Scientific Report

concerning the implementation of the project

ROmanian MArine Renewable solutions - ROMAR

in the period January – April 2020

In the third stage of the project implementation (E3 – *Protection of the Romanian coastal area throughout projects that use marine energy*) carried out in the period above mentioned, the specific objectives of the project were considered for investigation, as follows:

- **3.1** Establish the nearshore currents variations in the presence of a wave farm (Act 3.1).
- **3.2** Identify the variations of the sediment transport from the Romanian environment under the influence of a wave farm (Act 3.2).
- **3.3** Evaluate the environmental impact on to the Romanian marine ecosystem expected from the development of a renewable energy project (Act 3.3).
- **3.4** Dissemination of the results.
- **3.5** Conclusions.

3.1 Establish the nearshore currents variations in the presence of a wave farm

A significant part of the global population lives near the coastal areas. It is estimated that almost 20% of the total population is located in a strip area of 25 km from the coast. The share increases to up to 40% of the total population when extending the considered strip area to 100 km. A particularity of these areas is that they are very dynamic environments, which present an annual urban growth of 2.6%. At the same time, the number of coastal cities has itself increased about 4.5 times since 1950. Although these areas are defined by numerous opportunities, they are also facing some threats coming from the surrounding environment, such as coastal erosion, a natural event during which the balance between accretion and erosion is continuously shifting. These natural events occur on various spatial and temporal scales, being influenced by many factors, such as wind, waves and nearshore currents. Moreover, it is expected that climate change will have a negative impact on coastal areas in the future, with sea levels being supposed to rise and the marine conditions becoming more aggressive. Although multiple parameters shape the coastline processes, the wave action has a significant impact on the coastal erosion.

Four different European coastal areas were considered in this work, two at the North Atlantic Ocean and other two in sea environments (Mediterranean and Black Sea, respectively). These four target areas are illustrated in Figure 1. The first two are related to the nearshore areas facing the ocean environment, more precisely on the Portuguese continental coast (zone A). In the south of this zone, a coastal sector located close to the Sines peninsula was evaluated, while, in the north, a sector located close to the Leixoes area (north of the city of Porto) was considered. Going east, we identified a second target area (zone B) that is located in the Mediterranean Sea. In this case, we evaluated an island environment, Sardinia. The north-western part of the Black Sea was also taken into account (zone C), more precisely the Saint George sector (in the Romanian nearshore), which is part of the Danube Delta.

