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PERFORMANCE ASSESSMENT OF A 5 MW AWES GENERATOR OPERATING IN THE BLACK SEA WESTERN AREA

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ABSTRACT

These days, the energy sector is a controversial one from the point of view of price variation and security. We hear more and more that the European continent is heading towards an unprecedented energy crisis and that many countries are reorienting towards conventional energy sources to combat the effects of rising prices and availability. However, we consider that the energy sector must remain oriented toward renewable sources. Even if the implementation of green technologies is expensive, the bill we will receive in the next decade for the ecological effects will be lower. In this paper, the latest technologies in the field were compared for a reduced geographical area. The data show that the conversion of electrical energy from wind sources is comparable in the studied area with other areas in Europe and the world.

Keywords: Black Sea, airborne, wind speed, turbine, Romania, annual energy production (AEP).

1. INTRODUCTION

The increasing need for renewable energy sources in the next decades necessitates a detailed understanding of available wind resources and their vulnerability to climate change. In this regard, the offshore wind industry has shown extremely high dynamics in recent years. An aspect that makes this sector so attractive is given by the wind speeds that are much stronger than those on land, but also the availability of larger areas for the location of wind farms.

While some states have made substantial progress in offshore wind energy, others have not established a specific legal framework, yet, and certain marine basins remain undeveloped. This is also applicable for the Black Sea, which has shown a high potential for offshore wind energy development [1–4]. Currently, in Romania, there is no law that regulates the activity regarding offshore wind energy, currently, the only legislative regulation is a draft law on the necessary measures to carry out operations for the exploitation of offshore wind energy, which was launched in 2019, but which it has not been adopted, yet. In addition, there is a law that has just been launched, which is a legislative proposal on the measures necessary to carry out offshore wind energy operations and which would probably replace the first above-mentioned law [5].

Several researches used wind speed data from re-analysis databases to assess the wind energy potential of coastal regions near Romania and Bulgaria [6–9]. In addition to these studies, wind speed estimation of the target station in the western part of the Black Sea was carried out by analyzing the wind dataset provided by the National Institute of Marine Geology and Geoecology [10]. There were other studies that evaluated areas where offshore wind energy is used on the Black Sea, demonstrating the good qualities of the wind as energy resource in this region [11].

In recent years, in addition to classic wind turbines, new technologies have been developed for harvesting energy from the wind, airborne wind turbines. These devices aim to capture the energy from the wind at the highest possible altitudes. Among the types of airborne systems, the most attractive for studies are Ground-Generator Airborne Wind Energy Systems (GG-AWES) or Pumping Kite Generators [12]. For the production of energy and its conversion, these kites go through two phases, the first phase is related to the production of energy when the kite rises and moves in a circular manner in the shape of eight, and the second phase is the recovery phase when it returns back to the ground. Airborne systems, unlike conventional turbines, have the ability to fly at much higher altitudes in the range of 500-15000 m [13], which increases the amount of energy and it is represented by much smaller bodies. In the case of conventional turbines, it has been observed that the tip of the blade (approximately 30% of its length) produces the largest amount of energy [12], and the airborne comes to replace its inner part. To place an airborne on the water, the costs are significantly reduced as compared to conventional turbines. The floating assembly consists of a kite attached by a tether to a floating platform and which is then anchored to the seabed [14]. In terms of projects launched offshore, we can mention the pilot test from SkySail that attached a kite to a yacht to produce propulsion while crossing the Atlantic [15]. There are other pilot tests carried out, but onshore such as Ampyx Power, EnerKite, Kitenergy, Makani Power [15], and the start-up called Altaeros Energies which is supposed to supply energy to remote Alaska [16].

2. MATERIALS AND METHODS

2.1 Target Area

The Black Sea basin is a geographical area with both economic and energetic potential. This sea is an enclosed one with a climate influenced by the cumulative interaction of different types of air masses (polar, continental and marine-tropical) that generate high risk climatological conditions.

