Scientific Report

concerning the implementation of the project

Renewable Energy extraction in MARine environment and its Coastal impact

REMARC

in the period July – December 2017

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

1. Analysis of the main databases for wind and waves, available for the continental European coasts, including the basin of the Black Sea (Act. 1.1).
2. Designing the webpage for the project dissemination, a page that will be systematically updated (Act. 1.2).
3. Dissemination of the results.

1. Analysis of the main databases for wind and waves, available for the continental European coasts, including the basin of the Black Sea

1.1 *Databases considered and the quantities evaluated*

The main database considered at this stage in the REMARC project is ECMWF (European Centre for Medium range Weather Forecast) https://www.ecmwf.int/. The most relevant data for the project are the significant wave height H_s, the wave period T_e and the wind velocity V_w, with a spatial resolution of 0.75°X 0.75° and a temporal resolution of 6 hours. All data is available starting with 1979 and up to now.

Considering the existing data, in the REMARC project, there were estimated the wind power density (P_{wind} în W/m^2) and wave power (*Pw* în kW/m). The wind power density is an index, which is frequently used to identify the energy potential of a particular site by evaluating the energy concentrated in the air flow. It can be defined by the following expression:

$$P_{wind} = \frac{1}{2} \times \rho \times U_{80}^3 \tag{1}$$

where, ρ represents the air density (≈1.22 kg/m^3) and U_{80} the wind speed reported at a height of 80 m above sea level. The parameter P_{wind} is considered to be a comprehensive index in assessing the wind resources being possible to define a particular site by using classes of wind power density which reveal the energy potential. As it can be observed, the energy potential of a site is proportional to the cube (the third power) of the wind speed, being also influenced by the density of the air.

However, since most of the wind turbines operate at a much higher depth, usually at 80 meters, the wind speed at the height of 80 meters was further considered and analyzed. Thus, to estimate the wind speed at a different height than 10m, wind data need to be recompiled using a logarithmically varying profile correction, assuming neutral stable conditions of the atmosphere. The wind speed *U* at a certain height *z* can be expressed as:

$$U_z = U_{zref} \frac{\ln(z/z_0)}{\ln(z_{ref}/z_0)} \tag{2}$$

where U_{ref} represents the known wind speed at the height z_{ref} (in this case 10m), while U_z is the wind speed at the height *z* (80m). The sea surface roughness length z_0 has a value of 2×10^{-4}m.

Another important index is the wave power (*Pw*), reported for deep water conditions, which is obtained throughout the expression:

$$Pw = \frac{\rho \times g^2}{64 \times \pi} \times T_e \times H_s^2 \quad (3)$$

where: *Pw* – energy flux (kW/m), ρ – density of the seawater (1025 kg/m^3), g – gravitational acceleration (9.81 m/s^2), *Te* (s) - wave energy period, which represents the ratio of the first negative moment of the spectrum to the zeroth moment of the spectrum, *Hs* (m) - significant wave height, which represents the mean wave height of the highest third of the waves.

Another relevant database is represented by NCEP (US National Centers for Environmental Prediction), http://www.ncep.noaa.gov/ In this case, the space-temporal resolution is higher 0.325° X 0.325° and 3 hours respectively. Taking into account that this data represents a very good source as regards the wind fields, it might be used for forcing phase averaged spectral wave models (such as SWAN, WAM, WW3) that can provide high resolution wave fields and can identify also the hot energy spots.

AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic Data) is an important source of satellite measurements regarding the wind and wave parameters. https://climatedataguide.ucar.edu/climate-data/aviso-satellite-derived-sea-surface-height-above-geoid As a principle, it measures the time taken by a pulse to travel back and forward from a satellite antenna to its receiver. Altimeter data are used also to compute the wind velocity and the significant wave height. For processing altimeter data from diverse missions (Saral, Cryosat-2, Jason-1&2, T/P, Envisat, GFO, ERS-1 & 2 and even Geosat) the Ssalto/Duacs system processes are used. A spatial resolution of 1^0x1^0 was considered at this stage of the work.

Finally, another data source is represented by the *'in situ'* measurements provided by meteorological stations, buoys and other devices. They present the advantage of a great accuracy but, on the other hand, they can provide only point data which are also not only limited but quite expensive. In this phase of the REMARC project, such measurements were considered especially as regards the western side of the Black Sea, which represents one of the main target areas of the project.

1.2 *Design of the wind and wave energy maps, identifying the energy hot spots and assessing the synergy between these resources*

A first aspect, which is highlighted in the work plan of the REMARC project, is represented by the action Act 1.1 and it has as an expected result the design of the wind and wave energy maps. This includes identifying the energy hot spots and assessing the synergy between these resources, based on various datasets. From this perspective, based on the ECMWF data, the wind energy map has been designed for Europe, including the both the continental, marine and oceanic zones. This is illustrated in Figure 1, where the average values of the parameter P_{wind} corresponding to the 38-year time period (1979-2016) of ECMWF data are represented. Furthermore, Figure 2 illustrates the wave energy map corresponding to the same 38-year time period (1979-2016) of ECMWF data. This includes both the marine and oceanic zones and the average values of the parameter P_w have been represented.

Starting from the spatial charts presented in Figures 1 and 2, the analysis has been continued and focused on some specific coastal zones that have been considered separately. As an example, Figure 3 presents the wind and the wave roses for some marine sites in the Mediterranean and the Black seas. Since a directional analysis has been employed the wind and wave vectors have been considered. The wave vector is defined by the significant wave height and the wave direction.

Furthermore, taking into account the importance of these renewable in the island environment one of the target areas is represented by the Greek islands. Thus, Figure 4 illustrates the geographical positions of the 26 reference points considered for the in depth analysis: (A) Ionian Sea, (B) Aegean Sea, (C) Sea of Crete and (D) Levantine Sea and (E) Libyan Sea.