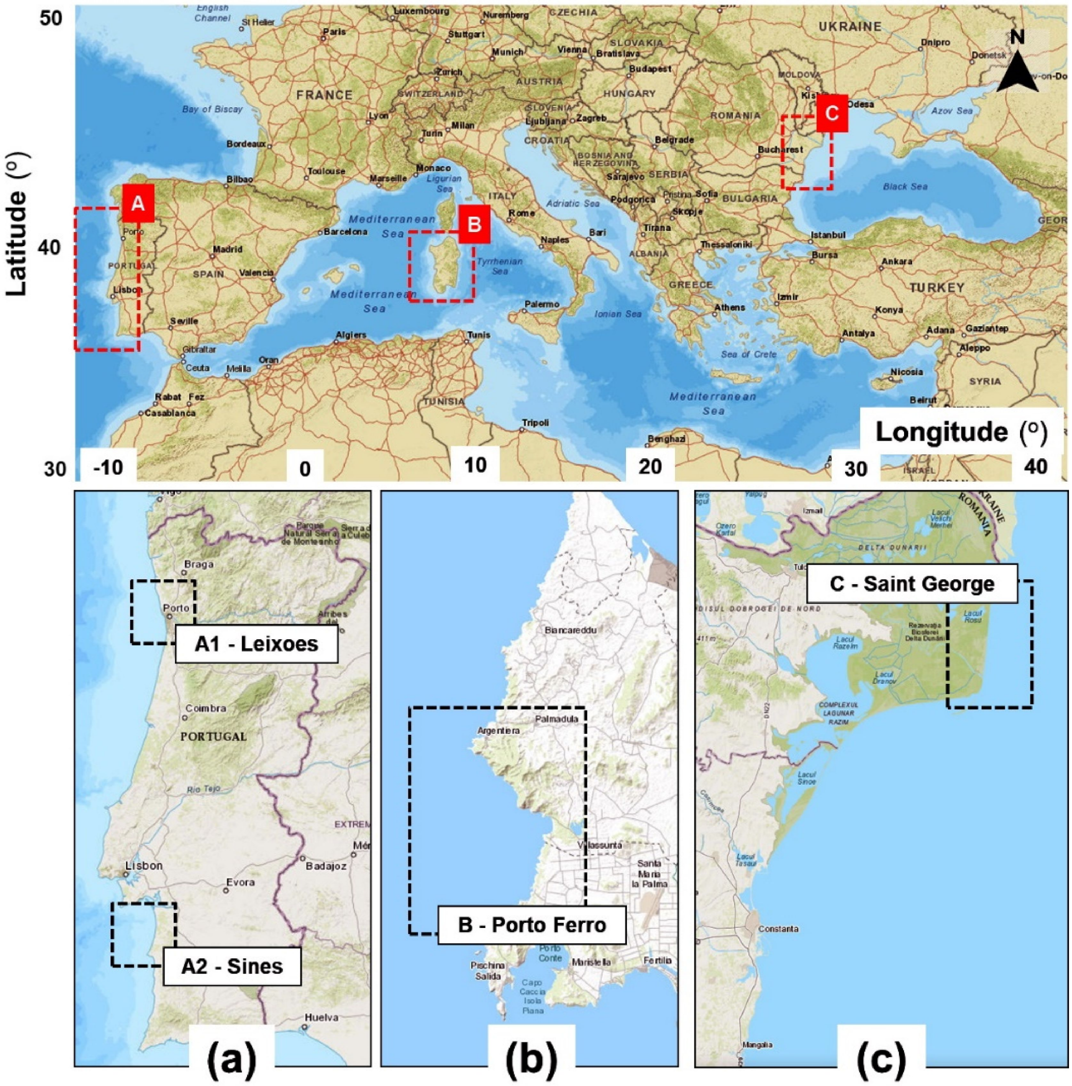

Figure 1. Locations of the target areas considered for assessment, where: (**a**) Portugal continental (North Atlantic Ocean); (**b**) Porto Ferro, Sardinia (Mediterranean Sea); (**c**) Saint George (Black Sea). Figures processed from Google Earth (2019).

A first step in the evaluation of the coastal impact is related to the identification of some relevant environmental conditions. In this case, such conditions would be the most important wave parameters, namely: significant wave height—*Hs* (in meters); mean wave period—*Tm* (in seconds); mean wave direction—*Dir* (in degree). Table 1 summarizes the wave statistics. The main idea was to consider approximately the same wave conditions, which are identified as most relevant, in all areas in order to assess and compare the coastal response to the presence of the marine energy farms. From this perspective, it must be highlighted that, although all the four different wave conditions defined are realistic for all the coastal environments considered, they represent in general different categories for the ocean waves than for the sea waves.

For example, what represents total time average for the ocean waves is very close to the winter time average in the case of the sea waves and the conditions corresponding to a regular storm in the European side of the North Atlantic is close to a high storm in the nearshores considered for the Mediterranean and Black seas. This assumption was based on various analyses that were performed on the general characteristics of the wave climates in the areas targeted. The case studies presented in this work were processed by using the ISSM (Interface for SWAN and Surf Models) modelling tool that combines a wave model with a surf model.

Table 1. Wave conditions defined for the different coastal areas targeted and their characteristics

Area	Conditions	***Hs*** **(m)**	***Tm*** **(s)**	***Dir*** **(°)**
A1—Leixoes (North Atlantic)	Total time average (denoted with total average)	1.5	7	300 (corresponding to 30 ° in relation to the normal to the shoreline)
	Winter time average (winter average)	3	8	
	High non-storm (non-storm)	4.5	9	
	Regular storm (storm)	6	11	
A2—Sines (North Atlantic)	Total average	1.5	7	300 (corresponding to 30 ° in relation to the normal to the shoreline)
	Winter average	3	8	
	Non-storm	4.5	9	
	Storm	6	11	
B—Porto Ferro (Mediterranean Sea)	Winter average	1.5	5	300 (corresponding to 30 ° in relation to the normal to the shoreline)
	Non-storm	3	6	
	Storm	4.5	7	
	High storm (denoted with high-storm)	6	9	
C—Saint George (Black Sea)	Winter average	1.5	5	60 (corresponding to 30 ° in relation to the normal to the shoreline)
	Non-storm	3	6	
	Storm	4.5	7	
	High-storm	6	9	

Figure 2 illustrates the case studies considered. For each target area, a line of 3 km in length was considered, aiming to replicate the influence of a generic marine energy farm. A 2 km distance between the marine energy farm and the shoreline was considered, while the orientation of the farm was made according to the particularity of each target area.