In this study, the target areas are Romania and Bulgaria Exclusive Economic Zone (EEZ), as shown in Figure 1. As can be noticed, 15 points were chosen from the perimeter of these zones. From this total, 7 points (A1, A2, B1, B2, C1, C2, and C3) are exclusive in the Romania EEZ, 2 points (A3 and B3) are located on the boarder of both countries EEZ, and the last 6 (A4, A5, B4, B5, C4, and C5) are found in Bulgaria EEZ. In addition, the studied points can be classified otherwise. Thus, 6 points (A1, A2, A3, A4, and A5) are located onshore while the others 9 offshore (B1, B2, B3, B4, B5, C1, C2, C3, C4, and C5). The reason underlying the definition of these points is that a detailed analysis of the wind conditions is desired for as many depth/height patterns as possible.

2.2 Wind data

The wind climate conditions data (ERA5) were downloaded from Copernicus Climate Change Service (C3S). This service is provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). The ERA5 data (1959 to present) is published within three months of real time and this is considered to be the improved version of ERA-Interim. ERA5 database covers the planet on a 30 km grid and estimates hourly variables associated with oceanic and land climate [15].

In this paper, ERA5 wind data at 100 m height were analyzed for a 20-year interval (January 2002–December 2021) for four-hourly intervals: 00:00:00, 06:00:00, 12:00:00, and 18:00:00). The raw data were used for the wind turbine analysis while for the AWES, there were transformed using a logarithmic law [16].

2.3 Wind Generators

The efficiency of a wind generator (wind turbine or airborne wind energy system) can be summarized through a power curve. Figure 2 presents the performances of two 5 MW wind generators meaning a wind turbine and an airborne wind energy system (AWES). The power curves from Figure 2 have some key elements: cut-in speed, rated output power, cut-out speed.

The cut-in speed is the wind speed, which generates sufficient torque to rotate the turbine blades. Depending on the technology, the cut-in speed can vary between 3 m/s and 4 m/s. This aspect is valid for wind turbine type energy generators. Regarding AWES technologies, the cut-in speed may exceed the previously presented range. In this case, according to Figure 2, the cut-in speed is about 6 m/s.

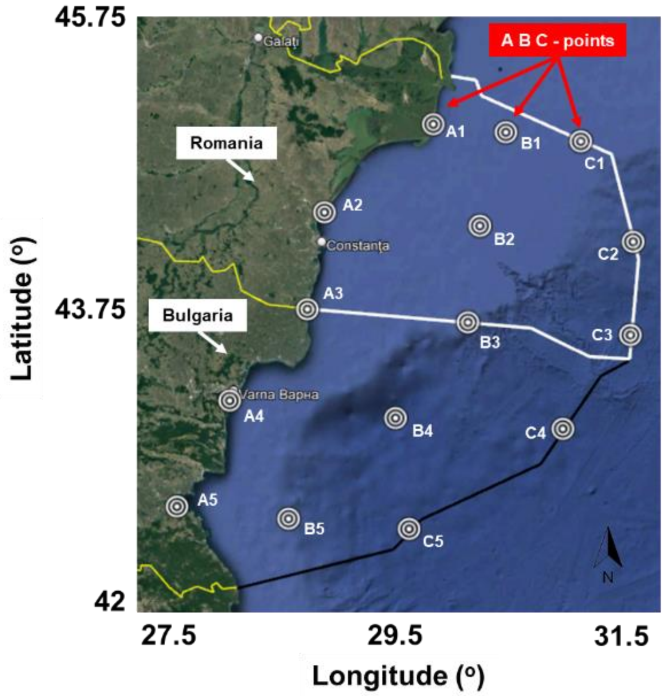

Figure 1. Reference points located inside the Romania/Bulgaria Exclusive Economic Zone. Information processed from Google Earth 2022.

