5 | 6.7 | 6.9 | 6.4 | 5.8 |
| 6.5 |  |  |  | 13.5 | 11.6 | 10.4 | 9.8 | 9 | 7.6 | 7.3 | 7.5 | 6.2 | 6.4 |
| 7 | 0 | 0 | 0 | 15 | 12.9 | 10.9 | 10 | 8.8 | 8.6 | 8.2 | 7.6 | 7.3 | 6.8 |

Wave Dragon

| *Hs* (m) | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 160 | 250 | 360 | 360 | 360 | 360 | 360 | 360 | 320 | 280 | 250 | 220 | 180 |
| 2 | 640 | 700 | 840 | 900 | 1190 | 1190 | 1190 | 1190 | 1070 | 950 | 830 | 710 | 590 |
| 3 | 0 | 1450 | 1610 | 1750 | 2000 | 2620 | 2620 | 2620 | 2360 | 2100 | 1840 | 1570 | 1310 |
| 4 | 0 | 0 | 2840 | 3220 | 3710 | 4200 | 5320 | 5320 | 4430 | 3930 | 3440 | 2950 | 2460 |
| 5 | 0 | 0 | 0 | 4610 | 5320 | 6020 | 7000 | 7000 | 6790 | 6090 | 5250 | 3950 | 3300 |
| 6 |  |  |  | 0 | 6720 | 7000 | 7000 | 7000 | 7000 | 7000 | 6860 | 5110 | 4200 |
| 7 |  |  |  | 0 | 0 | 7000 | 7000 | 7000 | 7000 | 7000 | 7000 | 6650 | 5740 |

Pelamis

| *Hs* (m) | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.0 | 0 | 22 | 29 | 34 | 37 | 38 | 38 | 37 | 35 | 32 | 29 | 26 | 23 | 21 | 0 | 0 | 0 |
| 1.5 | 32 | 50 | 65 | 76 | 83 | 86 | 86 | 83 | 78 | 72 | 65 | 59 | 53 | 47 | 42 | 37 | 33 |
| 2.0 | 57 | 88 | 115 | 136 | 148 | 153 | 152 | 147 | 138 | 127 | 116 | 104 | 93 | 83 | 74 | 66 | 59 |
| 2.5 | 89 | 138 | 180 | 212 | 231 | 238 | 238 | 230 | 216 | 199 | 181 | 163 | 146 | 130 | 116 | 103 | 92 |
| 3.0 | 129 | 198 | 260 | 305 | 332 | 340 | 332 | 315 | 292 | 266 | 240 | 219 | 210 | 188 | 167 | 149 | 132 |
| 3.5 | 0 | 270 | 354 | 415 | 438 | 440 | 424 | 404 | 377 | 362 | 326 | 292 | 260 | 230 | 215 | 202 | 180 |
| 4.0 | 0 | 0 | 462 | 502 | 540 | 546 | 530 | 499 | 475 | 429 | 384 | 366 | 339 | 301 | 267 | 237 | 213 |
| 4.5 | 0 | 0 | 544 | 635 | 642 | 648 | 628 | 590 | 562 | 528 | 473 | 432 | 382 | 356 | 338 | 300 | 266 |
| 5.0 | 0 | 0 | 0 | 739 | 726 | 731 | 707 | 687 | 670 | 607 | 557 | 521 | 472 | 417 | 369 | 348 | 328 |
| 5.5 | 0 | 0 | 0 | 750 | 750 | 750 | 750 | 750 | 737 | 667 | 658 | 586 | 530 | 496 | 446 | 395 | 355 |
| 6.0 | 0 | 0 | 0 | 0 | 750 | 750 | 750 | 750 | 750 | 750 | 711 | 633 | 619 | 558 | 512 | 470 | 415 |
| 6.5 | 0 | 0 | 0 | 0 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 743 | 658 | 621 | 579 | 512 | 481 |
| 7.0 |  |  | 0 | 0 | 0 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 676 | 613 | 584 | 525 |
| 7.5 |  |  | 0 | 0 | 0 | 0 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 686 | 622 | 593 |
| 8.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 690 | 625 |

**Fig. 2.** Power matrices of the considered wave generators, which include Seabased – 15 kW (rated power), Pelamis – 750 kW and Wave Dragon – 7000 kW.

One way to assess the reliability of a particular system is to evaluate the capacity factor ($C_f$), which is defined as [21]:

$$C_f = \frac{P_E}{R_P}, \qquad (3)$$

$P_E$ is the electric power expected to be generated by each system, and $R_P$ represents the rated power of each system according to the values presented in Figure 2.

