Scientific Report

concerning the implementation of the project

ROmanian MArine Renewable solutions - ROMAR

in the period May – December 2018

In the first stage of the project implementation (E1) carried out in the period above mentioned, the specific objectives of the project were considered for investigation, as follows:

1.1 Assessment of the wind resources from the Romanian area by processing different datasets (Act. 1.1).
1.2 Identify the economical and technical performances of an offshore wind farm (Act. 1.2).
1.3 Compare the results with similar ones from European marine sites where operate such projects. Evaluate different sites located on the northern, center and southern part of Romanian coastline (Act. 1.3).
1.4 Designing the webpage for the project dissemination.
1.5 Dissemination of the results.

1.1 Assessment of the wind resources from the Romanian area by processing different datasets

1.1.1 Evaluation of the Black Sea nearshore wind resources

The energy market and carbon emissions seem to have a strong connection, and since the energy demand is expected to increase in the near future, the negative impacts on the environments will be more noticeable. A possible way to tackle this issue is to use natural resources (such as solar or geothermal) to secure a sustainable future and limit the effects of fossil fuels products. One of the most successful sectors is wind energy, which has already demonstrated its technical-economic viability in various parts of the world, being possible to develop projects on land or in the marine environment.

The Black Sea is a semi-enclosed basin defined by an area of 423,000 km^2 and a maximum depth of 2258 m. The geographical coordinates of its extreme points are 41°N/46°N and 27°E/42°E. In the western part, an extended continental shelf defined by a lower water level can be noticed, while for the rest of the sea a steep continental slope ends with a flat sea bed, where the depths easily exceed 2000 m. On a large scale, the wind conditions are under the influence of the Siberian and Azores high-pressure areas and by the Asian low-pressure area.

Figure 1 illustrates the locations of the twenty reference sites (denoted clockwise from P1 to P20) considered for assessment, which are distributed between four sectors (A–D). Each site is associated to a major Black Sea city or harbor, as shown in Table 1. Furthermore, they were defined in water depths of 26–31 m, being the average depth at which we may find most European wind projects. However, the sites Odessa (14 m) and Kerch (11 m) have smaller depths, while the last one is located in the Azov Sea. A maximum distance from the shore of

42 km corresponds to Site P3 (Bilhorod-Dnistrovskyi, Ukraine), while a minimum of 0.9 km is indicated for Site P19 (Primorsko, Bulgaria).

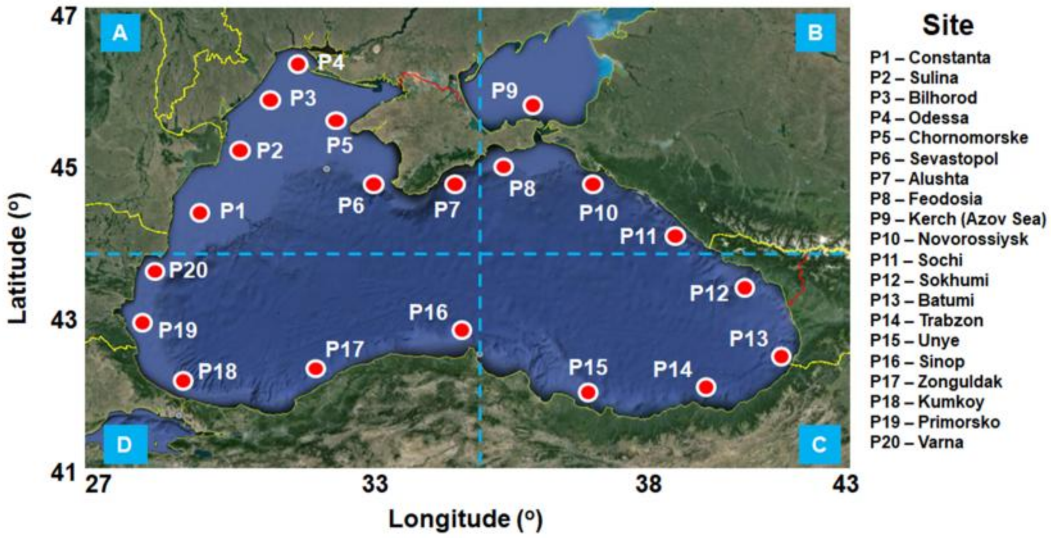


Figure 1. The Black Sea area and the location of the reference sites (map from Google Earth, 2018).