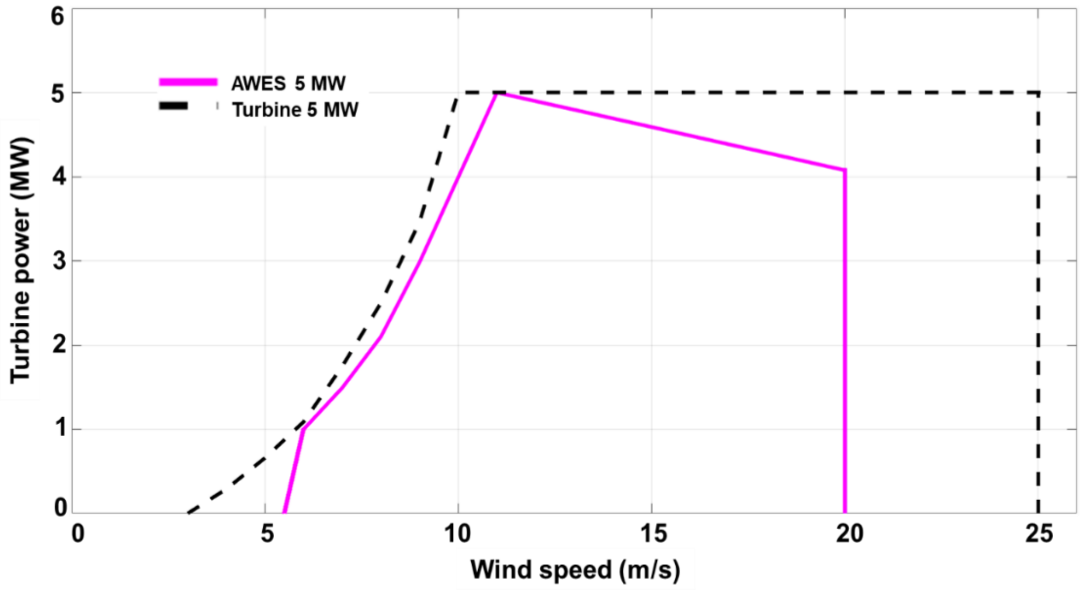

Figure 2. Power curves of a 5 MW wind generators (turbine and AWES) according to the information provided in Weber *et al* [17].

The rated output power is the wind generator's upper limit at which maximum power is produced. The rated output power is in a directly proportional relationship to the rated output wind speed. Both parameters can vary depending on the technology. In this case, the rated power output is 5 MW for both generators. Regarding the rated output wind speed, this is 10% higher for the AWES relative to the wind turbine.

The last parameter is the cut-out speed. The increase of wind speed above the rated output wind velocity can affect the integrity of a wind generator. As the velocity of the wind rises, the stability of the structure diminishes. Thus, in this case, the mechanical resistance is susceptible to degradation. A brake system is activated to stop the rotor. The cut-out speed is approximate 25 m/s for the wind turbine.

3. RESULTS

The aim of this paper is to evaluate the efficiency of two wind generators in Romania and Bulgaria Exclusive Economic Zones. This aspect implies both knowing the pattern of climatological conditions and the efficiency parameters associated with the studied technologies (power curves). The climatological conditions aspects were discussed in a previous research article [18]. With the help of power curves, it can be anticipated the energy conversion potential. This characteristic can be validated by two crucial parameters. The first one is the annual energy production (AEP). This parameter represents the total electrical energy produced in a year, which can be measured in kilowatt hours (kWh), megawatt hours (MWh), or gigawatt hours (GWh). Figures 3 and 4 contain the pattern of annual electricity production (GWh), at 100 m hub height for the wind turbine and 200 m height for the AWES, respectively.

By analyzing the data in Figures 3 and 4, several aspects can be concluded. Thus, it can be observed that the wind turbine is more efficient in terms of energy conversion. According to the climatological conditions at 100 m height, the wind turbine can produce 17.96 GWh/year. Another particularly important aspect is that the central and northern area of Romania's EEZ is significantly suitable for the implementation of both wind and AWES farms.

The capacity factor (CF) of a wind generator is the second key parameter in this technology evaluation. The CF represents the average power output divided by the maximum power capacity. In addition, the CF parameter describes the difference between nominal and realistic power production. This evaluation is performed at a certain geographical location or area over a time period. More precisely, the capacity factor is the ratio (%) of the wind power generator's actual power output related to the nominal or maximum power output.