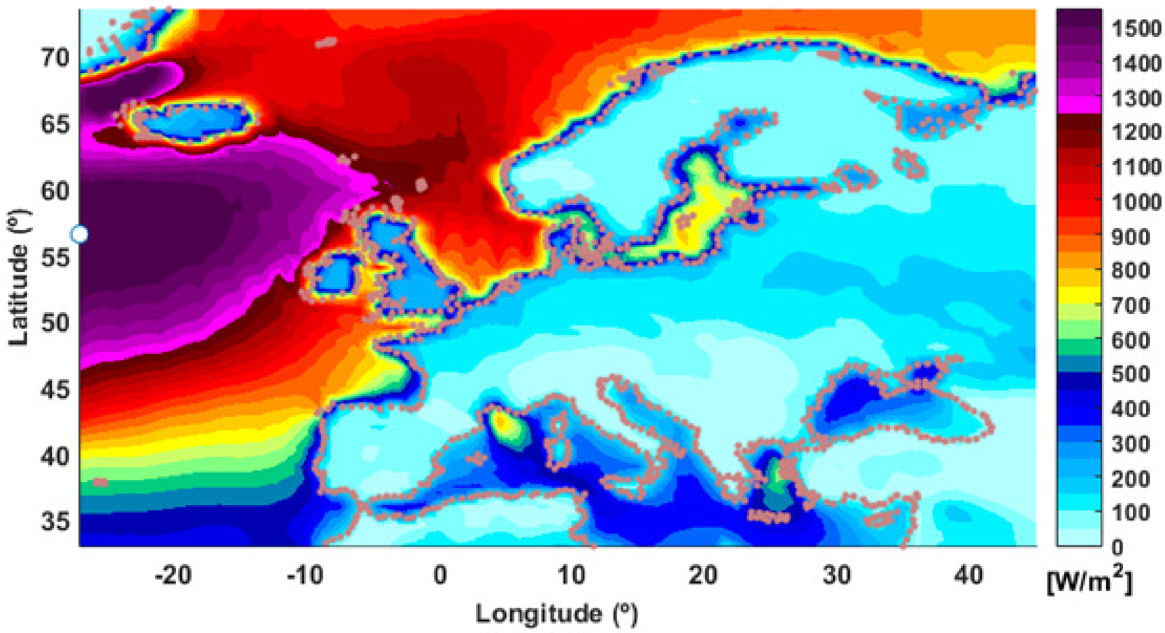


Figure 1. The wind energy map designed for Europe and including the both the continental, marine and oceanic zones The average values of the parameter P_{wind} are represented for the 38-year time period (1979-2016) of ECMWF data ($P_{windmax}$=1663W/m^2).

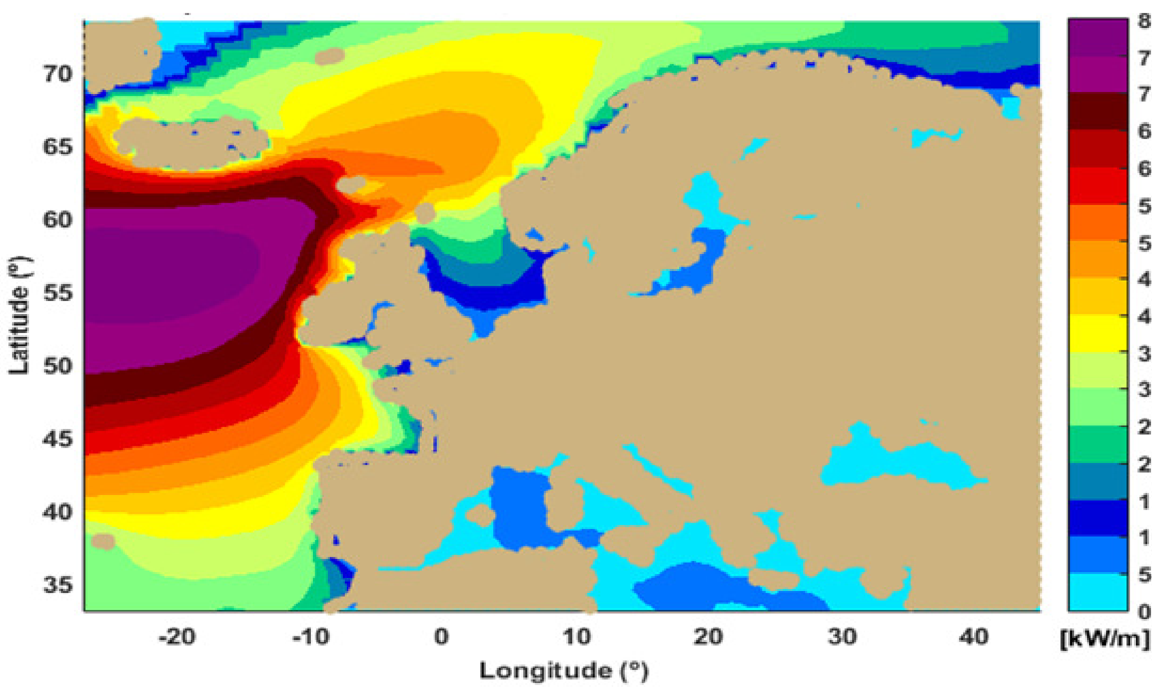
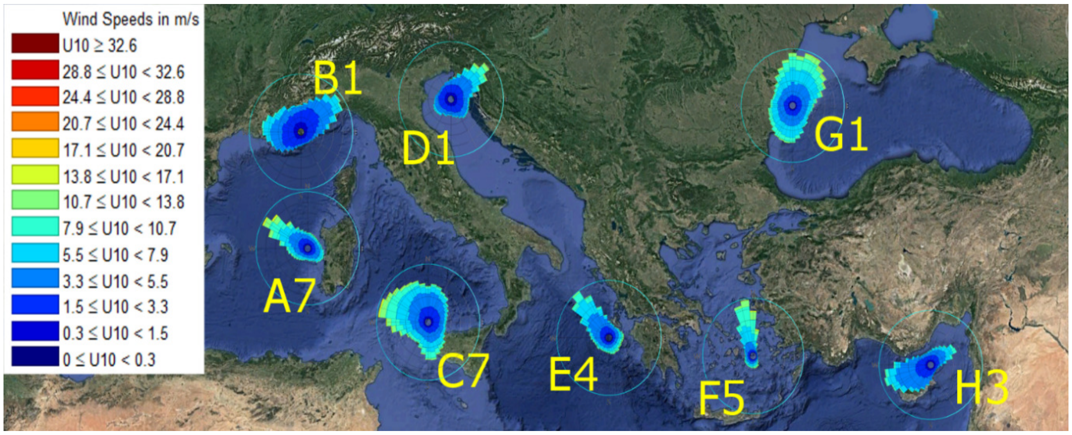
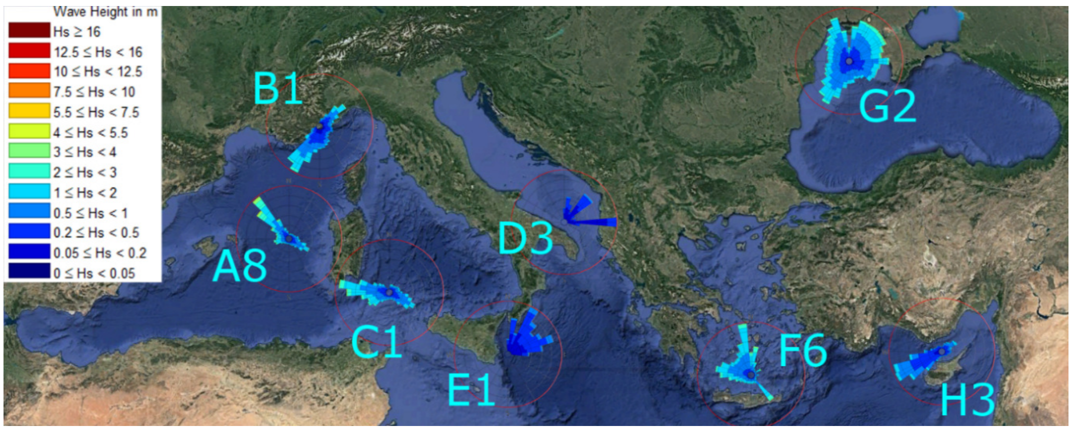