Table 1. The main characteristics of the sites considered.

No.	Site	Country	Sector	Long (°)	Lat (°)	Water Depth (m)	Distance from Coastline (km)
P1	Constanta	Romania	A	28.77	44.15	31	9.32
P2	Sulina		A	29.90	45.09	28	7.17
P3	Bilhorod-Dnistrovskyi	Ukraine	A	30.82	45.78	26	42.37
P4	Odessa		A	31.18	46.45	14	32
P5	Chornomorske	Russia	A	32.66	45.57	28	6.93
P6	Sevastopol		A	33.36	44.58	32	1.46
P7	Alushta		A	34.45	44.66	30	3.16
P8	Feodosia		B	35.52	44.95	30	9.66
P9	Kerch (**Azov Sea*)		B	36.48	45.61	11	18.11
P10	Novorossiysk		B	37.77	44.62	31	3.23
P11	Sochi		B	39.68	43.57	30	1.95
P12	Sokhumi		C	41.02	42.97	29	3.19
P13	Batumi	Georgia	C	41.56	41.64	31	3.59
P14	Trabzon	Turkey	C	39.71	41.02	32	1.4

Figure 2 illustrates the distribution of the average *U*80 parameter (wind speed at 80 m), reported for various intervals, such as total time (full time distribution), winter season (December–February), spring season (March–May), summer season (June–August) and autumn season (September–November). Usually, the attractiveness of a site for a wind project is indicated throughout wind classes, denoted C1–C7, with higher classes being considered more promising for renewable projects. As expected, the most energetic season is winter, while summer has much lower values. The energy pattern is visible in the case of Sites P1–P10 which indicates values in the range 6–9 m/s, more promising results being expected for Sites P6 (Sevastopol) and P9 (Kerch-Azov Sea), which during the winter present values located close to C6 wind class. In addition, Sites P18 and P20 seem to be defined by relevant wind resources, which nevertheless do not exceed the C4 class. Much lower wind conditions are noticed near Sites P11–P17 (south and southeast), indicating average values located in the C1 class, regardless of the time interval considered for assessment.

Figure 3 presents the distribution of the *U*80 parameter (average values based on the AVISO satellite measurements) for Sites P1–P20. As noticed, some sites have missing values (*NaN*, Not A Number values) which may indicate that the selected sites are located too close to the coastline and the satellite missions are not able to accurately measure the local wind conditions.

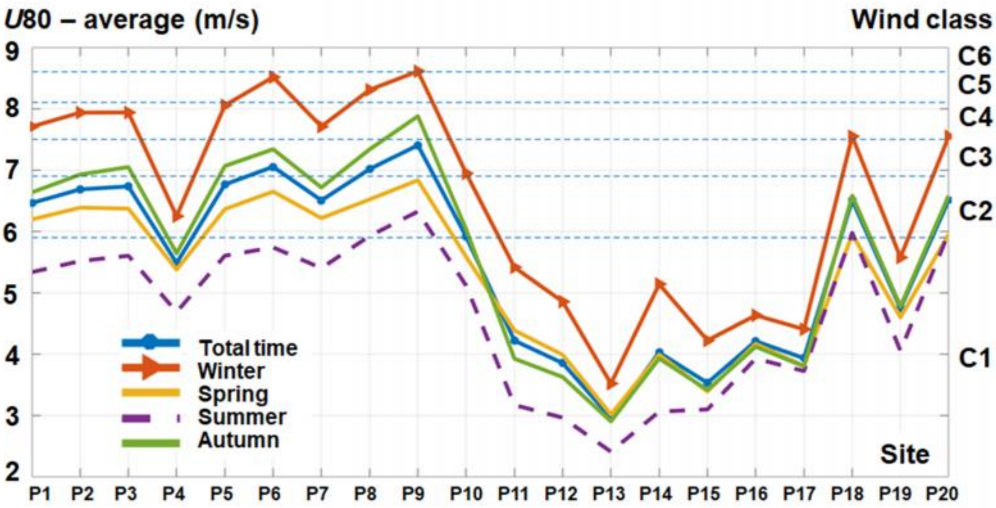


Figure 2. Distribution of the *U*80 average values corresponding to the full-time distribution and the representative seasons, considering the ERA-Interim data (January 1998–December 2017). The wind class levels (C1–C6) are also indicated.

