The potential of wave energy in the coastal region of Romania

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Abstract: In this study, the wave energy potential in the coastal region of Romania was analyzed. For this purpose, a reanalysis data set downloaded from ECMWF (European Centre for Medium-Range Weather Forecasts) was used. The reanalysis data contains information for various models. In this analysis the significant height of combined wind waves and swell, the mean wave direction and the mean wave period were analyzed in order to determine the potential of extracting clean energy from waves. The aim of this research is to analyze some performances factors (capacity factor, rated capacity, operating capacity, annul electricity production) of some of the most used wave energy convertors.

1. Introduction

The driving force of a constantly changing society is the energy sector. The traditional resources (oil, gas, coal, etc.) are in limited quantities, constantly decreasing but also very polluting for the environment. For these reasons, primary resources, the sources (sun, wind, water, biomass, etc.) have captured the attention of many researchers around the world.

Studies in coastal areas of Canada, Australia, Ireland, United Kingdom, France, Portugal, Spain, Greece, Bulgaria, Romania have allowed the assessment of both wind and hydroelectric energy potential [1-4].

The hydroelectric source is considered as a major source worldwide due to the fact that the installed power is high with relatively low capture costs [5].

The wave characterized by height and period can be considered as an important hydroelectric source. Wave energy is converted into electricity using energy converters (WEC), which have developed a global scale [6,7].

In order to make investments more efficient, it is very important to find the best locations for WEC placement [8].

The seasonal variability of the waves raises a real and important problem in the energy production and that is why it is very important to create maps with their distribution over time [9].

The height and power of the waves are also variable according to the geographical area. Thus, it has been found that the coastal area of the ocean is more recommended in the location of WECs than the maritime areas [10].

According to Eurostat [11], of the 28 EU member states, 11 have already reached the level necessary to achieve the 2020 national target energy: Bulgaria, Czechia, Denmark, Estonia, Croatia, Italy, Lithuania, Hungary, Romania, Finland and Sweden.

Romania ranks 9th in the hierarchy of EU states with 24% of energy consumed in 2020, a percentage that has increased 67.5% compared to 2004 (16.2%).

According to the data recorded in the National Energy System [12], during the last 10 years, it is observed that the average energy production generated by waters represents between 20.45% and
33.03% of the total energy production showing an upward trend, while the average energy production from coal represents between 23.64% and 41.94% of the total production, the trend being downward. A uniform trend is found in nuclear energy whose average production varies between 17.77% and 20.09% of total average production.

Regarding the energy produced from photovoltaic and biomass sources, an increasing trend is observed even if the average production has relatively low values of 2.34% (photovoltaic) and 0.74% (biomass) (figure 1 and 2).

![Figure 1. Average production and trend of conventional/unconventional energy](image1)

![Figure 2. Average production and trend of unconventional energy (photovoltaic and biomass)](image2)

The data from figure 3 show that in Romania the production from coal ranges from 50 MW to 2068 MW for 50% of the analyzed time and 50% between 2068 MW and 4408 MW. The smallest variations are found for three of the seven types of energy recorded, namely: biomass, photovoltaic and nuclear. The production of energy from water ranges from 1276 MW to 4728 MW for 75% of the analyzed time and wind energy varies between 821 MW and 2820 MW only 25% of the analyzed time (figure 3).

![Figure 3. The representation of energy production recorded for 10 years (2010-2019) according to SEN [12]](image3)
The purpose of this study is the analysis of the energy potential of the Romanian coastal area by evaluating performance factors (capacity factor, rated capacity, operating capacity, annual electricity production) of some of the most used wave energy converters. For this purpose, a reanalysis data set downloaded from ECMWF (European Centre for Medium-Range Weather Forecasts) was used.

2 Research methods

In this study, the Black Sea from the coastal area of Romania is analyzed on a distance from the coast between 35 km and 115 km (figure 4). The three analyzed points are located near the localities Sulina, Navodari and Mangalia at a depth between 114 m and 323 m, whose geographical indications are indicated in table 1. The points were chosen near some cities precisely to facilitate their energy supply.

![Figure 4. The geographical locations of the 3 reference points considered in the study](image)

| Table 1. The considered points coordinates |
|------------------------------------------|
| Latitude | Longitude | Elevation | Distance to shore [km] |
|----------|-----------|-----------|-----------------------|
| P 1      | 45.00°    | 30.05°    | -114                  | 35.5                   |
| P 2      | 44.25°    | 30.00°    | -205                  | 103.2                  |
| P 3      | 43.45°    | 30.00°    | -323                  | 115.6                  |

To determine the energy potential from waves in the area shown in figure 3, the following parameters were analyzed: the significant height of combined wind waves and swell (Hs) which represents the average height of the highest third of the surface of the waves generated by wind and swell; the mean wave direction (MWD) which represents the average direction of surface waves calculated as the average of all frequencies and directions of the two-dimensional wave spectrum and the mean wave period (MWP) which represents the average time required between two consecutive wave crests passing through a fixed point. All these parameters are used in coastal applications to assess the state of the sea and swell [13].