The variations of the wave conditions in the presence of the marine energy farm will be assessed in the geographical space through spatial maps, while a deeper analysis of these fluctuations will be highlighted along the L-reference lines, or by the analysis performed in some offshore and nearshore points (O-points or NP-points).

In order to provide a complete picture of the influence of an energy farm, two case studies were evaluated, as can be noticed from Table 2. The first one involved a realistic scenario where the wave farm was defined by a moderate absorption (denoted with M-farm) considering an absorption percentage of only 20% of the incoming waves. The other case study was related to a high absorption scenario (denoted with H-farm) and involved absorption of almost 40% of the waves, this being the case of a wave farm defined by several lines of WECs.

Table 2. Set-up of the generic wave farm.

Case study	Transmission (0%—no farm; 100%—complete blockage)	Reflection (0%—no farm; 100%—complete reflection)
Moderate absorption (M-farm)	20%	5%
High absorption (H-farm)	40%	10%

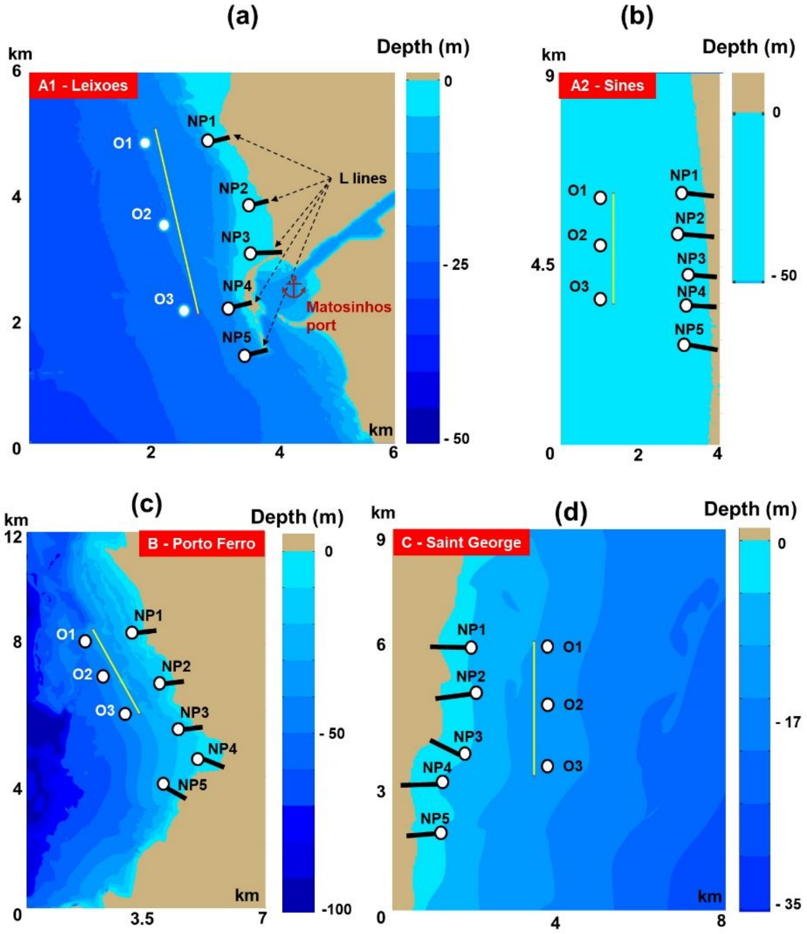

Figure 2. Case studies and computational domains considered for evaluation, where: (**a**) Leixoes; (**b**) Sines; (**c**) Porto Ferro; (**d**) Saint George. In the foreground, the configurations of the wave farms are presented, while in the background, the bathymetric map is represented.

It is well known that coastal areas are also influenced by the presence of the longshore currents. These currents are generated by the breaking waves that enter in the surf area, it being expected that in the case of storm events the current velocity will indicate higher values.