Much lower values are reported compared to ERA-Interim data (Figure 2), while in this case, the reference location P5 seems to have the best wind resources compared to P9 as indicated by the reanalysis dataset. The sites located in Sector A report relatively small differences, while the sites located in Sector C seem to register moderate wind resources, a minimum of 3.78 m/s being observed close to P14.

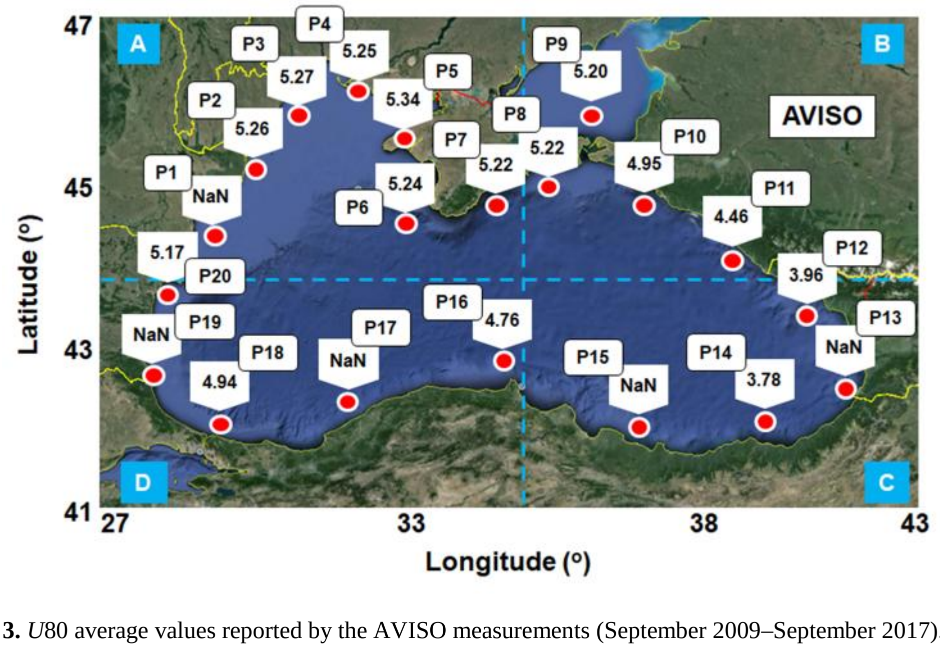


Figure 3. *U*80 average values reported by the AVISO measurements (September 2009–September 2017).

More details concerning the wind resource distribution in the Black Sea area can be found in the paper [1] from the list of publications, work published in Energies journal.

1.1.2 Evaluation of the Romanian nearshore wind resources

The results presented in paper [3] are focused only on the Romanian coastal area, as we can notice from Figure 4. Several marine sites were considered for assessment, including an onshore site that was associated with the Fantanele-Cogealac operational wind project.

Figure 4. The Romanian coastal area and the onshore reference sites considered for assessment (map from Google Earth, 2018).

For each marine site, the wind resources were assessed for different distances from the shore (0 km, 20 km, 40 km, 60 km and 80 km), as indicated in Figure 5 where the variation of the water depth was represented.

