SUSTAINABLE SITING OF OFFSHORE WIND FARMS FOR AN ISOLATED ISLAND SYSTEM

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Abstract

This article highlights a 5-steps methodological framework for evaluating the available marine areas for the installation of offshore wind farms. Furthermore, the study area of our work is the island of Crete, the biggest and most populous island of Greece. The selected area has unique characteristics and great offshore wind potential.

Subsequently, the exclusion and the evaluation criteria are selected in terms of the national and European legislation and according to the study area's characteristics. After that, the evaluation criteria are assessed, through the process of personal interviews and questionnaires, from different groups of stakeholders, and then the AHP method is implemented in order to produce the relative importance of the criteria.

Finally, all exclusion criteria are performed to a unique layer of GIS and the combination emerged constitutes the exclusion map. However, the evaluation criteria are classified to scale from 1 to 5 (5 the higher suitability) and a layer for each criterion is also produced and the final evaluation map with a ranking suitability from 1-5. Eventually, the final suitability map is produced by multiplying the exclusion and evaluation map with Raster calculator.

This work contains an analysis of 4-criteria evaluation and exclusion at the same time. A more analytic and extensive work employing 14-criteria exclusion and 16-criteria evaluation is ongoing.

Keywords: Renewable Energy, Offshore Wind Farms, Sustainable Siting, Insular Environment, Analytical Hierarchy Process (AHP),

1. Introduction

More and more industries and nations/countries are orientated towards the development of Renewable Energy Strategies, Policies, Systems and Solutions nowadays, in order to meet European goals until 2030, concerning the diminution of fossil fuels and as a consequence the reduction of CO_2 emissions (2030 Climate & Energy Framework, Climate Action, 2020). Greece has a high installed capacity of onshore wind energy, surpassing the 3.5 GW (Hellenic Wind Energy Association (HWEA), 2020). Concerning the offshore wind projects, no remarkable progress has been made yet in the country. So, in this context and in order to avoid the additional land-use conflicts (International Energy Agency (IEA), 2019), this work has as a target to indicate the suitable marine areas which hold a high wind potential and meet the socio-economic, environmental and technical demands, simultaneously. Furthermore, this project is implemented in the island of Crete, as it requires a huge annual energy demand, especially in the summer period where the number of visitors is extremely high (Tsoutsos et al., 2015). It is also worth mentioning that a project like this, combined with the electrical interconnectivity, which has been scheduled within the next 2-3 years of the island of Crete with continental Greece could actually offer a variety of advantages for the local and the national economy, too (Independent Power Transmission Operator, 2019).

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2. Methodology

This work provides a methodological framework based on Multi-Criteria Decision Methods (MCDM) and Geographic Information Systems (GIS). More specifically, the relative weights are extracted from the questionnaires sent to different groups of local groups stakeholders. Consequently, the Analytical Hierarchy Process (AHP) is implemented and along with the use of GIS, the exclusion, as well as the evaluation maps, are exported. The selected criteria are divided into two categories the exclusion and the evaluation, accordingly. Finally, the developed methodology could be adopted by all stakeholders and competent authorities as a decision-making tool, since it could integrate the stakeholders' opinions and result to a sustainable siting of an offshore wind farm, facilitating in this way the transition into the decarbonization era (Höfer et al., 2016; Giamalaki & Tsoutsos, 2019).

In the first step of our method, the indispensable stage of the literature review was conducted. This helped us to acknowledge all the criteria used by the international scientific community in this sector of interest. Subsequently, the criteria which were satisfying the national legislation and were harmonised with the local characteristics of the island were selected as evaluation and placed in the questionnaires. The questionnaires were comprised of a matrix 16 x 16 for pairwise comparisons to become, as the number of evaluation criteria was 16. After that, the answers were received from the experts and the results were processed, based on the method of AHP and the final relative weights were derived for each evaluation criterion. Afterwards, the exclusion stage was taken place, where 14 exclusion criteria were identified (supplementary or not to the evaluation criteria) and the exclusion map with the combined criteria was accrued, so the inappropriate and the suitable areas are now obvious. Finally, the suitable areas are classified into a class from 1 - 5 (the most suitable), based on the weights coming from the stakeholders' opinions, with the aid of the software GIS. In the following Fig. 1 is depicted the summarized process of our methodology.

Fig. 1: Methodological framework for Offshore Wind Farms sustainable siting.