Figure 3 presents the velocity distribution for the Porto Ferro area. In this case, more important variations are noticed close to the line L3, where the presence of a wave farm decreases the current velocity to a minimum of 0.2 m/s (non-storm/H-farm and storm/H-farm). The line L2 indicates no significant variation, regardless of the case study considered, while as we go to the scenarios storm and high-storm it appears that a marine energy farm will not have a big impact on the nearshore currents (excepting the line L3). In addition, it is important to mention that for the case studies winter average and non-storm, the velocity will increase along the line L1, reaching maximum values of 0.99 (winter average) or 1.37 m/s (non-storm), respectively.

Figure 4 illustrates the maximum values of the current velocity along the reference lines, by considering this time the Saint George area. By looking at these results, we notice that mixed patterns occur for each case study. Thus, in the case of the line L1, the velocity corresponding to the case studies winter average and high-storm increases in the presence of a high absorber farm and decreases for a moderate one. For the scenario winter average/no farm, the current velocity decreases near the lines L3, L4 and L5, reaching minimum values of 0.07 m/s for winter average/M-farm and 0.01 m/s for winter average/H-farm. Since the wave direction is a crucial parameter in the development of the nearshore currents, the fact that the marine energy farm may produce significant changes in terms of wave direction may also affect the longshore current velocity. That is why, although the waves lose energy in the presence of the marine energy farm, in certain situations, due to such changes in wave direction, the longshore current velocity can increase down-wave from a marine energy farm.

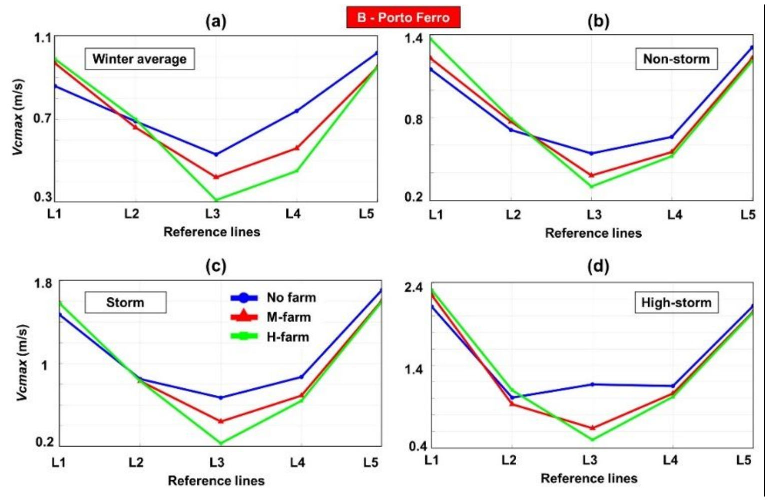

Figure 3. Porto Ferro study—maximum current velocity (*Vcmax* in m/s) estimated along the five reference lines considered (L1–L5). The results are indicated for: (**a**) winter average; (**b**) non-storm; (**c**) storm; (**d**) high-storm.

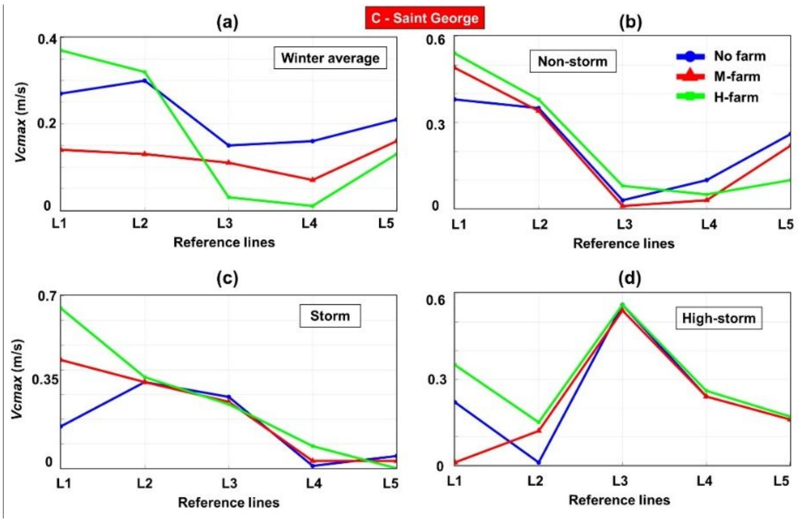

Figure 4. Saint George study—maximum current velocity (*Vcmax* in m/s) estimated along the five reference lines considered (L1–L5). The results are indicated for: (**a**) winter average; (**b**) non-storm; (**c**) storm; (**d**) high-storm.