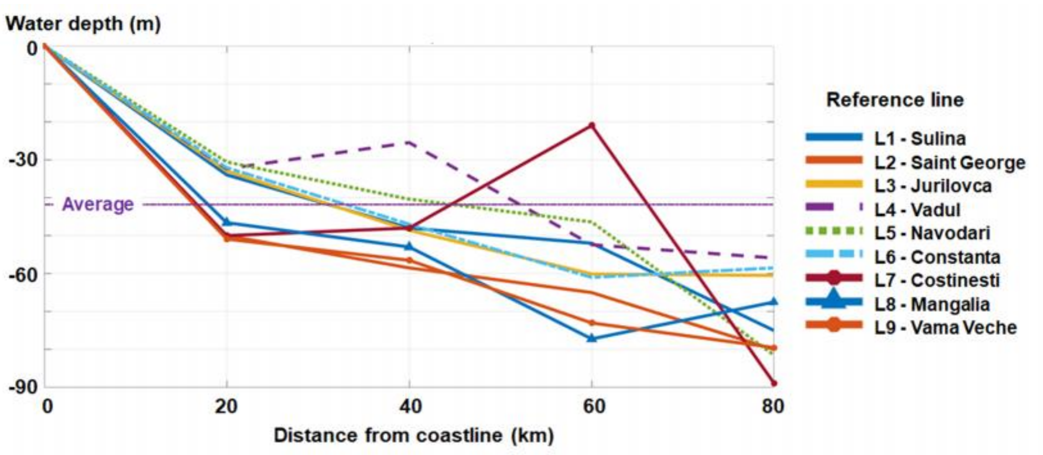
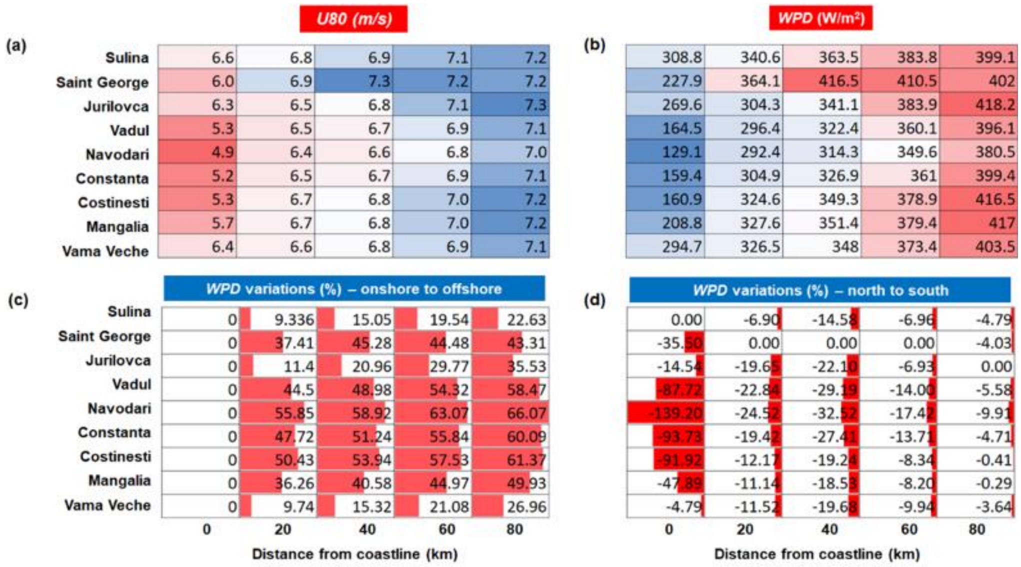


Figure 5. Variation of the water depth for each site considering various distances from the shore (0 km, 20 km, 40 km, 60 km and 80 km).

For this case study, the wind conditions were evaluated for the time interval from January 1998 to December 2017 by using the ERA-Interim dataset defined by a high spatial resolution (0.125^{o} x 0.125^{o}). The parameters taking into account were the wind speed reported at 80 m height (U80) and the wind power density (WPD in W/m^2), as illustrated in Figure 6.



(a) U80 (m/s)

Site	0	20	40	60	80
Sulina	6.6	6.8	6.9	7.1	7.2
Saint George	6.0	6.9	7.3	7.2	7.2
Jurilovca	6.3	6.5	6.8	7.1	7.3
Vadul	5.3	6.5	6.7	6.9	7.1
Navodari	4.9	6.4	6.6	6.8	7.0
Constanta	5.2	6.5	6.7	6.9	7.1
Costinesti	5.3	6.7	6.8	7.0	7.2
Mangalia	5.7	6.7	6.8	7.0	7.2
Vama Veche	6.4	6.6	6.8	6.9	7.1

(b) WPD (W/m²)