3. Analysis

Crete is the largest and most populous Hellenic island and it disposes an off-grid energy supply system depending mainly on petrol oil. Therefore, the electric interconnectivity with the mainland is under construction, so there will be emerged many advantages; one of these is the fact that the penetration of Renewable energy installations could be achieved more effectively (Fig. 2).

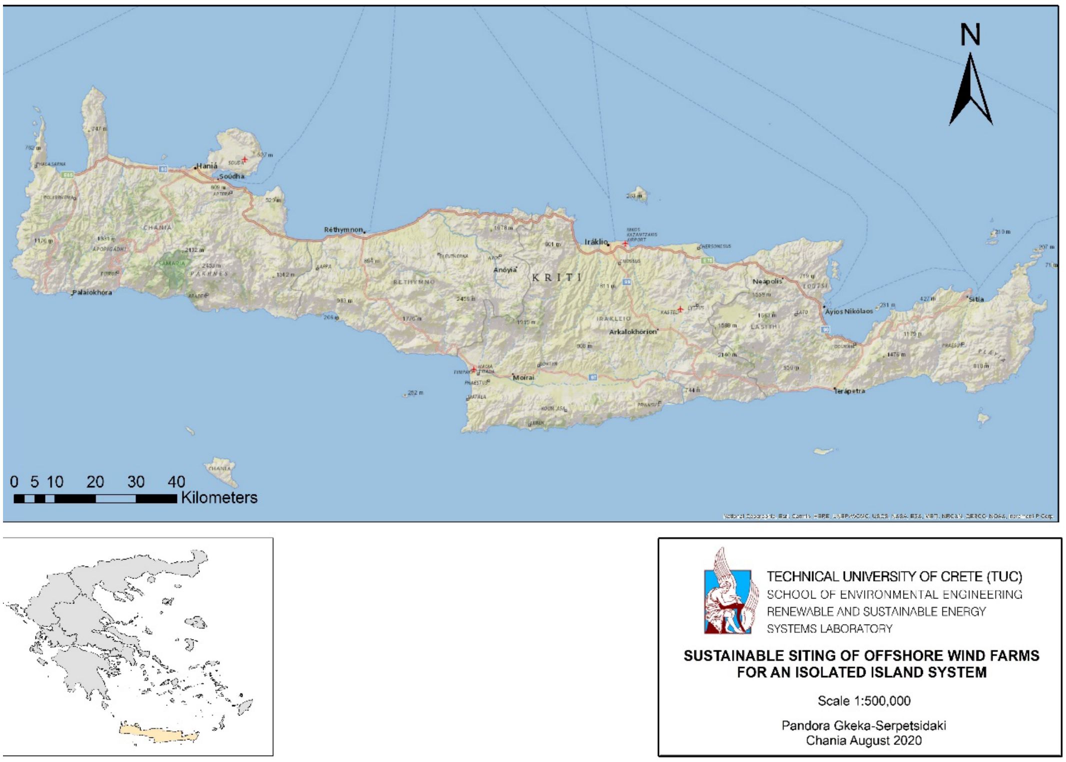

Fig. 2: Study area map, the island of Crete (Greece).

In this stage of our work, it has to be noted that were used fourteen exclusion and sixteen evaluation criteria. These evaluation criteria were assessed by thirty-three involved stakeholders/experts. Consequently, the relative weights of each criterion were calculated through the implementation of AHP method. The final results are actually under further analysis.

In this paper, four out of fourteen basic exclusion criteria were selected to be adapted and highlight our methodology. These criteria are briefly described below:

3.1 Water Depth

The water depth consists a crucial factor to determine where the installations of wind turbines have to be embedded. Today, the fixed wind turbines could reach a maximum depth of 60-80m. Generally, the shallower waters are preferred to deeper because of the great cost. The available marine areas with greater depths than 100m (red colour) are excluded from our study, according to the Fig. 3.

3.2. Environmentally Protected Areas

The environmentally protected areas are a sum of four other subcategories such as the Natura 2000 sites, the Important Bird Areas, the Posidonia oceanica meadows and the migratory corridors of birds. It was considered fair to exclude these areas from our work, because there is no reason to strain the environment further and there are also abundant marine areas for development of Offshore Wind Farms. The excluded marine areas are presented with green/blue colour in the following Fig. 4.