## 3 Results

A first evaluation of the wave conditions is presented in Table 1, where the *Hs* percentiles were taken into account.

**Table 1.** Statistical evaluation of the *Hs* parameter, reported for the interval 1998-2017.

| Site | Percentiles |  |  |
|---|---|---|---|
|  | 20th | 50th | 95th |
| A1 | 0.14 | 0.22 | 0.65 |
| A2 | 0.17 | 0.27 | 0.81 |
| A3 | 0.23 | 0.36 | 1.10 |
| B1 | 0.36 | 0.57 | 1.72 |
| B2 | 0.36 | 0.57 | 1.74 |
| B3 | 0.37 | 0.58 | 1.77 |
| C1 | 0.42 | 0.64 | 1.98 |

| | | | |
|---|---|---|---|
| **C2** | 0.42 | 0.64 | 1.98 |
| **C3** | 0.43 | 0.65 | 2.01 |

As expected, the wave height increases as we go further in the offshore area. Significant variations are noticed by the A-points, which may go from 0.65 m to 1.1 m in the case of the 95th percentile. The sites located along the line B and C seem to reveal a constant distribution of the *Hs* parameter, regardless of the water depth and distance to the shore.

A more detailed evaluation of the wave resources (indicated in kW/m) is presented in Figure 3, where was also included the winter season (from October to March).

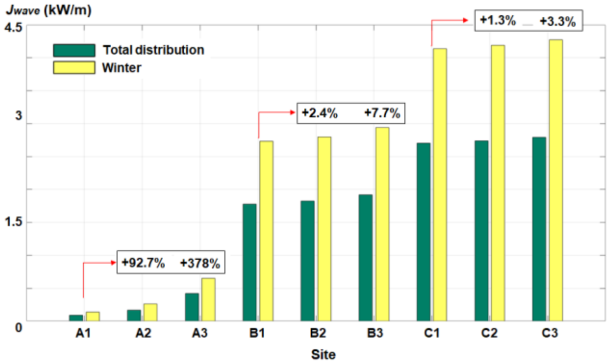


**Fig. 3.** Distribution of the wave energy flux (average values) reported for the total distribution and winter season. The percentage represents the variations of the values reported to the sites located at 5 km from shore (A1, B1 and C1).

For this target area, a maximum value of 4.3 kW/m is reported for the C-sites during winter, while a 2.8 kW/m is representative for the total distribution. In general, the variations reported during the winter and total time are very small and, therefore, only the total values were indicated (in percentages). The variations reported for the A-sites seem to be more important, reaching a maximum of 378% (A3 reported to A1). By looking on these results we can notice that the site A1 seems to be least suitable for a wave project, reporting values of 0.09 kW/m and 0.14 kW/m during the total and winter time interval. For the rest of the sites, the wave power may vary with a maximum of 7.7% for the B-sites, while a 3.3% is expected along the C line.

Going to the wave energy converters, in Figure 4 are presented the performances of the Seabased generator that may operate in the Romanian area. By looking on these values, we may exclude the A-sites since the power output will be insignificant (close to zero). During the winter season, we may expect a maximum of 0.68 kW close to B3, which represent an increase with 6.51% compared to the site B1 (reported to winter value). For the C-sites, the reported values do not exceed 1 kW, being reported a maximum variation of 5.04% for the site C3.

A similar analysis is performed in Table 2, by taking into account only the variations reported for the Pelamis and Wave Dragon generator. The sites B2 and B3 were compared with the B1 site (5 km), while the sites C2 and C3 were reported to C1 (5 km). These variations are more significant, being possible in some cases to reveal higher values for the total distribution than in winter.

For the Pelamis generator, the values oscillate between 1.18% (C2 – winter) and 17.83% (B3 – total distribution). As for the Wave Dragon, we may expect a maximum variation of 18.03% close to B3, while a minimum of 0.97% is accounted by C2.