Site	0	20	40	60	80
Sulina	308.8	340.6	363.5	383.8	399.1
Saint George	227.9	364.1	416.5	410.5	402
Jurilovca	269.6	304.3	341.1	383.9	418.2
Vadul	164.5	296.4	322.4	360.1	396.1
Navodari	129.1	292.4	314.3	349.6	380.5
Constanta	159.4	304.9	326.9	361	399.4
Costinesti	160.9	324.6	349.3	378.9	416.5
Mangalia	208.8	327.6	351.4	379.4	417
Vama Veche	294.7	326.5	348	373.4	403.5

(c) WPD variations (%) – onshore to offshore

Site	0	20	40	60	80
Sulina	0	9.336	15.05	19.54	22.63
Saint George	0	37.41	45.28	44.48	43.31
Jurilovca	0	11.4	20.96	29.77	35.53
Vadul	0	44.5	48.98	54.32	58.47
Navodari	0	55.85	58.92	63.07	66.07
Constanta	0	47.72	51.24	55.84	60.09
Costinesti	0	50.43	53.94	57.53	61.37
Mangalia	0	36.26	40.58	44.97	49.93
Vama Veche	0	9.74	15.32	21.08	26.96

(d) WPD variations (%) – north to south

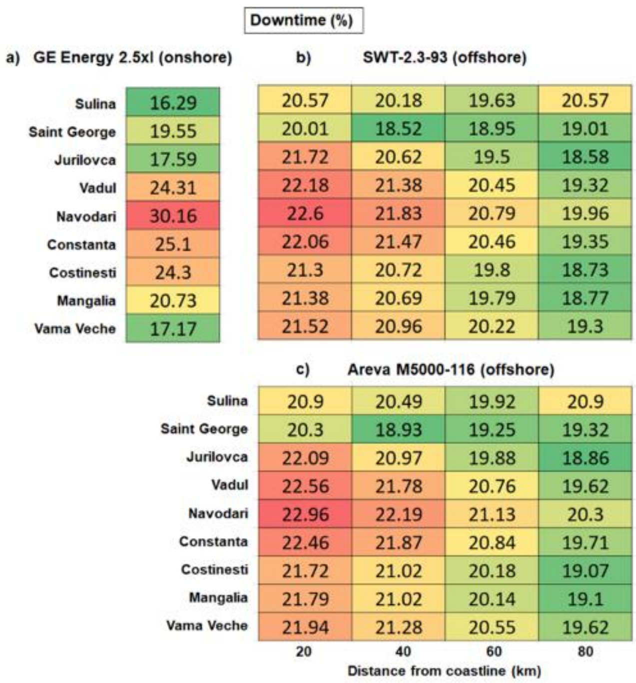
Site	0	20	40	60	80
Sulina	0.00	-6.90	-14.58	-6.96	-4.79
Saint George	-35.50	0.00	0.00	0.00	-4.03
Jurilovca	-14.54	-19.65	-22.10	-6.93	0.00
Vadul	-87.72	-22.84	-29.19	-14.00	-5.58
Navodari	-139.20	-24.52	-32.52	-17.42	-9.91
Constanta	-93.73	-19.42	-27.41	-13.71	-4.71
Costinesti	-91.92	-12.17	-19.24	-8.34	-0.41
Mangalia	-47.89	-11.14	-18.53	-8.20	-0.29
Vama Veche	-4.79	-11.52	-19.68	-9.94	-3.64

Distance from coastline (km)

Figure 6. Spatial distribution of the wind parameters, considering ERA-Interim data for the time interval from January 1998 to December 2017. The results are indicated for: (a) *U80* parameter – average values; (b) *WPD* parameter – average values; (c) *WPD* variations – onshore to offshore; (d) *WPD* variations – north to south considering the maximum value (per each column) as a reference.

1.2 Identify the economical and technical performances of an offshore wind farm

Another research direction is related to the performance assessment of some state-of-the-art wind turbines that may operate near the Romanian coastal area, more precisely close to the sites presented in Figure 4. A first analysis is presented in Figure 7 indicating the period (in %) during which the wind turbines will not generate electricity. The results were obtained by combining the power curve of each generator with the ERA-Interim wind dataset (0.125° x 0.125°).