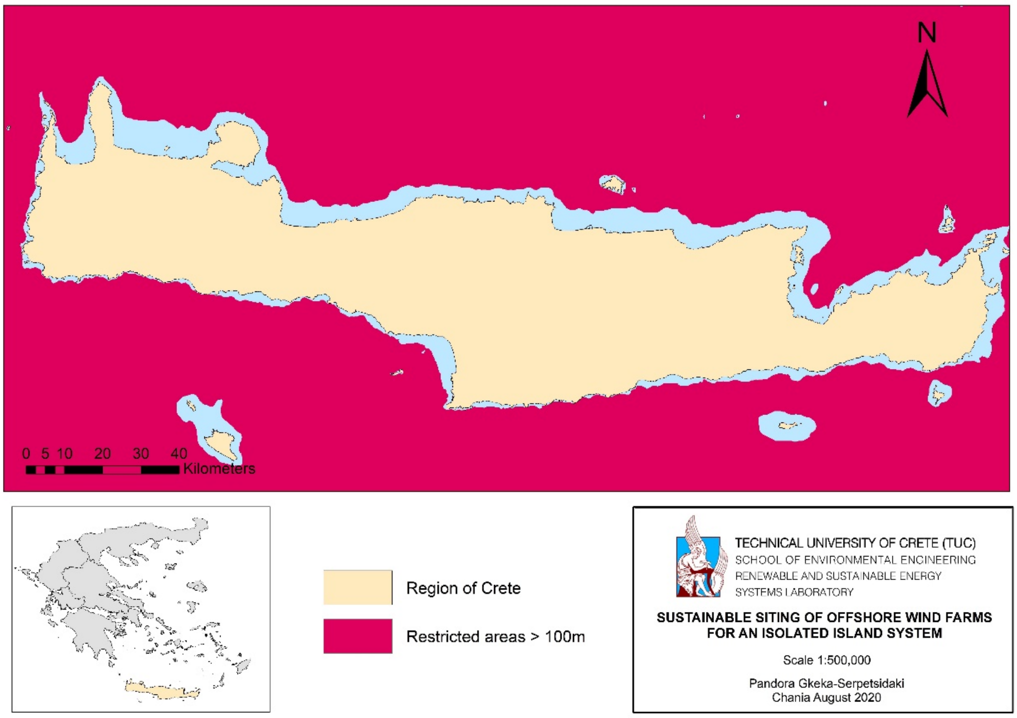

Fig. 3: Constraint of water depth.

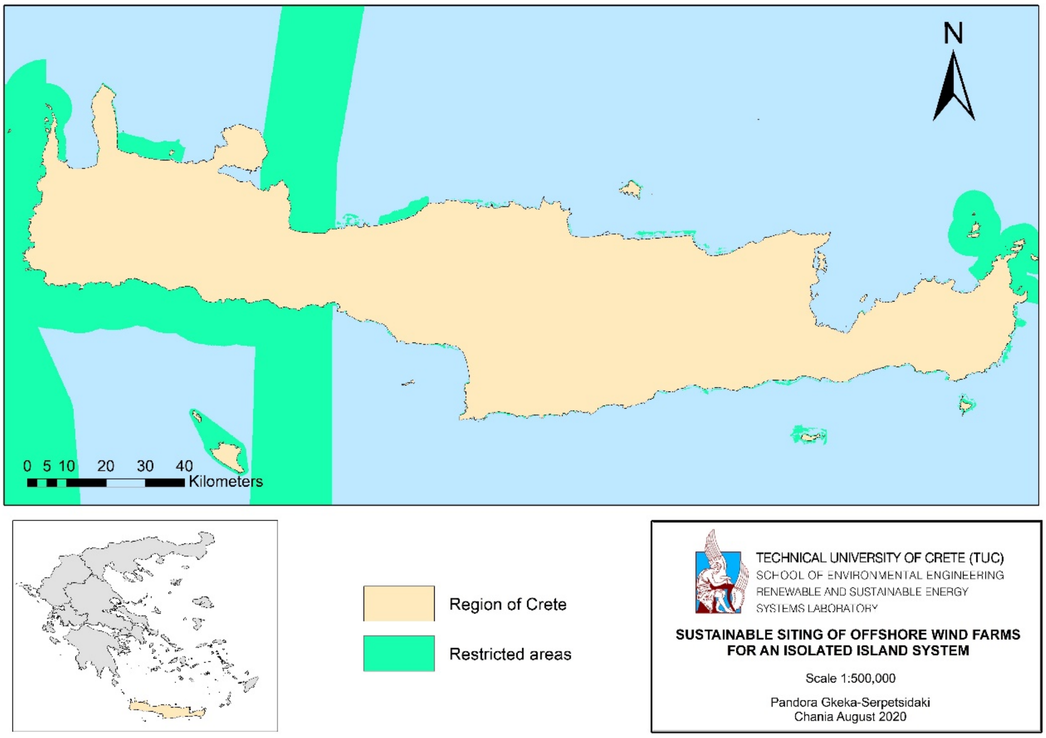

Fig. 4: Constraint of environmentally protected areas.