Figure 2. The wave energy map designed for Europe, including the both the marine and oceanic zones The average values of the parameter P_w are represented for the 38-year time period (1979-2016) of ECMWF data (P_{wmax}=78.7kW/m).



(a)



(b)

Figure 3. Wind (a) and wave (b) roses for some marine sites in the Mediterranean and the Black seas.

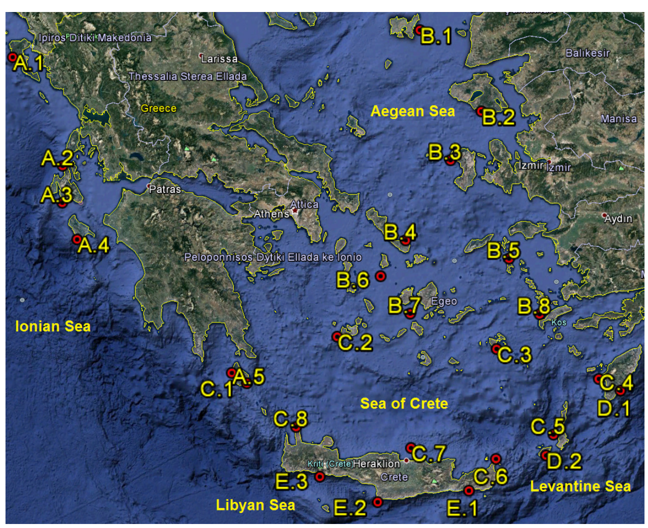
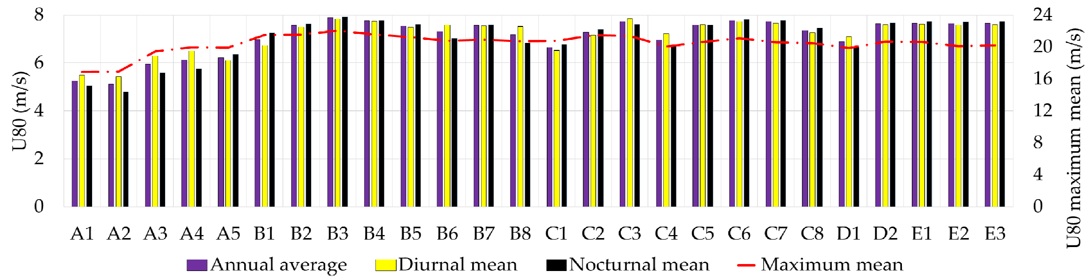
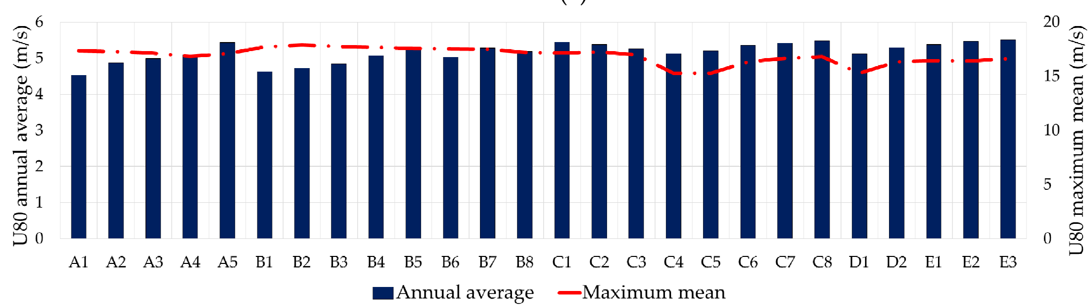


Figure 4. The geographical positions of the 26 reference points: (A) Ionian Sea, (B) Aegean Sea, (C) Sea of Crete and (D) Levantine Sea and (E) Libyan Sea, Figure processed from Google Earth (2017).