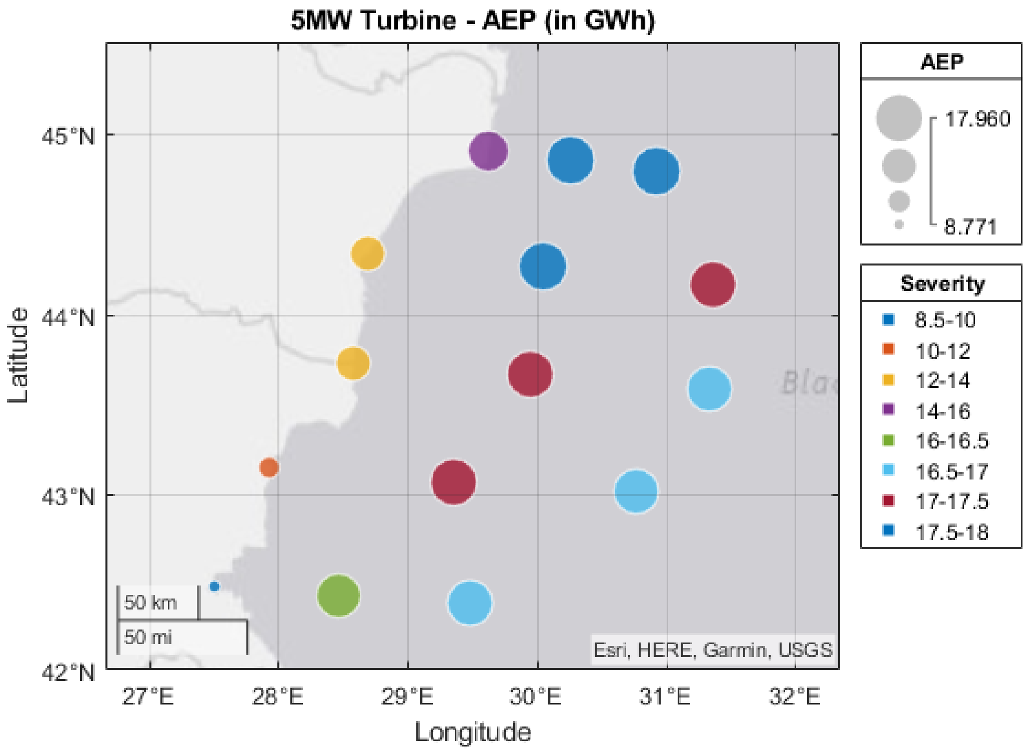

Figure 3. Annual electricity production (GWh) – 5 MW wind turbine operating at 100 m hub height.

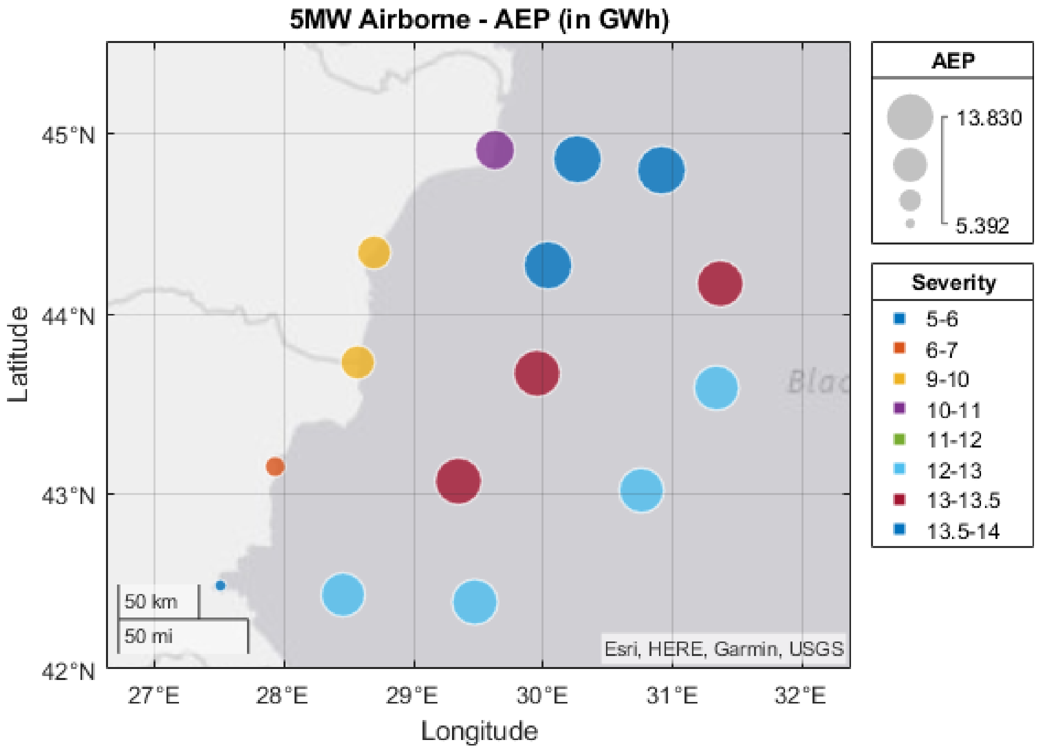

Figure 4. Annual electricity production (GWh) – 5 MW airborne operating at 200 m altitude flight.