Downtime (%)

a) GE Energy 2.5xl (onshore)

Site	Downtime (%)
Sulina	16.29
Saint George	19.55
Jurilovca	17.59
Vadul	24.31
Navodari	30.16
Constanta	25.1
Costinesti	24.3
Mangalia	20.73
Vama Veche	17.17

b) SWT-2.3-93 (offshore)

Site	20	40	60	80
Sulina	20.57	20.18	19.63	20.57
Saint George	20.01	18.52	18.95	19.01
Jurilovca	21.72	20.62	19.5	18.58
Vadul	22.18	21.38	20.45	19.32
Navodari	22.6	21.83	20.79	19.96
Constanta	22.06	21.47	20.46	19.35
Costinesti	21.3	20.72	19.8	18.73
Mangalia	21.38	20.69	19.79	18.77
Vama Veche	21.52	20.96	20.22	19.3

c) Areva M5000-116 (offshore)

Site	20	40	60	80
Sulina	20.9	20.49	19.92	20.9
Saint George	20.3	18.93	19.25	19.32
Jurilovca	22.09	20.97	19.88	18.86
Vadul	22.56	21.78	20.76	19.62
Navodari	22.96	22.19	21.13	20.3
Constanta	22.46	21.87	20.84	19.71
Costinesti	21.72	21.02	20.18	19.07
Mangalia	21.79	21.02	20.14	19.1
Vama Veche	21.94	21.28	20.55	19.62

Distance from coastline (km)

Figure 7. Downtime period of the wind turbines (%), considering wind values located below the cut-in speed of (a) GE Energy 2.5xl; (b) SWT-2.3-93; (c) Areva M5000-116. Results reported for the time interval from January 1998 to December 2017.

Figure 8 illustrates the distribution of the capacity factor, which is frequently used to predict the efficiency of a particular wind turbine. As we can see better results are reported in the northern part of the Romanian region being also indicated some sites from south, such as Mangalia and Vama Veche.

Capacity factor (%)

a) GE Energy 2.5xl (onshore)

Sulina	25.18
Saint George	19.71
Jurilovca	22.46
Vadul	14.59
Navodari	11.54
Constanta	14.15
Costinesti	14.25
Mangalia	17.98
Vama Veche	23.73

b) SWT-2.3-93 (offshore)

Distance from coastline (km)	20	40	60	80
Sulina	25.82	27.13	28.24	29.07
Saint George	27	29.73	29.48	29.08
Jurilovca	23.41	25.62	27.99	29.76
Vadul	22.85	24.45	26.64	28.58
Navodari	22.53	23.91	26	27.7
Constanta	23.25	24.61	26.57	28.65
Costinesti	24.33	25.82	27.5	29.46
Mangalia	28.65	25.89	27.46	29.44
Vama Veche	24.37	25.66	27.1	28.7

c) Areva M5000-116 (offshore)

Distance from coastline (km)	20	40	60	80
Sulina	11.88	12.48	12.99	13.37
Saint George	12.42	13.68	13.56	13.38
Jurilovca	10.77	11.78	12.88	13.69
Vadul	10.51	11.25	12.26	13.15
Navodari	10.36	11	11.96	12.74
Constanta	10.69	11.32	12.22	13.18
Costinesti	11.19	11.88	12.65	13.55
Mangalia	13.18	11.91	12.63	13.54
Vama Veche	11.21	11.8	12.47	13.2

Figure 8. Capacity factor values reported for: (a) GE Energy 2.5xl; (b) SWT-2.3-93; (c) Areva M5000-116.