Since one of the important objectives at this stage is also to perform comparisons between various data sources, Figure 5 presents a comparison between the wind data provided by ECMWF in the 26 reference points, while Figure 6 presents the averaged values of the wave parameters (significant wave height H_s and wave energy period in the same 26 reference points considering the ECMWF data (2005-2015).

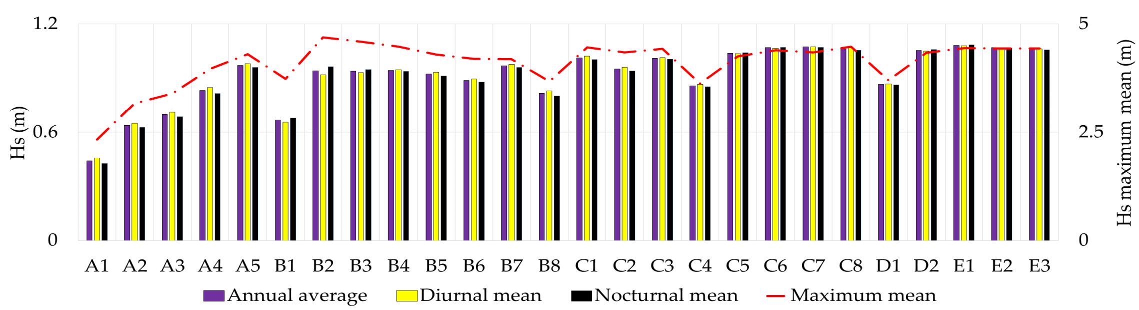


(a)

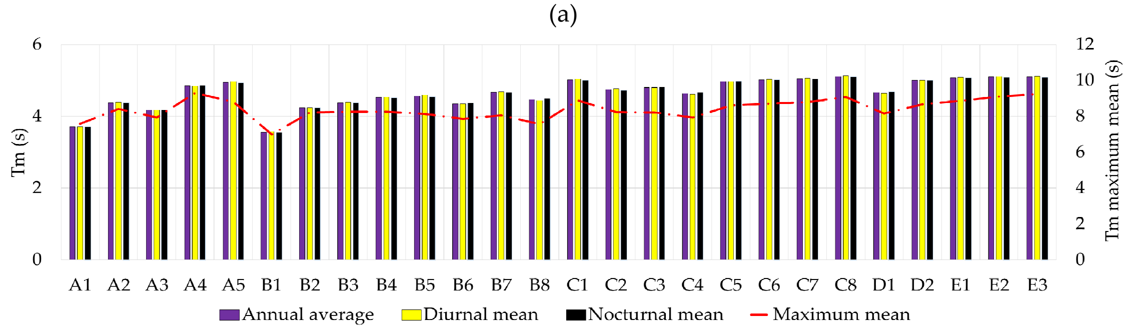


(b)

Figure 5 Wind speed at 80 m height, evaluation corresponding to all 26-reference points. ECMWF data were processed (a) for the 11-year period (2005-2015), and AVISO data set (b) for the 6-year period (2010-2015).



(a)



(b)

Figure 6. Main wave parameters, evaluation corresponding to all 26-reference points. ECMWF data were processed (a) significant wave height (m); (b) wave period.

1.3 *Evaluation of the energy potential in some coastal areas where wind farms already operate*

An important indicator in relationship with the energy efficiency is LCOE (levelized cost of electricity). https://en.wikipedia.org/wiki/Cost_of_electricity_by_source This is a measure of a power source which attempts to compare different methods of electricity generation on a consistent basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCOE can also be regarded as the average minimum cost at which electricity must be sold in order to break-even over the lifetime of the project.

In relationship with this indicator (LCOE), it has to be mentioned that the price of the *‚offshore wind'* had in the last 2-3 years a spectacular dynamics. Thus, in only a few years LCOE of the *‚offshore wind'* becomes almost half, from about 120 Euro/MWh to about 65 Euro/MWh in 2017. Furthermore, if we take also into account that for the atomic energy LCOE has values around 110 Euro/MWh and that the risks and the environmental impact of the marine parks are much lower than in the case of the atomic energy, but even than in the case of the *'onshore wind'*. From this perspective, it is expected in the near future a significant increase of the number and of the dimensions of the marine wind parks. In such circumstances, the wave energy sector can also boost through the *‚collocation'* process. This means the deployment of the WEC (wave energy converters) areas where wind farms already exist.

From this perspective, in the framework of the REMARC project some studies have been made even from this initial stage concerning the possibility to collocate WECs in places where wind farms operate. As an example, Figure 7 illustrates the locations of the marine reference sites considered for various European renewable energy projects, where the points are identified through three target areas (denoted as A, B and C).