3.3 Distance from shoreline

This criterion constitutes mainly a legislative criterion and the restriction is that the territorial waters are up to 6miles from the shore. So, all the marine activities have to be taken place into these limits. Furthermore, according to (Hellenic Republic, 2008) the sites very close to the shore should be excluded for safety and aesthetic reasons, so a minimum distance from the shoreline was set to 1500m (e.g. bathing waters restriction). The excluded areas are in the following Fig. 5 with light green colour, whereas the suitable ones with purple colour.

3.4. Wind Velocity

The last essential criterion is the wind velocity and it is from economic and investment aspect, the most important to check for a region. For this reason, the minimum wind speed limit was set to 6 m/s and these areas were excluded from the survey. The green marine areas dispose a wind potential under 6 m/s, so they are excluded (Fig. 6).

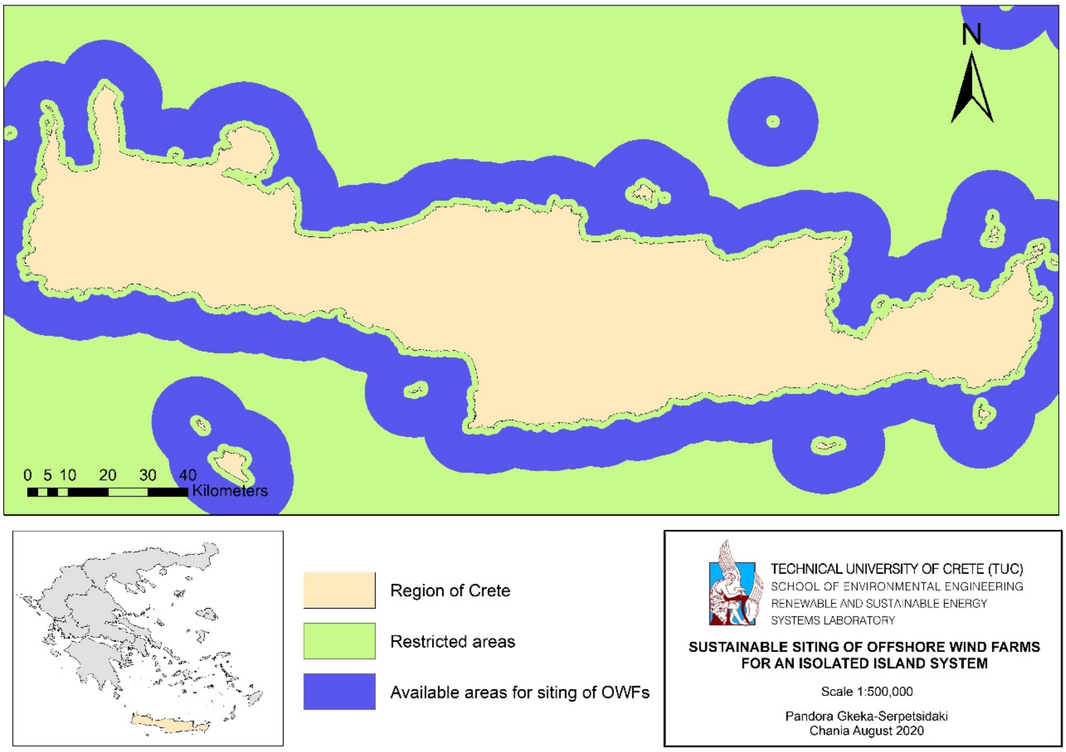

Fig. 5: Constraint of distance from shoreline.