In order to establish the configuration of an offshore wind farm, was considered as a reference the Romanian energy production according to the CIA World Factbook (https://www.cia.gov/library/publications/the-world-factbook/geos/ro.html), and in order to provide a realistic estimation, were estimated the numbers of wind turbines required to cover 1% (6.2 billion kWh) from the Romanian production. This evaluation is presented in Figure 9
.

a) GE Energy 2.5xl (onshore)

Sulina	113
Saint George	144
Jurilovca	126
Vadul	195
Navodari	246
Constanta	201
Costinesti	199
Mangalia	158
Vama Veche	120

b) SWT-2.3-93

Distance from coastline (km)	0	20	40	60	80
Sulina	129	119	114	109	106
Saint George	168	114	104	105	106
Jurilovca	146	132	120	110	104
Vadul	232	135	126	116	108
Navodari	298	137	129	119	111
Constanta	240	133	125	116	108
Costinesti	238	127	119	112	105
Mangalia	185	108	119	112	105
Vama Veche	137	127	120	114	107

c) Areva M5000-116

Distance from coastline (km)	0	20	40	60	80
Sulina	52	49	46	45	43
Saint George	68	47	43	43	43
Jurilovca	59	54	49	45	43
Vadul	93	55	51	47	44
Navodari	120	56	52	48	46
Constanta	96	54	51	47	44
Costinesti	96	52	49	46	43
Mangalia	75	44	49	46	43
Vama Veche	56	52	49	47	44

Figure 9. Estimated number of turbines to cover 1% from the Romanian energy production. Results indicated for: (a) GE Energy 2.5xl; (b) SWT-2.3-93; (c) Areva M5000-116.

The economical aspects related to the implementation of an offshore wind project close to the Romanian coastal environment are under investigation, and the results will be disseminated in future publications.

1.3 Compare the results from the Romanian area with similar ones from European marine sites where offshore wind turbines operate.

Although the best sites from the point of view of the wind resources seem to be located close to the Crimea Peninsula, considering the current geopolitical issues, it is difficult to believe that a renewable project can be developed in the near future. Therefore, attention probably needs to be shifted to an EU country, such as Romania, which also seems to present better wind resources according to AVISO and ERA-Interim data, thus Site P2 (Figure 3) is considered for comparison with some European projects.

The wind conditions in the vicinity of 171 offshore wind projects were considered for assessment, including projects in Belgium, Denmark, France, Germany, Netherlands, Sweden and United Kingdom. By comparing the wind resources at Site P2 (Black Sea, Romania) with the ones in Europe, a top 10 best agreement was identified, as presented in Figure 10. The projects in the early stages of development are denoted with an asterisk symbol (*). According to the AVISO values (Figure 10a), all of the European sites seem to have better wind resources than Site P2, on average values are between 5.7 m/s and 5.9 m/s, being noticed a constant distribution between Borkum and Wikinger.