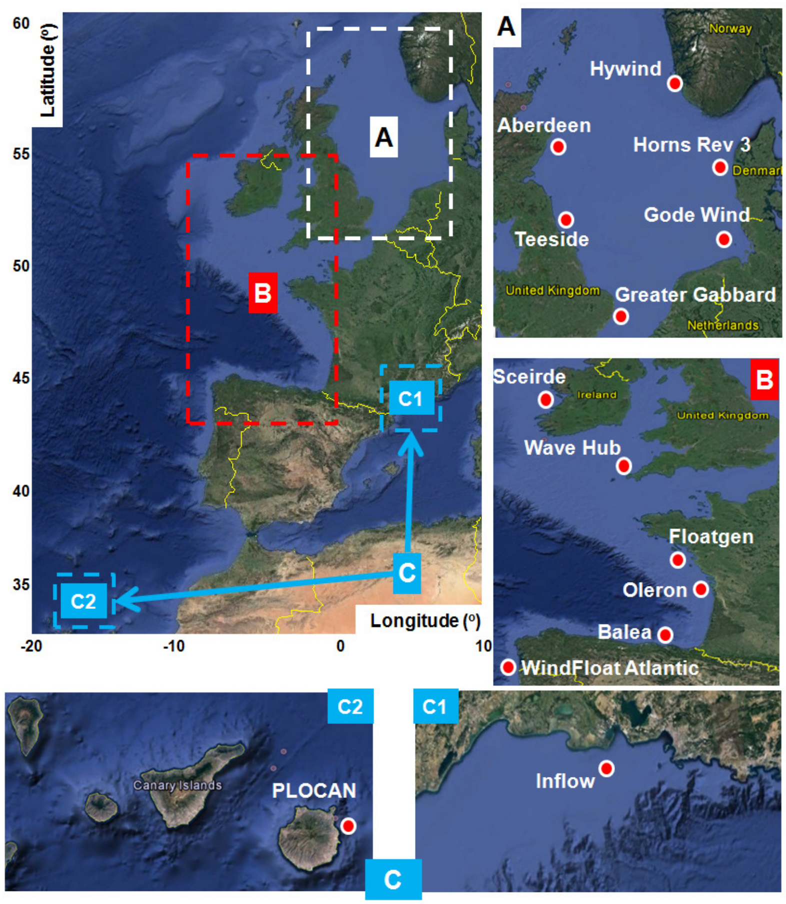


Figure 7. The locations of the marine reference sites considered for various European renewable energy projects, where the points are identified through three target areas (A, B and C). Figures processed from Google Earth (2016).

Considering the ECMWF wind and wave data, corresponding to the 10-year time interval 2005-2014, Figure 8 presents the mean values of the parameters considered for analysis (*U10* şi *Hs*). These values clearly indicate that the zones where wind projects already operate are generally appropriate also for the wave energy extraction. Such solution presents at least 2 major advantages. First, it exists the infrastructure and the connection to the network, and this means a reduction of the LCOE. Second, through the wave energy absorption the WECs can protect the wind farms.

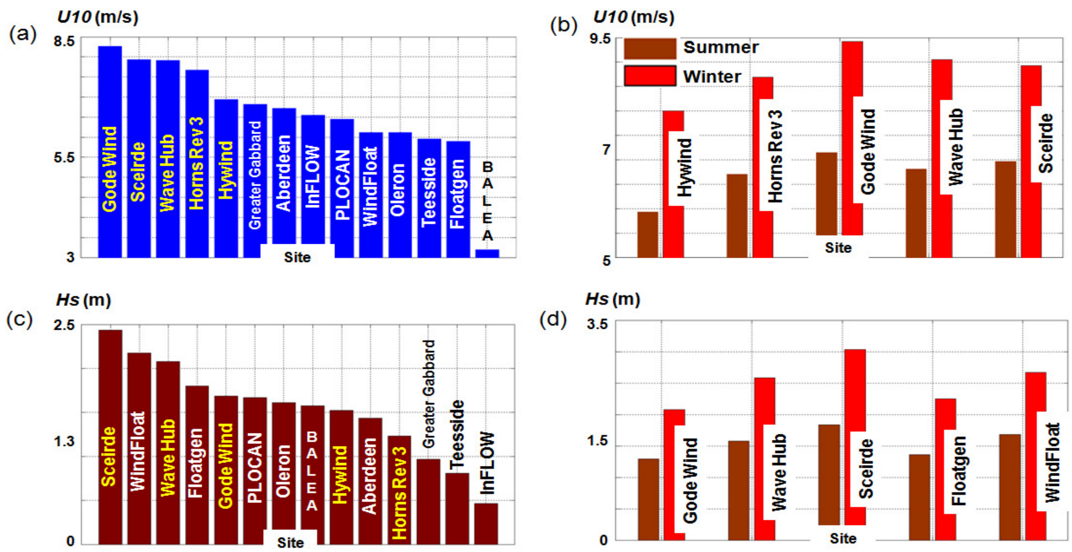


Figure 8. Mean values of the parameters considered for the analysis: a) and c) *U10* and *Hs* corresponding to the total time; b) and d) *U10* and *Hs* corresponding to the summer and winter time, respectively.

1.4 *Evaluation of the synergy between wind and wave power in the coastal environment of the Black Sea*

As mentioned even from the stage of submitting the project proposal, a special attention will be payed in the research to the basin of the Black Sea and especially to its western side including the Romanian nearshore.

Considering the NCEP wind fields, that have a higher resolution, an analysis of the wind conditions was first performed corresponding to the 20-year period 1997-2016. Figure 9 indicates the percentage of the wind speeds at 80m between the cutting and cut-out values [3-25] m/s, for the time interval 1997-2016. As it can be noticed in this figure the western part of the Black Sea and also the Sea of Azov are more energetic from the point of view of the wind energy, the percentage in this case being between 80-90%.

In the DAMWAVE project (2013-2016), Implementation of data assimilation methods to improve the wave predictions in the Romanian nearshore, CNCS – UEFISCDI, project number PN-II-ID-PCE-2012-4-0089, http://www.im.ugal.ro/DAMWAVE/index_engleza.htm, which was leaded by a team member of the present project, it was designed and implemented a wave prediction system based on spectral wave models with data assimilation. Such system has been proven enough reliable even in the Black Sea, where the conditions are more complicated from the point of view of the numerical modeling than in the open ocean or even than in the Mediterranean Sea. Using the same NCEP wind fields, which have a higher resolution, numerical simulations have been performed with this system, the results being focused on the coastal environment of the Black Sea considering water depths in the range [25-100] meters. Figure 10 presents for the time interval 1997-2016, the mean wind power at 80m, and the mean wave power. From this figure the synergy between these two resources can be also noticed.