For the non-storm situation, the current velocity will increase near the line L1, while an opposite trend is noticed close to the lines L4 and L5. Smaller fluctuations are noticed near the lines L2 and L3, while a similar situation is reported by the scenario storm (L2, L3, L5) or by high-storm (L3, L4, L5).

3.2 Identify the variations of the sediment transport from the Romanian environment under the influence of a wave farm

Table 3 presents the evolution of the significant wave heights corresponding to the nearshore point group NP, considering only the Saint George area. These values are important because they will be further used to identify the influence on the sediment transport.

Table 3. Saint George case study - variation of the *Hs* wave parameter in the presence of the marine energy farm corresponding to the five nearshore points.

Scenario	***Hs* values (m)**									
	Winter average					Non-storm				
No farm	1.02	1.01	0.98	0.90	0.92	1.84	1.76	1.73	1.61	1.60
M-farm	0.95	0.86	0.83	0.81	0.88	1.72	1.48	1.50	1.46	1.55
H-farm	0.89	0.72	0.69	0.73	0.84	1.62	1.22	1.25	1.32	1.51
	Storm					High-storm				
No farm	2.21	2.44	2.11	2.15	1.96	2.37	2.82	2.30	2.35	2.12
M-farm	2.15	2.12	2.03	2.10	1.95	2.34	2.69	2.29	2.34	2.12
H-farm	2.09	1.72	1.85	1.99	1.95	2.28	2.35	2.25	2.31	2.12
	NP1	NP2	NP3	NP4	NP5	NP1	NP2	NP3	NP4	NP5
	Reference points					**Reference points**				

The current approaches for coastal protection mainly involve seawalls and breakwaters. Since the aim of a WEC farm is to extract energy from the waves, a wave farm represents a very suitable alternative. Nevertheless, such farms are not beneficial in every environment, as is the case of enclosed seas, which do not represent the best option for the development of a wave project. This is because the wave conditions are significantly reduced compared to the ocean environment. On the other hand, Europe is an active player in the development of the WEC systems, and since a large part of this region is surrounded by semi-enclosed seas, there are higher chances to see marine farms operating in these waters in the future.

In any coastal area, the sediment transport is divided between bedload and suspended load, it being estimated that the most important hydraulic parameter for littoral transport is represented by the wave conditions. The littoral drift is influenced by several parameters (significant wave height; wave direction; grain size, etc.) which can be used to determine the littoral transport rate, denoted with Q (m^3/24 hrs). For example, in the case of an incident angle of 30° (like the one considered in the present work – see Table 1), the transport rate of a beach sand is associated with the following values: Hs = 1 m; Q = 300 m^3/24 hrs; Hs = 3 m; Q = 10,000 m^3/24 hrs; Hs = 5 m; Q = 65,000 m^3/24 hrs. This assumption can be applied for most of the target areas, taking into account that the Saint George sector is defined by quartz sands (medium-fine sands), with a similar situation being noticed for the Sines area, where the local rivers represent the main source of sediments.

By interpolating the results presented in reference, it is possible to assess the transport rate corresponding to the nearshore points (from NP1 to NP5), assuming that the wave conditions are considered for a time interval of 24 hours. Table 4 present the transport rates for some representative nearshore points. According to these results, we can notice that even small changes in the wave heights may lead to a significant reduction in the littoral transport rate generated by the wave action.

Table 4. Transport rate of the beach sand considering the scenario when the incident wave angle is 30°. The results are presented for all the target areas considered: Leixoes, Sines, Porto Ferro and Saint George.

Leixoes	*	total average /NP5	winter average /NP4	non-storm /NP4	storm/NP4
	**	759	5680	23200	62900
	***	M-farm – 15.7%; H-farm – 22.4%	M-farm – 60.6%; H-farm – 74.4%	M-farm – 52.6%; H-farm – 72.4%	M-farm – 40.6%; H-farm – 66.3%
Sines	*	total average/NP5	winter average/NP2	non-storm/NP2	storm/NP1
	**	878	5840	22800	60450
	***	M-farm – 15.5% H-farm – 29%	M-farm – 42.5% H-farm – 69.2%	M-farm – 42.1 H-farm – 66%	M-farm –14.5% H-farm – 67.9%
Porto Ferro	*	winter average/NP5	non-storm/NP5	storm/NP5	high-storm/NP5
	**	827	4160	17000	55560
	***	M-farm – 6.2% H-farm – 8.2%	M-farm – 7.7% H-farm – 9.6%	M-farm – 5.9% H-farm – 7.1%	M-farm – 3.7 % H-farm – 4.3%
Saint George	*	winter average/NP3	non-storm/NP3	storm/NP3	high-storm/NP3
	**	294	1541	2880	4400
	***	M-farm – 15.3% H-farm – 29.6%	M-farm – 25.4% H-farm – 53%	M-farm – 22.2% H-farm – 39.4%	M-farm – 1.8% H-farm – 9.1%