Figure 5 and Figure 6 present the results of the capacity factor analysis. As in the case of the AEP parameter, the data show that the wind turbine CF is higher in comparison to that of AWES. The capacity factor for the 5 MW wind turbine is 41%, while, for the AWES, it is approximately 32%. These values are characteristic of the central and northern areas of Romania EEZ. In addition, a slightly different image can be observed. Regarding the CF for the AWES at 200 m height, it has comparable values even in the central and northern areas of Bulgaria EEZ.

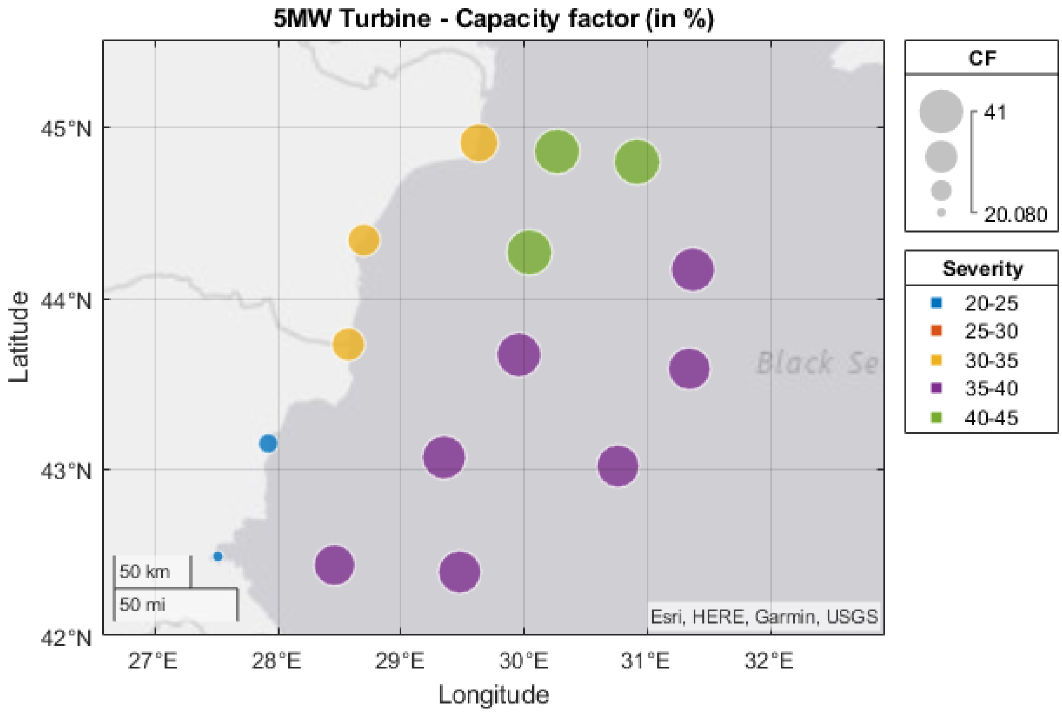

Figure 5. Capacity factor (in %) – 5 MW wind turbine operating at 100 m hub height.