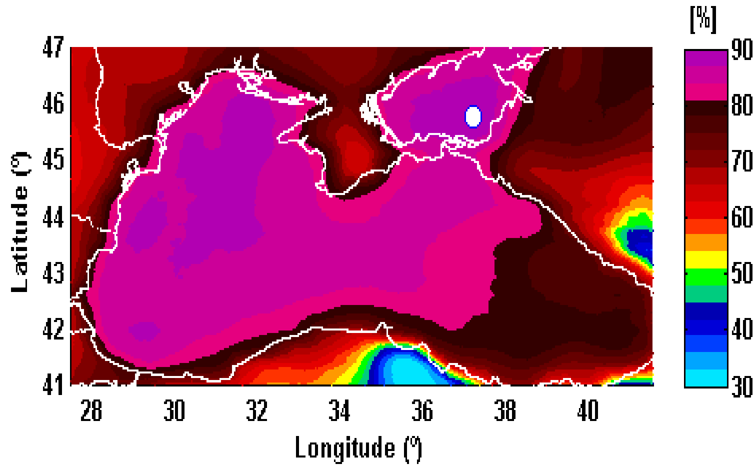
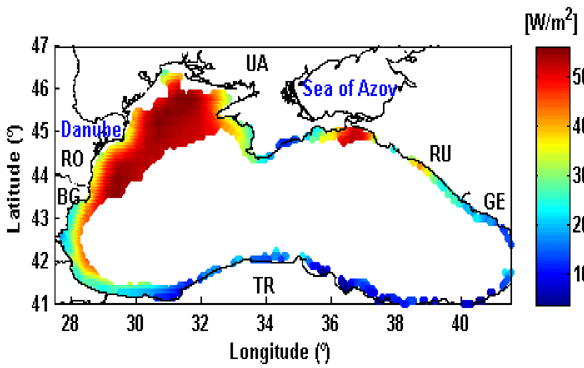
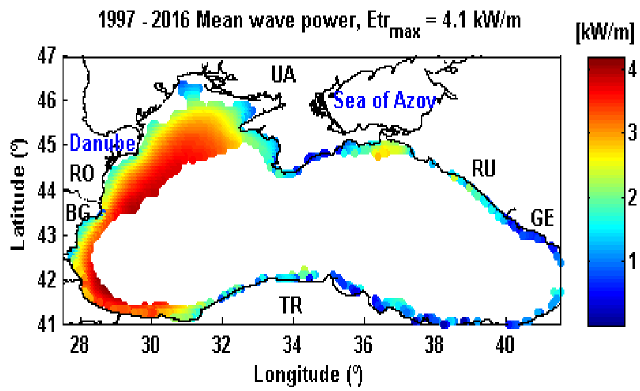


Figure 9. The percentage of the wind speeds at 80m between the cutting and cut-out values [3-25] m/s, the time interval 1997-2016.





a) b)

Figure 10. Representations for the time interval 1997-2016, a) Mean wind power at 80m, corresponding to the reference points located in the depth range (25 – 100) m, the maximum value 561 W/m^2. b) Mean wave power corresponding to the reference points located in the depth range (25 – 100m), the maximum value 4.1 kW/m.

Taking into account the importance in the present research of the western side of the Black Sea, the analysis has been completed with data coming from some *‚in situ'* measurements and also with altimeter data. Thus, Figure 11 presents the map of the Black Sea, illustrating the locations of the studied sites, 11 meteorological stations, denoted as A points and 21 reference points, considered in the analyses of the satellite data.

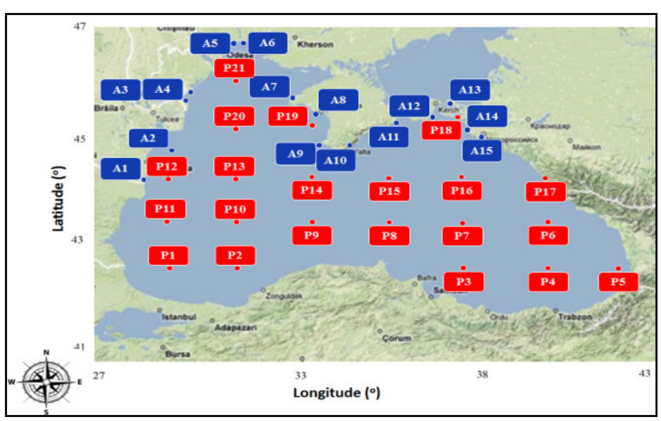


Figure 11. Map of the Black Sea, illustrating the locations of the studied sites (11 meteorological stations, denoted as the A points and 21 reference points, considered in the analyses of the satellite data, denoted as the P points). Figure processed from Google Earth (2016).

This analysis was focused first on the wind data. Thus, Table 1 presents the wind statistics for the meteorological stations located in the northern sector of the Black Sea (the A points) corresponding to the time interval 1994-2009. Figure 12a presents the distribution of the median wind speed conditions, as reflected by the satellite data in the P points for the time interval (2006-2011). The analysis is completed with the wave measurements performed at the Gloria platform, which operates in the western side of the Black Sea at about 50 m depth. Figure 12b presents the *Hs* monthly average and maximums in the time interval 2001-2005, as registered at the Gloria drilling unit. The research and analyses concerning the synergy between wind and wave energy in the western side of the Black Sea, especially focused on the Romanian nearshore, are still ongoing. During the project unfolding new aspects will be disclosed, especially taking in consideration the technological advances that are expected to be very high in the near future in the area of the marine renewable energy.

Table 1. Wind statistics for the meteorological stations located in the northern sector of the Black Sea