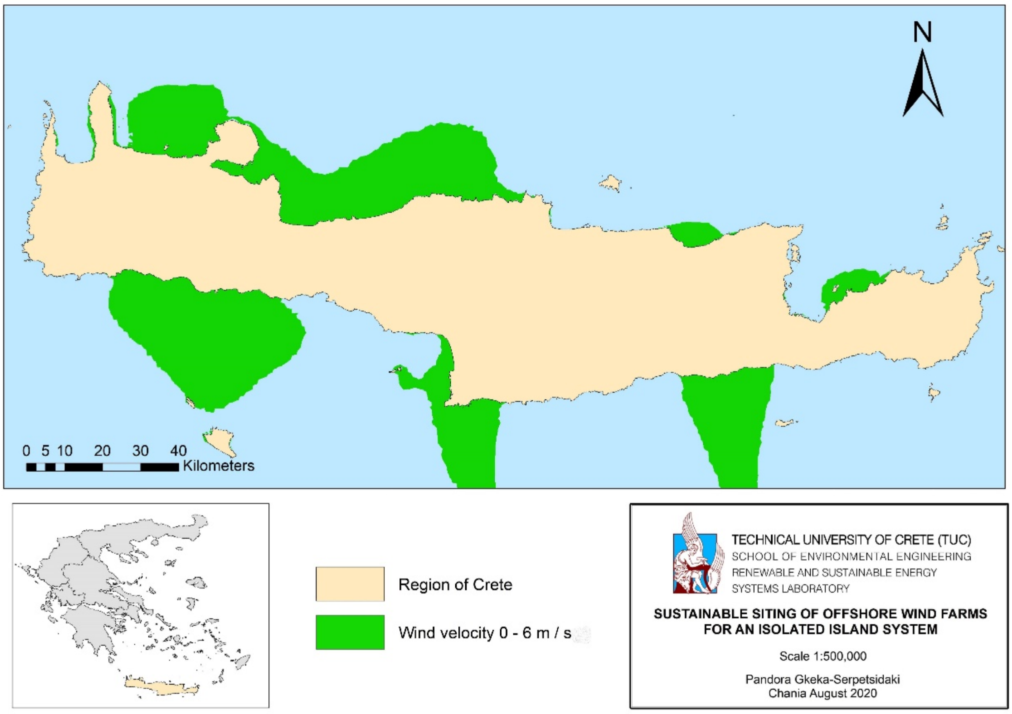

Fig. 6: Constraint of wind velocity.

In Table 1 are presented the digital data used in this work and the relevant source that they were taken from.

Table 1: Digital data used in this study and the source retrieved from.

Data	Source
1. Water Depth	(Hellenic Navy Hydrographic Service (HNHS), 2020)
2. Environmentally Protected Areas	(Hellenic Republic, 2008; Ministry of the Environment and Energy (Greece), 2010)
3. Distance from shoreline	(Hellenic Republic, 2008; Ministry of the Environment and Energy (Greece), 2010)
4. Wind Velocity	(Global Wind Atlas, 2020)