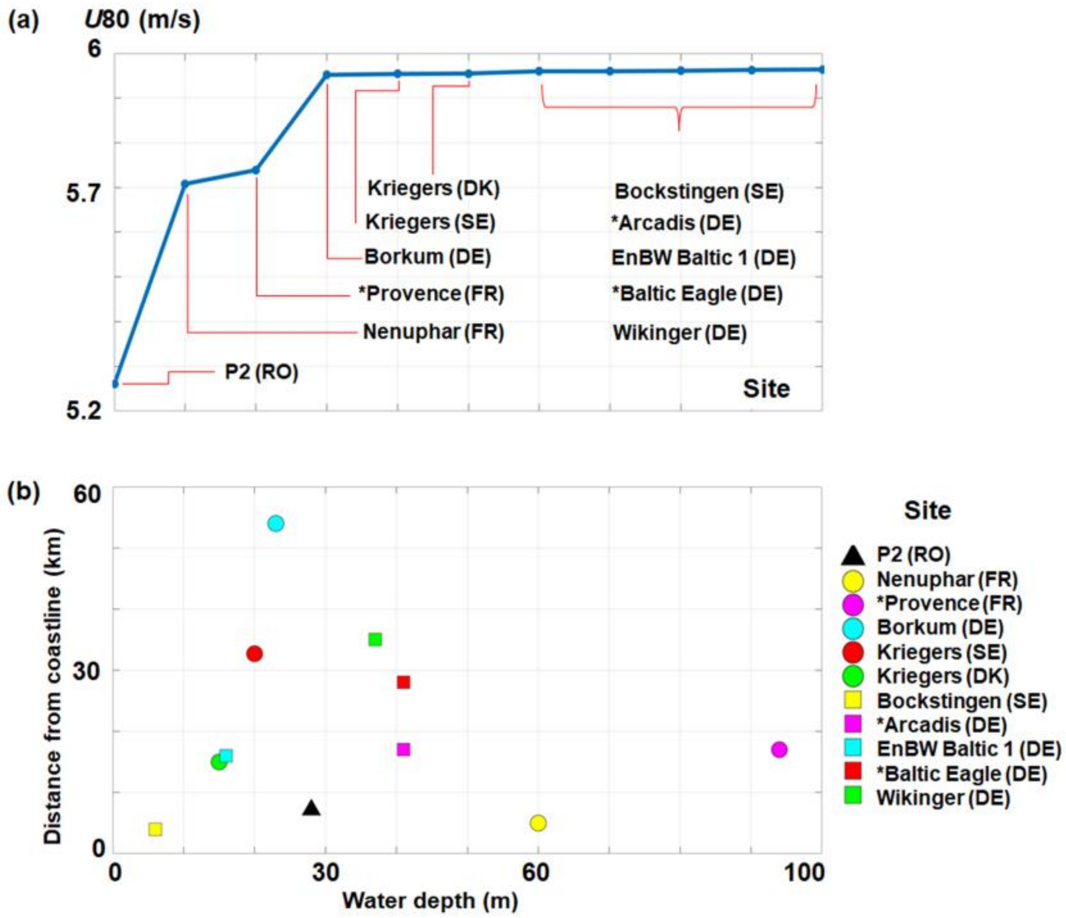


Figure 10. Direct comparison between the wind conditions reported close to reference point P2 and some European wind projects, where the dataset correspond to the AVISO measurements (September 2009–September 2017). The results correspond to: (**a**) *U*80 comparison; and (**b**) main characteristics of the selected sites.

1.4 Making the web page (Ro – Eng.) of the ROMAR project

A web page associated with the ROMAR project was created http://193.231.148.42/romar/index_en.php, being updated with the activities and publications related to this project. ROMAR project was also included in the ResearchGate platform and it was made a direct link between the project web page and this scientific network.
https://www.researchgate.net/project/ROmanian-MArine-Renewable-solutions-ROMAR

1.5 Dissemination of the results.

Publications in international journals (1)

1. Onea F, Rusu L, 2018. Evaluation of some state-of-the-art wind technologies in the nearshore of the Black Sea. Energies 11(9), 2452 **(WoS, IF=2.676)**. https://www.mdpi.com/1996-1073/11/9/2452

Participation in international conferences (2)

2. Onea F, Rusu L, 2018. Evaluation of the Black Sea wind energy potential for a renewable energy perspective. 3rd International Conference on Power and Renewable Energy, September 21-24, 2018, Berlin, Germany. http://www.icpre.org/
3. Onea F, Rusu L, 2018. Assessment of the Romanian coastline wind energy potential. 4th International Conference "Water resources and wetlands", September 5-9, 2018, Tulcea, Romania. https://www.limnology.ro/wrw2018/wrw2018.html

Publications in national journals indexed in international databases (1)

4. Onea F, Caranfil V, Rusu L, 2018. Renewables and the Romanian energy system. Mechanical Testing and Diagnosis 2018, 2, pp. 5-10 http://www.im.ugal.ro/mtd/download/2018-2/1_MTD_Volume%201_2018_Onea%20xx%20xx%20final.pdf Presented at CSSD-UDJG 2018, 7-8 June 2018, Galati, Romania http://www.cssd-udjg.ugal.ro/index.php/abstracts-2018.

In addition to these, at the ICPRE conference (paper 2) the author received the Best Presentation Award.
(https://www.researchgate.net/project/ROmanian-MArine-Renewable-solutions-ROMAR)

1.6 Conclusions

By looking on the expected results proposed for this stage of the project (1 ISI article - 2 conferences - 1 web page), we can notice that the author fully completed his objectives and in addition, one BDI paper was published. At this point, it is important to mention that the logistic required for this project was obtained in the second part of this stage, and therefore the time interval required to process the wind dataset was significantly reduced. Therefore, for the next stages of the project, we expect to reach at least the proposed objectives (and outcomes) which will be disseminated throughout scientific publications with high international visibility.

<u>Budget (2018) 82.110,00 lei (aprox 17 620 EUR)</u>

Project Director
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