* Wave conditions and reference points; ** No farm – (Q in $m^3/24$ hrs); *** Wave farm (Q attenuation in %)

The longshore current velocity represents another parameter considered for investigation, which was assessed in each target area (from Figure 3 and Figure 4). The Hjulström curve is frequently used by hydrologists to determine if a river will transport/deposit sediment or will erode by taking into account the water velocity and the sediment particle size. If the water velocity is below 3 m/s, the sediment will be transported or deposited based on their size (<0.01 mm—transportation), while after this threshold the erosion processes may occur. At this point, it is important to mention that the Hjulström diagram is able to provide only a first-order analysis of the interaction between flowing water and sediments. From the analysis of the results in the Leixoes area, we notice that the erosion process may occur in the sector located close to the line L1, where in fact the presence of the farm increases the current velocity. For the scenarios total average, winter average and non-storm, a marine energy farm significantly reduces the current velocity for the lines L4 and L5, contributing in this way to the protection of the coastline. Regarding the Sines area, a marine energy farm may increase the erosion processes in the upper part of the shielded region (lines L1 and L2) and will significantly decrease the current velocity in the lower part (lines L4 and L5).

As for the Porto Ferro area, by looking at the results corresponding to the high-storm scenario, we notice that near the line L3, the current velocity reduces. This does not necessarily mean that this sector will be protected, taking into account that the wave farm has no impact on the current velocity reported in the adjacent sectors. Regarding the expected values from the Saint George sector, we notice that they cannot be considered a source of coastal erosion, being assumed to be involved more in the sediment flow. For this sector, the coastal erosion will probably be more directly related to the wave action that can be generated during a storm event (storm and high-storm), with orbital velocities in the range of 1.3 and 1.5 m/s.

3.3 Evaluate the environmental impact on to the Romanian marine ecosystem expected from the development of a renewable energy project

The environmental impact was briefly mentioned in the published papers related to this project. In general, there are concerns related to the interaction between birds and marine mammals (collision, noise or electromagnetism), which seems to be more important in the case of the offshore wind projects. From a positive point of view, the presence of a physical structure can be associated to a marine protected areas, being noticed in some cases (ex: offshore projects) an increase of the local biodiversity.

3.4 Dissemination of the results

Publications in journals with WoS quotations (1)

Raileanu A, **Onea F**, Rusu E, 2020. *An Overview of the Expected Shoreline Impact of the Marine Energy Farms Operating in Different Coastal Environments*. J. Mar. Sci. Eng. 2020, 8, 228, **IF=1.732**, https://www.mdpi.com/2077-1312/8/3/228

Papers presented in international scientific conferences (1)

Onea F, Rusu L, 2020. *Impact Assessment of a Generic Wave Farm on the Wave Conditions at the Entrance to Danube Delta*. Academics World International Conference, March 23–24, 2020, Bucharest, Romania. http://www.academicsworld.org/Conference2020/Romania/1/ICRAMHS/

Papers presented in Romanian national conferences (1)

Ruiz A, Rusu E, **Onea F**, 2020. *An Evaluation of the Offshore Wind Power Resources in the Spanish Nearshore*. Scientific Conference organized by the Doctoral Schools of “Dunărea de Jos” University of Galati (SCDS-UDJG) 2020, 18-19 June 2020, Galati, Romania. http://www.cssd-udjg.ugal.ro/ (**Accepted for presentation**).

3.5 Conclusions

Since at this moment there are no operational wave farms, it is difficult to say what the configuration of such a project will be, and as a consequence throughout various ``what-if`` case studies it is possible to estimate the expected implications for the coastal protection. The results from the present report are in the line with the current research that considers hybrid modelling systems, which combine the output of a wave model with other simulation tools (ex: sediment transport; longshore currents). Therefore, throughout the use of a generic farm it is possible to find an optimal balance between the electricity production and coastal protection, even for enclosed area like the Black Sea.

Budget (2020) 42.090,00 lei (approx. 8770 Euro)

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