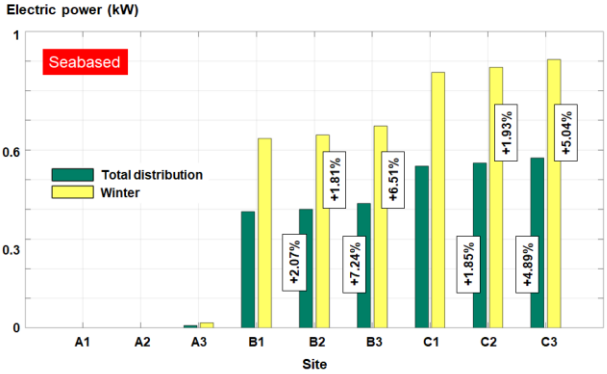


**Fig. 4.** Power output and variations expected from the Seabased wave generator.

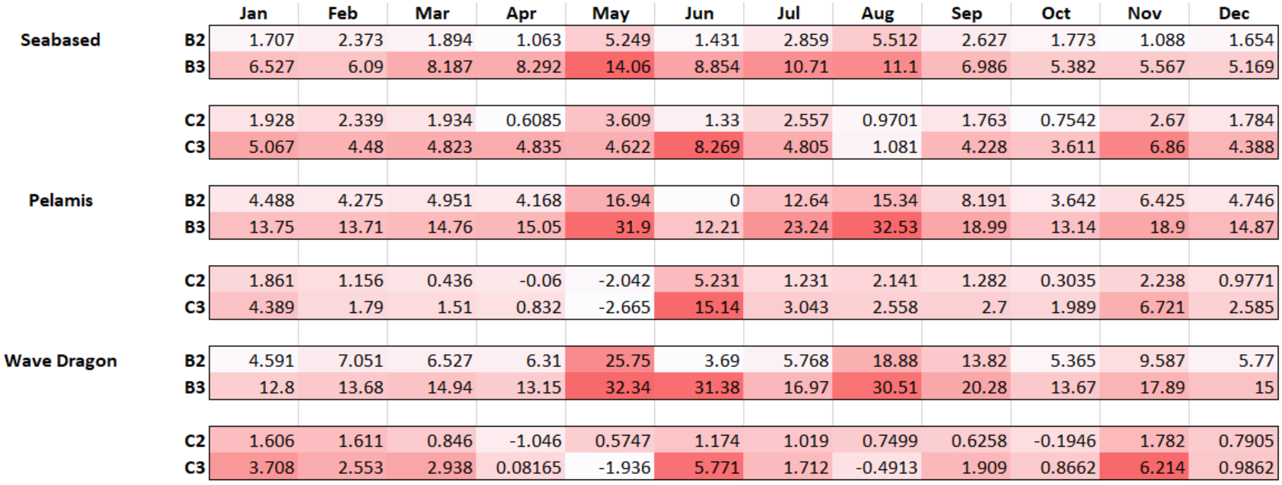
**Table 2.** Variations of the electric power (in %) associated with the Pelamis and Wave Dragon systems. The results are reported to the sites B1 and C1.

| **WEC→** | **Pelamis** | | **Wave Dragon** | |
|---|---|---|---|---|
| **Interval** | **Total** | **Winter** | **Total** | **Winter** |
| B2 | 5.27% | 4.79% | 7.48% | 6.53% |
| B3 | 17.83% | 16.86% | 18.03% | 16.7% |
| C2 | 1.20% | 1.18% | 0.97% | 1.09% |
| C3 | 3.17% | 3.15% | 2.46% | 2.78% |

A more detailed evaluation of the WEC performances is presented in Figure 5, where the power variation is assessed on a monthly level. In general, more significant variations are being reported during the summer time and some important values can be found during November. For the Seabased system, a maximum variation of 14% may be expected in May for the site B3, while a 6.86% and 8.26% are reported by the site C3 in June and November, respectively.

For the Pelamis generator, the months May and August seem to be more dynamic in the case of B3, a similar pattern being observed in the case of C3 for June. It is important to mention that, for this system are reported negative values (or close to zero). Negative values are also noticed in the case of Wave Dragon, a minimum of 1.93% being accounted by C3.

Table 3 reveals the capacity factor of the considered WECs, these values being reported for the total and winter distribution. The A-sites reveal values close to zero, while for the B-sites we may expect a maximum of 4.5% for the Seabased (B3-winter).



| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Seabased** | **B2** | 1.707 | 2.373 | 1.894 | 1.063 | 5.249 | 1.431 | 2.859 | 5.512 | 2.627 | 1.773 | 1.088 | 1.654 |
| | **B3** | 6.527 | 6.09 | 8.187 | 8.292 | 14.06 | 8.854 | 10.71 | 11.1 | 6.986 | 5.382 | 5.567 | 5.169 |
| | | | | | | | | | | | | | |
| | **C2** | 1.928 | 2.339 | 1.934 | 0.6085 | 3.609 | 1.33 | 2.557 | 0.9701 | 1.763 | 0.7542 | 2.67 | 1.784 |
| | **C3** | 5.067 | 4.48 | 4.823 | 4.835 | 4.622 | 8.269 | 4.805 | 1.081 | 4.228 | 3.611 | 6.86 | 4.388 |
| | | | | | | | | | | | | | |
| **Pelamis** | **B2** | 4.488 | 4.275 | 4.951 | 4.168 | 16.94 | 0 | 12.64 | 15.34 | 8.191 | 3.642 | 6.425 | 4.746 |
| | **B3** | 13.75 | 13.71 | 14.76 | 15.05 | 31.9 | 12.21 | 23.24 | 32.53 | 18.99 | 13.14 | 18.9 | 14.87 |
| | | | | | | | | | | | | | |
| | **C2** | 1.861 | 1.156 | 0.436 | -0.06 | -2.042 | 5.231 | 1.231 | 2.141 | 1.282 | 0.3035 | 2.238 | 0.9771 |
| | **C3** | 4.389 | 1.79 | 1.51 | 0.832 | -2.665 | 15.14 | 3.043 | 2.558 | 2.7 | 1.989 | 6.721 | 2.585 |
| | | | | | | | | | | | | | |
| **Wave Dragon** | **B2** | 4.591 | 7.051 | 6.527 | 6.31 | 25.75 | 3.69 | 5.768 | 18.88 | 13.82 | 5.365 | 9.587 | 5.77 |
| | **B3** | 12.8 | 13.68 | 14.94 | 13.15 | 32.34 | 31.38 | 16.97 | 30.51 | 20.28 | 13.67 | 17.89 | 15 |
| | | | | | | | | | | | | | |
| | **C2** | 1.606 | 1.611 | 0.846 | -1.046 | 0.5747 | 1.174 | 1.019 | 0.7499 | 0.6258 | -0.1946 | 1.782 | 0.7905 |
| | **C3** | 3.708 | 2.553 | 2.938 | 0.08165 | -1.936 | 5.771 | 1.712 | -0.4913 | 1.909 | 0.8662 | 6.214 | 0.9862 |

**Fig. 5.** Monthly variations of the power output considering as a reference the sites located at a 5 km distance from the shore (A1, B1 and C1).

**Table 3.** Capacity factors (in %) of the WECs considered for assessment.

| Site | Seabased | | Pelamis | | Wave Dragon | |
|---|---|---|---|---|---|---|
| | TT | WT | TT | WT | TT | WT |
| **A1** | 0 | 0 | 0 | 0 | 0 | 0 |
| **A2** | 0 | 0 | 0 | 0 | 0 | 0 |
| **A3** | 0.06 | 0.12 | 0 | 0 | 0 | 0 |
| **B1** | 2.6 | 4.3 | 0.8 | 1.4 | 0.48 | 0.84 |
| **B2** | 2.7 | 4.3 | 0.84 | 1.5 | 0.51 | 0.9 |
| **B3** | 2.8 | 4.5 | 0.94 | 1.7 | 0.56 | 0.98 |
| **C1** | 3.6 | 5.7 | 1.8 | 3 | 1 | 1.7 |
| **C2** | 3.7 | 5.9 | 1.8 | 3.1 | 1 | 1.7 |
| **C3** | 3.8 | 6 | 1.8 | 3.1 | 1 | 1.7 |

The C-sites seems to represent the best solution for the implementation of a wave project being indicated values in the range of 3.6% – 6% for Seabased, 1.8% – 3.1% for Pelamis, 1% – 1.7% for Wave Dragon. When comparing our results whit those reported in the ocean environment [2], we may notice that it is possible to reach a maximum 30% in the case of Seabased or 40% in the case of Pelamis, respectively.

## 4 Conclusions

In this work, an evaluation of the wave energy potential from the Romanian coastal area have been performed, a particular attention being given to the variation of these resources as the distance from the shoreline increases. From the selected sites, the points A3 and C3 are considered to be located in deep-water areas (>50 m) which are more suitable for the development of a wave project. Since the Black Sea is an enclosed sea, the wave resources are more limited, this aspect being reflected by the performances of the selected WECs, which, for example, in the case of the A-sites are close to zero. According to the ERA-Interim, the wave energy increases as we approach to the southern part of this target area. Since Bulgaria is located in south, it is possible to report better wave resources, but the study presented in this work is only limited to the Romanian coastal sector.

Significant seasonal and monthly variations are being reported as we go from nearshore to offshore, and it is possible to find some cases with negative values that reveal more energetic conditions close to shore. By looking on the expected power and capacity factors reported by the Seabased, Pelamis and Wave Dragon, we may conclude that in general, a wave project located in those sites will be inefficient from a technical-economical point of view. Most of the wave generators are projected to work in the ocean areas and, therefore, it is important to optimize these systems for enclosed seas, such as the Black Sea.