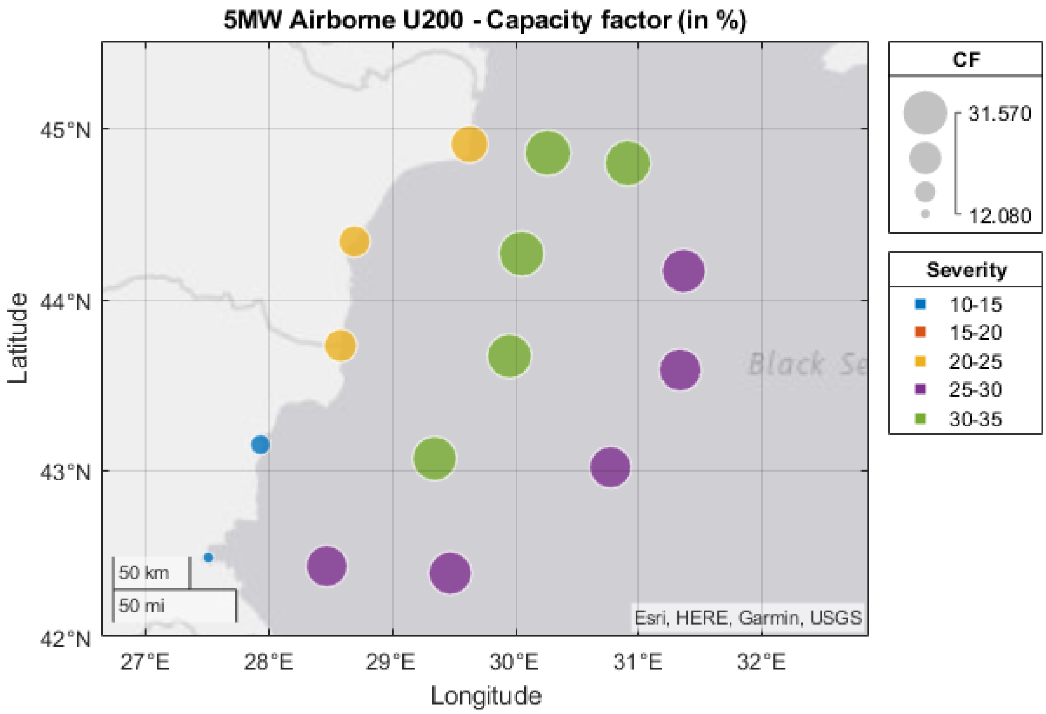

Figure 6. Capacity factor (in %) – 5 MW airborne operating at 200 m altitude flight.

The AEP differences in %, expected between the 5 MW wind turbine (U100) and the 5 MW airborne system (U200) are presented in Figure 7. The most considerable differences can be observed for the onshore location for both countries, but mainly in the area of Bulgaria. According to Figure 7, the AEP differences are found in the interval of 23.03% – 38.54%.

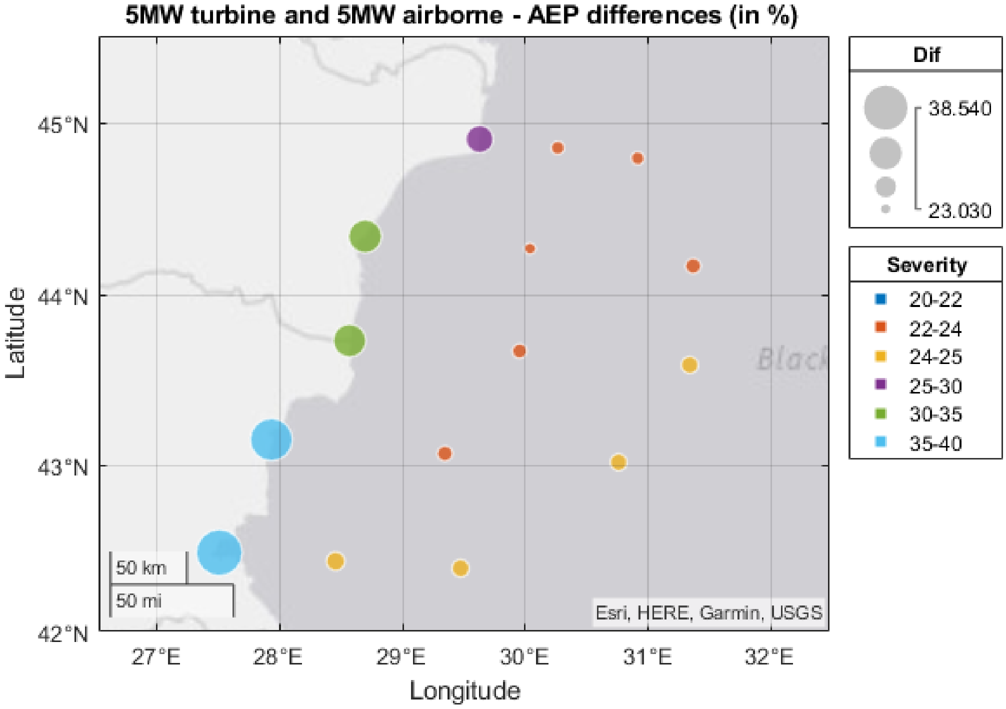

Figure 7. AEP differences (in %) expected between the 5 MW wind turbine (U100) and the 5 MW airborne system (U200).