4. Results and Conclusions

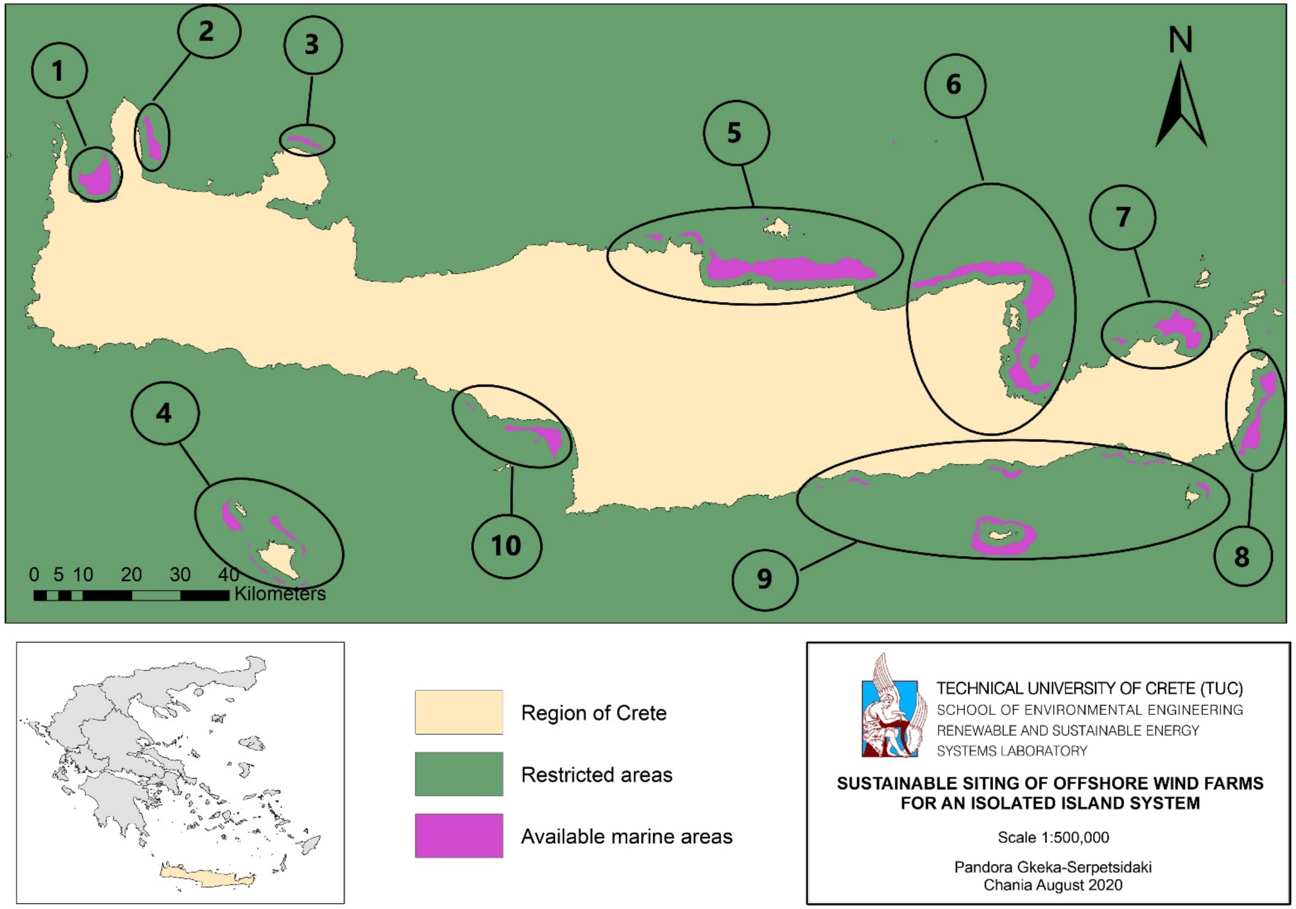

Fig. 7: Indicative results for siting of Offshore Wind Farms.

Table 2: Indicative locations for siting of Offshore Wind Farms and the relevant number of wind turbines fitted.

Indicative locations for Offshore Wind Farms siting	Area [km^2]	MHI Vestas Offshore V112 3.3 MW			MHI Vestas Offshore V164 8.0 MW			MHI Vestas Offshore V164 9.0 MW
		Rotor Diameter	No of Turbines	MW	Rotor Diameter	No of Turbines	MW	MW
LOCATION 1	30.67	112	49	161.7	164	23	184	207
LOCATION 2	14.58	112	23	75.9	164	11	88	99
LOCATION 3	6.07	112	9	29.7	164	4	32	36
LOCATION 4	21.95	112	35	115.5	164	16	128	144
LOCATION 5	132.52	112	215	709.5	164	100	800	900
LOCATION 6	113.92	112	185	610.5	164	86	688	774
LOCATION 7	34.83	112	56	184.8	164	26	208	234
LOCATION 8	33.53	112	54	178.2	164	25	200	225
LOCATION 9	58.39	112	94	310.2	164	44	352	396
LOCATION 10	23.23	112	37	122.1	164	17	136	153
Sum	469.68		757	2498.1		352	2816	3168

This work describes an analysis of 4-criteria exclusion. A more analytic and extensive work which used 14 exclusion criteria exclusion and 16 evaluation criteria is currently under full analysis.

After the imposition of the exclusion mentioned above criteria, the tool cell statistics from the toolbar spatial analyst, software (ArcGIS 10.5) were used in order to combine all the layers and resulting in the final map presented in Fig. 7.

The total area of suitable marine areas for installations of offshore wind turbines extends to 469.68 km^2 (Table 2). Furthermore, the number of wind turbines of the selected models. The available ten marine areas are analytically described in Table 2, as well as some commercial models of offshore wind turbines that could be fixed in (the number and the MW). The array of offshore wind turbines that adopted for exporting these results was 7 D, where D is the Rotor Diameter of the turbine (Nyserda, 2018). Subsequently, 3 commercial models of Vestas were indicatively selected so as to highlight the capacity of available marine areas for siting of an offshore wind farm, for the island of Crete (MHI Vestas Offshore Wind, 2020).

5. Acknowledgements

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