Nevertheless, taking into account that the Romanian coastal area is defined by a continental shelf area, it is possible to search for some other offshore sites. Maybe the best application, for a wave farm operating close to the Romanian nearshore will be for coastal protection, taking into account the erosion problems caused by the storm waves.

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## References

1. Mikhaylov AS, Mikhaylova AA, Kuznetsova TY. Coastalization effect and spatial divergence: Segregation of European regions. Ocean & Coastal Management 2018;161:57–65. doi:10.1016/j.ocecoaman.2018.04.024.
2. Rusu L, Onea F. The performance of some state-of-the-art wave energy converters in locations with the worldwide highest wave power. Renew Sust Energ Rev 2017;75:1348–62. doi:10.1016/j.rser.2016.11.123.
3. Matthijs Soede. Ocean Energy. EU Policy perspectives. 2018.
4. Rusu E, Onea F. Joint Evaluation of the Wave and Offshore Wind Energy Resources in the Developing Countries. Energies 2017;10:1866. doi:10.3390/en10111866.
5. Onea F, Rusu E. Sustainability of the Reanalysis Databases in Predicting the Wind and Wave Power along the European Coasts. Sustainability 2018;10:193. doi:10.3390/su10010193.
6. Arinaga RA, Cheung KF. Atlas of global wave energy from 10 years of reanalysis and hindcast data. Renewable Energy 2012;39:49–64. doi:10.1016/j.renene.2011.06.039.
7. Aydoğan B, Ayat B, Yüksel Y. Black Sea wave energy atlas from 13 years hindcasted wave data. Renewable Energy 2013;57:436–47. doi:10.1016/j.renene.2013.01.047.
8. Divinsky B, Kosyan R. Parameters of wind seas and swell in the Black Sea based on numerical modeling. Oceanologia 2018;60:277–87. doi:10.1016/j.oceano.2017.11.006.
9. Akpınar A, van Vledder GP, Kömürcü Mİ, Özger M. Evaluation of the numerical wave model (SWAN) for wave simulation in the Black Sea. Continental Shelf Research 2012;50–51:80–99. doi:10.1016/j.csr.2012.09.012.
10. Onea F, Rusu L. A Long-Term Assessment of the Black Sea Wave Climate. Sustainability 2017;9:1875. doi:10.3390/su9101875.
11. Rusu L, Ganea D, Mereuta E. A joint evaluation of wave and wind energy resources in the Black Sea based on 20-year hindcast information. Energy Explor Exploit 2018;36:335–51. doi:10.1177/0144598717736389.
12. Rusu L, Butunoiu D. Evaluation of the Wind Influence in Modeling the Black Sea Wave Conditions. Environ Eng Manag J 2014;13:305–14.
13. Diaconu S, Rusu E. The Environmental Impact of a Wave Dragon Array Operating in the Black Sea. Sci World J 2013:498013. doi:10.1155/2013/498013.
14. Onea F, Rusu L. Coastal Impact of a Hybrid Marine Farm Operating Close to the Sardinia Island. New York: Ieee; 2015.
15. Astariz S, Perez-Collazo C, Abanades J, Iglesias G. Hybrid wave and offshore wind farms: A comparative case study of co-located layouts. International Journal of Marine Energy 2016;15:2–16. doi:10.1016/j.ijome.2016.04.016.
16. Dee DP, Uppala SM, Simmons AJ, Berrisford P, Poli P, Kobayashi S, et al. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Q J R Meteorol Soc 2011;137:553–97. doi:10.1002/qj.828.
17. Bento AR, Martinho P, Guedes Soares C. Wave energy assessement for Northern Spain from a 33-year hindcast. Renewable Energy 2018;127:322–33. doi:10.1016/j.renene.2018.04.049.
18. Guillou N, Chapalain G. Annual and seasonal variabilities in the performances of wave energy converters. Energy 2018;165:812–23. doi:10.1016/j.energy.2018.10.001.
19. Bozzi S, Archetti R, Passoni G. Wave electricity production in Italian offshore: A preliminary investigation. Renewable Energy 2014;62:407–16. doi:10.1016/j.renene.2013.07.030.
20. Pelamis, World's First Commercial Wave Energy Project, Agucadoura. Power Technology | Energy News and Market Analysis n.d. https://www.power-technology.com/projects/pelamis/ (accessed January 10, 2019).
21. Rusu E, Onea F. Estimation of the wave energy conversion efficiency in the Atlantic Ocean close to the European islands. Renew Energy 2016;85:687–703. doi:10.1016/j.renene.2015.07.042.