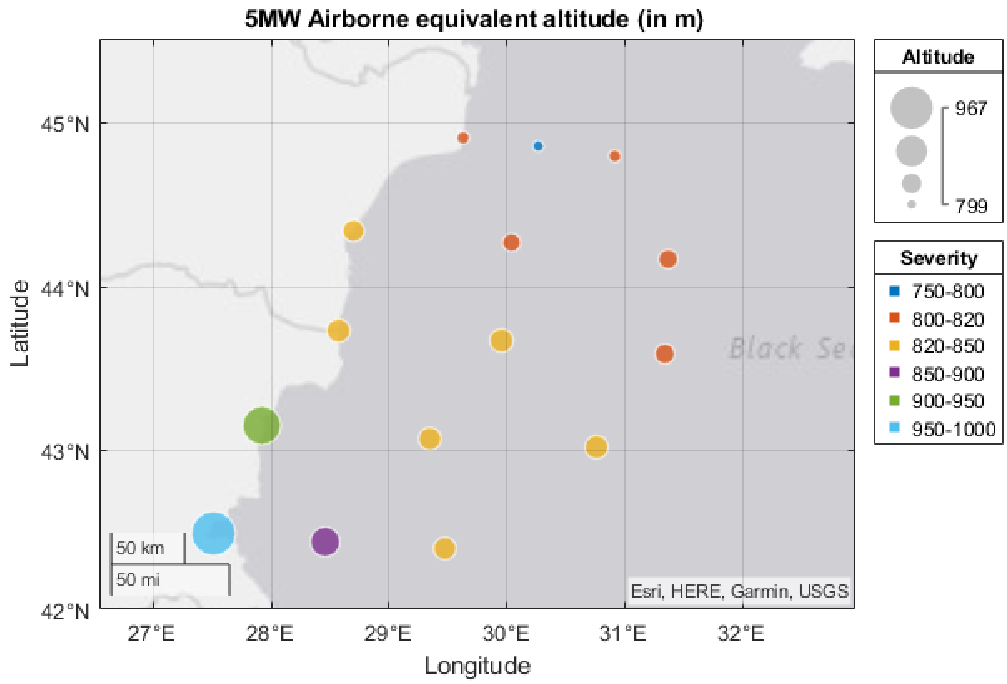

Figure 8. Equivalent altitude flight (in m) at which the annual electricity production of the 5 MW airborne system will be similar to the one coming from the 5 MW wind turbine.

Airborne wind energy system (AWES) is a wind energy conversion technology based on flying blades or wings. This system is attached to the ground by a tether. An interesting characteristic that may create a technological advantage is that the AWES can operate at different altitudes (up to 1000 m). Given that, with the increase in altitude, the wind energy also increases, the AWES have an important advantage. This aspect is presented in Figure 8 presenting the equivalent altitude flight (in meters), at which the annual electricity production of the 5 MW airborne will be similar to the one coming from the 5 MW wind turbine. Thus, the increase in altitude leads to increased performance from the point of view of *AEP*.

4. CONCLUSIONS

In this paper, two wind generators (5 MW wind turbine and AWES) were evaluated in terms of annual energy production and capacity factor. The evaluation was performed for the western part of the Black Sea (Romania and Bulgaria) by using the ERA5 re-analysis wind data covering a 20-year time interval (2002-2021). Based on these results, we can easily notice that the wind resources from the vicinity of the Romanian nearshore are slighty higher than the ones related to the Bulgarian side. In terms of the airborne wind turbines (or AWES), it seems that a such generator will need to operate in the range of 800-970 m in order to obtain a similar performance as compared to a classical wind turbine (5 MW capacity) that operate at a hub height of 100 m. Nevertheless, it is important to mention that the initial investments related to an AWES project will be significantly lower, since the costs related to the structural development will be significantly reduced.

Finally, we can conclude that the airborne generators seems to be a promising alternative for the offshore wind market, especially for the coastal areas where no such projects were developed so far.

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