The data were downloaded from the ERA5 database, which is the latest and most accurate version of the European Center for Medium-Range Weather Forecasts (ECMWF). ERA5 provides hourly estimates of a large number of climate variables having a temporal resolution of 1 h and a spatial resolution of 31 km and the period covered is 1950 [13].

The analyzed database covers a period of 20 years, namely from 01 January 2000 to 31 December 2019. The data were prevalent every 6 hours (0:00:00, 6:00:00, 12:00:00, 18:00:00) every day for the period mentioned above.
3. Results and discussions

For the analysis and prediction for the next 5 years of the Hs wave height for the 3 points considered, the moving average method was used. The method of moving averages consists in calculating the seasonal components of the chronological series by dividing the trend by the total of the successive values of the series [14].

In figures 5, 6 and 7 is presented the Hs variation for the period 01 January 2000 to 31 December 2019. Also, these figures contain the Hs forecast and the linear trend for the analysed data.

For example, the seasonality irregularity was in 2001 6% (for P1), 8% (for P2) and 9% (for P3) above the baseline (CMA), while in 2011 was 5% (for P3), 6% (for P2) and 7% (for P1) below the baseline.

![Figure 5. The representation of variation Hs for P1](image)

![Figure 6. The representation of variation Hs for P2](image)

![Figure 7. The representation of variation Hs for P3](image)

One of the most important performance factors of converters is the capacity factor (CF). It shows us the percentage of WEC (wave energy converters) running at full capacity.

Initially 6 WEC where analysed: Wave Dragon, Langlee, OE Bouy, Pontoon, Wavebob, Seabased AB. For each one the following parameters were evaluated: capacity factor CF (%) and annual energy production AEP (kW).

The wave Dragon has a rated power of 5900 kW, the Langlee – 1665 kW, the OE Bouy – 2880 kW, the Pontoon – 3619 kW, the Wavebob – 1000 kW and Seabased AB – 15kW [5, 16].

The calculated CF values for the 3 points considered and the 6 WEC are presented in Table 2.

From the presented data it can be seen that the highest performances are recorded for Seabased AB, followed by Wave Dragon and the weakest for OE Bouy.

The highest values for CF are recorded in point P3 (10.57% for Seabased AB, 6.88% for Wave Dragon and 1.54% for OE Bouy), which is the most profitable.
Table 2. The considered points coordinates

| CF%  | Wave Dragon | Langlee  | OE Bouy | Pontoon | Wavebob | Seabased AB |
|------|-------------|----------|---------|---------|---------|-------------|
| P 1  | 4.810867    | 2.26479  | 0.936494| 2.746353| 1.636509| 8.428131    |
| P 2  | 6.228961    | 2.975793 | 1.331474| 3.352864| 2.255537| 10.25934    |
| P 3  | 6.876712    | 3.234538 | 1.535112| 3.616167| 2.547016| 10.57002    |

The power matrices that formed the basis of the CF calculations are presented in figures 8, 9, 10, considering for a more detailed analysis only the 3 types of WEC mentioned above.

Figure 8. The power matrix for P1 and Wave Dragon

Figure 9. The power matrix for P2 and OE Bouy

Figure 10. The power matrix for P3 and Seabased AB

4. Conclusions
The energy produced by the world's seas and oceans is a clean and permanent resource. Moreover, humanity has an impressive reservoir, the planetary ocean. Research in the field has intensified in the last decade, thus highlighting the economic and environmental potential of the planet's ocean. Although the technologies that capture the energy produced by this resource are expensive and difficult to implement, mankind is making impressive progress in this direction.

In this study we analyzed the wave data from the ERA5 database for 3 points in the coastal area of the Romanian coast located near Sulina, Navodari and Mangalia. These data cover a period of 20 years, namely 1 January 2000 and 31 December 2019, being prevailed every 6 hours (0:00:00, 6:00:00, 12:00:00, 18:00:00) every day for the period mentioned above.

We analyzed the Hs trend and the forecast for the next 5 years and we noticed that the trend is approximately constant, slightly decreasing for point P1 while for point P3 it is slightly increasing.

In order to determine the efficiency of some WEC technologies in the Black Sea (close to the Romanian coast) we determined the parameters CF (%) and AEP (kW) based on the wave height and the period.
6 WEC were compared: Wave Dragon, Langlee, OE Bouy, Pontoon, Wavebob, Seabased AB. If we analyze the power matrices from manufacturers (in optimal operating conditions) with those resulting from this research, we notice that such technologies have a low economic efficiency but have important implications for environmental protection.

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