Station number	Time Period	Number of obs.	50th (ms^{-1})	95th (ms^{-1})	Mode (ms^{-1})	Std. (ms^{-1})	Skew	Kurt	%	
									< 3 ms^{-1}	3–20.2 ms^{-1}
A1	Total	10 228	3	8	2	2.19	1.65	7.70	45.00	54.97
	Winter	5250	3	8	2	2.42	1.69	7.51	42.62	57.35
A2	Total	10 228	7	13	5	3.40	0.35	3.10	11.29	88.63
	Winter	5250	8	14	8	3.46	0.29	3.28	6.80	93.04
A3	Total	17 528	5	12	3	3.30	0.83	3.58	18.91	81.07
	Winter	7986	5	12	3	3.52	0.77	3.35	18.09	81.88
A4	Total	8764	3	10	3	2.65	1.28	5.35	29.24	70.75
	Winter	4026	3	10	3	2.77	1.32	5.39	27.94	72.05
A5	Total	17 523	4	9	3	2.63	0.74	3.65	22.42	77.56
	Winter	7986	5	10	3	2.75	0.71	3.70	18.40	81.58
A6	Total	8764	3	7	2	2.20	1.39	5.70	45.17	54.82
	Winter	4026	3	9	2	2.41	1.37	5.47	40.26	59.73
A7	Total	17 524	4	10	2	2.82	0.84	3.58	30.11	69.87
	Winter	7986	4	10	2	3.00	0.70	3.27	25.05	74.93
A8	Total	17 527	4	9	2	2.61	1.31	5.39	30.27	69.72
	Winter	7986	4	10	3	2.87	1.19	4.76	27.04	72.95
A9	Total	14 300	4	10	2	2.81	0.78	3.24	28.68	71.31
	Winter	6006	5	11	2	3.05	0.59	2.89	22.31	77.68
A10	Total	17 527	2	7	2	1.95	1.26	5.30	56.80	43.19
	Winter	7986	2	7	2	2.15	1.15	4.45	52.98	47.01
A11	Total	8755	3	8	2	2.39	1.62	7.42	45.37	54.62
	Winter	4026	3	8	2	2.54	1.58	7.23	39.69	60.30

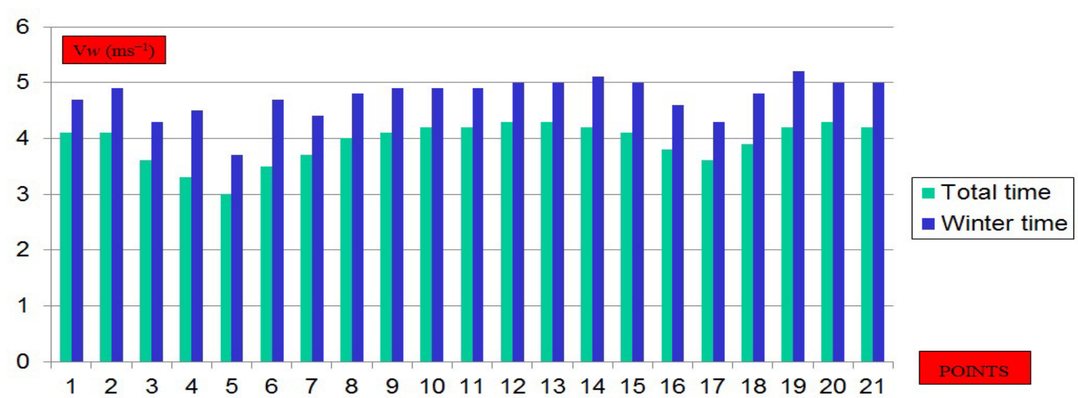


Figure 12a. The distribution of the median wind speed conditions, as reflected by the satellite data in the P points. (2006-2011).

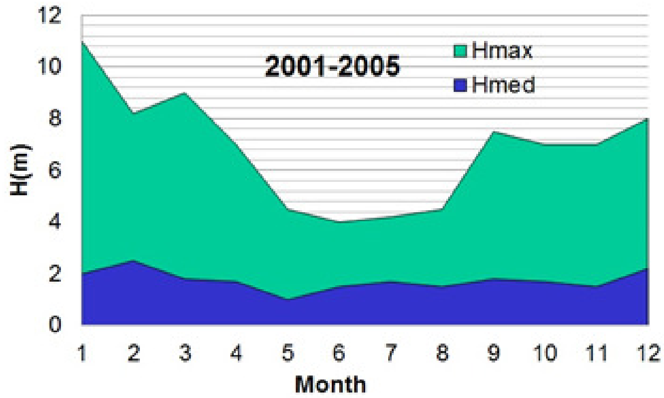


Figure 12b. *Hs* monthly average and maximum values in the time interval 2001-2005, as registered at the Gloria unit

In the final part of this section it can be also highlighted the fact that the project team started the work to accomplish the project objectives even from the beginning of the year 2017 (in fact, as it was specified in the project proposal), and thus before the project to be funded. First, this is because it is a fundamental research direction for the project director and for many team members and in this way the team continued its scientific work. At the same time, the score communicated via the preliminary report represented quasi a certitude that the project will be funded and gave momentum to the team in developing the proposed research.

2. Designing the web page (Ro-Eng) of the REMARC project

It was designed the web page for the dissemination of the REMARC project results (Act 1.2). http://193.231.148.42/remarc/index_en.php During the project unfolding this web page was updated with the activities and the publications corresponding to this first stage of the project and it will be periodically updated also from now on.

REMARC project was also included in the RESEARCHGATE platform and it was made a direct link between the web page and RESEARCHGATE. https://www.researchgate.net/project/REMARC-Renewable-Energy-extraction-in-MARine-environment-and-its-Coastal-impact

3. Dissemination of the results

3.1 Dissemination through scientific publications

- Publications in ISI indexed journals (3)

1. Rusu, E., Onea, F., 2017, Joint Evaluation of the Wave and Offshore Wind Energy Resources in the Developing Countries, *Energies* 2017, *10*(11), 1866; **IF=2.262,** http://www.mdpi.com/1996-1073/10/11/1866
2. Onea, F., Ciortan, S., Rusu, E., 2017, Assessment of the potential for developing combined wind-wave projects in the European nearshore, SAGE Journals, Energy & Environment, 2017, **IF=0.302** http://journals.sagepub.com/doi/abs/10.1177/0958305X17716947
3. Ganea, D., Amorțilă, V., Mereuță, E., Rusu, E., 2017, A Joint Evaluation of the Wind and Wave Energy Resources Close to the Greek Islands, Sustainability Journal, Special Issue Wind Energy, Load and Price Forecasting towards Sustainability, 2017, 9(6), 1025; doi:10.3390/su9061025, **IF=1.789**, http://www.mdpi.com/2071-1050/9/6/1025

- Presentations at international conferences and publication in the conference proceedings (3)

4. Rusu, E., 2017, *"The synergy between wind and wave power along the coasts of the Black Sea"*, the 17th International Congress of the International Maritime Association of the Mediterranean on "Maritime Transportation and Harvesting of Sea Resources", IMAM 2017, Lisbon, Portugal, 9 - 11 October 2017, http://www.imamhomepage.org/imam2017/ (ISI – indexed)

5. Niculescu, D., Rusu, E., 2017, *"Water flow and bathymetry - sensors integration for precise measurements"*, The International Symposium Protection of the Black Sea Ecosystem and Sustainable Management of Maritime Activities - PROMARE 2017, 8th Edition, 7-9 September 2017, Constanta, ROMANIA - Poster**)**

6. Picu, L., Rusu, E., 2017, Studies of vibrations induced and their effect on the river ship crew fatigue, poster presented at the International Conference TEME2017 http://www.teme.ugal.ro/, paper published in the proceedings.

- Publications in national journals (3)

7. Pintilie, V., Rusu, E., 2017 A brief overview of the renewable energy potential in Romania, Mechanical Testing and Diagnosis ISSN 2247 – 9635, 2017 (VII), Volume 2, pp. 24-29, http://www.im.ugal.ro/mtd/issue2017-2.htm

8. Covalenco, V., Ciortan, S., Rusu, E., 2017, Analysis of the extreme environmental conditions In the Black Sea considering different data sources , Mechanical Testing and Diagnosis ISSN 2247 – 9635, 2017 (VII), Volume 2, pp. 16-23 , http://www.im.ugal.ro/mtd/issue2017-2.htm

9. Picu, L., Rusu, E., 2017, *"Whole Body Vibration of A Pushtow Boat Crew Operating on the Danube River"*, Journal of Mechanical Testing and Diagnosis,ISSN 2247 – 9635, 2017 (VII), Volume 1, pp. 28-35, http://www.im.ugal.ro/mtd/issue2017-1.htm

To these 3 more works can be added that have been accepted to relevant international conferences that will be held in 2018

10. Rusu, E., Onea, F., 2017, The Synergy Between Wave and Wind Energy along the Latin American and the European Continental Coasts, SDEWES2018, LA.SDEWES2018-0013, http://www.rio2018.sdewes.org/programme.php

11. Rusu, L., 2017, The Wave and Wind Power Potential in the Western Black Sea, SDEWES2018, LA.SDEWES2018-0014, http://www.rio2018.sdewes.org/programme.php

12. Rusu, E., Onea, F., 2017, Evaluation of the shoreline effect of the marine energy farms in different coastal environments, ICACER2018, http://icacer.com/

Finally, it can be also mentioned that 4 other papers are currently under evaluation to international journals.

3.2 Dissemination through participation in international scientific committees

The international visibility of the team members is proved also through the participation as program chair or member in technical/organizing/scientific committee to relevant international meetings. Besides the prove of the international recognition of the project director and of the team members, this also represents a very good mean for disseminating the results of the REMARC project. Thus, there can be mentioned the followings:

Prof Eugen RUSU (project director): Program chair – 3rd International Conference on Advances on Clean Energy Research – ICACER2018, http://icacer.com/com.html

Prof Eugen RUSU (project director): Program chair – 2nd International Conference on Energy Economics and Energy Policy , ICEEEP2018, http://www.iceeep.com/com.html

Prof Eugen RUSU (project director): Member in the International Evaluation Panel of the Research Center MAREI (Center for Marine and Renewable Energy http://www.marei.ie/), Irleand (2017), appointed by Science Foundation Ireland, http://www.sfi.ie/

Prof Eugen RUSU (project director): organizing committee member, 2nd Edition of Global Summit on Renewable Energy & Emerging Technologies (2018), https://renewableenergy.euroscicon.com/organizing-committee

Prof Eugen RUSU (project director): technical committee member, International Maritime Association of the Mediterranean, IMAM2017 http://www.imamhomepage.org/imam2017/structure.aspx

Prof Eugen RUSU (project director): scientific committee member - 2nd International Symposium on Natural Hazards and Disaster Management (ISHAD2018), http://ishad.info/Content/Pages/Committees.aspx

Prof Eugen RUSU (project director): organizing committee member, 2018 International Conference on Clean Energy and Smart Grid (CCESG2018), http://www.ccesg.org/

Prof Liliana RUSU (team member): organizing committee member, 2018 International Conference on Clean Energy and Smart Grid (CCESG2018), http://www.ccesg.org/

Prof Liliana RUSU (team member) scientific committee member, 1st Latin American Conference on Sustainable

Development of Energy Water and Environment Systems, SDEWES2018, http://www.rio2018.sdewes.org/sab.php

3.3 Support for the young researchers

In the framework of the project have been published several papers where young scientists (PhD and master students) were included. This can be checked in the list of publications above presented. Besides this, two theses (one of master level and another one of bachelor level) have been finalized in the framework of the REMARC project, as described bellow.

Master theses finalized

Cristea Adriana (Master MSIM), the thesis entitled: *"Studies on the development of the wave energy extraction, present and future perspectives - Studii privind dezvoltarea extragerii energiei valurilor, prezent și perspective pentru viitor"*, supervisor Prof. Eugen Rusu

Bachelor theses finalized

Codreanu Andrei Gabriel (Licență IM), the thesis entitled: *"Studies on the wind potential in the coastal and marine areas - Studiu privind potențialul energetic eolian in zonele costiere și marine"*, supervisor Prof. Eugen Rusu

4. Conclusions

It can be finally appreciated that there were fully accomplished the objectives corresponding to this stage (through the two actions previewed Act 1.1 and Act 1.2). In fact, they were exceeded. Moreover, all the necessary premises exist for the REMARC project to continue in very good conditions and to produce valuable results with a high international visibility.

Budget (2017) 229.620,00 lei (aprox 50 000 EUR)

Project Director

Prof. dr. ing. Eugen Rusu