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Article

Site Selection of Hybrid Offshore Wind and Wave Energy Systems in Greece Incorporating Environmental Impact Assessment

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Abstract: This paper presents a methodological framework for evaluating marine areas in Greece for the purpose of identifying the most adequate sites for Hybrid Offshore Wind and Wave Energy Systems (HOWiWaES), with special focus on the HOWiWaES' environmental impact assessment evaluation. Nine evaluation criteria that reflect various environmental, economic, technical and socio-political aspects are considered, including Wind Velocity (WV), Wave Energy Potential (WEP), Water Depth (WD), Distance from Shore (DS), Connection to Local Electrical Grid (CLEG), Population Served (PS), Shipping Density (SD), Distance from Ports (DP) and Environmental Performance Value (EPV). Analytical Hierarchy Process (AHP) is performed to hierarchically rank twelve predefined siting alternatives. Questionnaires are used to collect information on pairwise comparisons of the evaluation criteria from a group of stakeholders/experts. Geographic Information Systems (GIS) are used as a metric tool for pairwise comparisons of each siting alternative with respect to the first eight evaluation criteria, while the last criterion is assessed through the development of an innovative environmental impact assessment tool. The results indicate that WV, WEP and EPV present the evaluation criteria with the highest relative significance, while PS, DP and SD correspond to less influencing criteria. The proposed methodology can be easily applied to other countries worldwide for supporting socially accepted siting of HOWiWaES.

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1. Introduction

Offshore renewable energy includes both offshore wind and ocean energy and presents a great potential for development. The European offshore wind energy sector has shown rapid development in recent years, and offshore installations grew 101% during 2017 compared to 2016 [1]. Up to now, most offshore wind farms operating in Europe have been installed in relatively shallow waters with average depths of 27.5 m and at an average distance from the shore of 41.0 km [2]. Moreover, the deployed support structures mainly correspond to fixed bottom configurations, i.e. monopile, gravity base, tripod and jacket [2]. However, the technology of floating offshore wind turbines is rapidly advancing during the last years aiming at giving access to more deep waters, where stronger winds exist. Therefore, various concepts of substructures for floating wind turbines have been and are still being developed, including the spar-buoy, the semi-submersible and the Tension Leg Platform

(TLP) concepts [3]. Moreover, in 2017 the first floating offshore wind farm (Hywind Scotland) started its operation [2]. On the other hand, wave energy technology presents one of the most advanced and rapidly developing ocean energy technologies, anticipated to be commercially available in the short-to-medium term [4] and, so far, different types of wave energy converters, in terms of energy absorption mechanism, have been designed and developed [5], such as oscillating water column devices (e.g. [6–8]), floating or submerged oscillating bodies (e.g. [9,10]), multi-module floating devices (e.g. [11,12]) and overtopping devices (e.g. [13–16]).

Although offshore renewable energy projects are considered environmentally friendly developments, there are some environmental impacts that should be taken into account and assessed during their life cycle. Consequently, the majority of offshore wind farm projects, as well as of all the marine renewable energy installations require Environmental Impact Assessment (EIA) to ascertain the effects of the above developments on various biological and physical processes and on the environment. Offshore wind farms affect negatively the marine environment through avian collisions [17,18], underwater noise [19–22] and electromagnetic fields [22–24]. However, there are also positive effects on local biodiversity as the offshore wind turbines can act as artificial reefs [24–26]. The extent and the nature of the effect is mainly dependent on the nature of the reef created, the location, and the characteristics of the native populations at the time of introducing the artificial reef [27]. A scientific review of the potential impacts of offshore wind farms on the marine environment identified key environmental issues related to offshore wind power development such as habitat impacts on fish, marine mammals, birds and benthos, and changes in hydrodynamic conditions and water quality [25]. Kaldelis et al. [28] summarized in their study the main environmental and social impacts (pre-construction and post-construction) associated with offshore wind energy developments and concluded that the marine environment is very distinct and that each project should be investigated separately, since the impacts vary greatly among different locations and are absolutely site specific.

The primary concern for wave energy applications is the risk of collisions below the sea surface [29]. Inger et al. [30] highlighted the potential impacts of wave farm installations, defining the negative impacts such as habitat loss/degradation, risk of collisions, production of underwater noise and production of electromagnetic fields. Woolf [31] states the urgency that the behavior of marine mammals, diving birds and fish in the vicinity of wave energy devices should be observed as a prerequisite for establishing any inherent risks. In addition, changes in water velocities can influence the sediment transport and might cause coastal erosion. Finally, large scale wave energy arrays lead to wave field changes (i.e. wave height attenuation in the leeward side of the farm), which may affect negatively coastal eco-systems and neighboring sea activities [32].

Recognizing the significance of minimizing potential negative environmental impacts in offshore renewable energy projects, several studies have included so far various environmental criteria into offshore wind farm siting applications (e.g. [33–36]). These criteria represent adequately specific environmental implications; however, they do not account for an explicit assessment of the potential environmental impacts of an offshore wind farm project during its whole life cycle based on an EIA study. Schillings et al. [33] included in their analysis nature conservation zones defined as the network of protected areas under the Birds Directive (Special Protection Areas (SPA)) and Habitat Directive (Special Areas of Conservation (SAC)). They provided a wildlife preservation map for the North Sea indicating the areas that are most significant in terms of nature values by applying a series of nature value/vulnerability maps for birds, fish and benthos. Vagiona and Karanikolas [34] excluded from their analysis of evaluating offshore wind farms in Greece, areas that are characterized as protected either by National or European legislation. Moreover, they used distance from protected areas as an evaluation criterion. Mekonnen and Gorsevski [35] ranked their decision alternatives for offshore wind farm suitability within Lake Erie using three environmental criteria: bird habitat, fish habitat and navigable waterways. Cristoforaki and Tsoutsos [36] excluded in their study on offshore wind farm siting in Chania (Greece), SPA, as well as marine areas with distance of less than 1.5 km from international importance wetlands, national forests, declared monuments of nature and aesthetic forests, as well as from Sites of Community Importance. On the other hand, the selection of a suitable site for wave energy projects adopts several environmental exclusive factors that amongst others include: SPA, SAC, sites included in the Emerald Network (Areas of Special Conservation Interest), International Wetland Conservation treaty Areas (Ramsar), habitats of endangered species, marine mammal breeding areas and migration routes and areas protected under regional and national planning and zoning directives [37]. Nobre et al. [38] identified the best location to deploy a wave energy farm for an area offshore the southwest Portuguese coast using marine protected areas as one of the several selection factors.

The option of simultaneously utilizing offshore wind and wave energy sources, through the deployment of Hybrid Offshore Wind and Wave Energy Systems (HOWiWaES), that combine in one structure an offshore wind turbine with wave energy converters, presents, nowadays, an important advantage in environmental terms, since it leads to: (i) a better exploitation of natural resources and (ii) reduced impacts compared to the impacts from independent installations [39]. However, the minimization of negative impacts of these applications on marine biodiversity and ecosystems is considered not only an essential precondition for environmental permission of such projects, but also a prerequisite for their social acceptance. In the framework of site selection for HOWiWaES, Cradden et al. [40] noted that some environmental issues may require additional monitoring during installation or operation of offshore renewable energy platforms, and this must be fully considered in site-selection. Moreover, in that study, the marine areas designated under Natura 2000 were excluded from potential site selection in the North European offshore areas, while the impact of excluding any development within 1 km from the Natura 2000 areas was additionally investigated. In a similar manner, Vasileiou et al. [41] used the Natura 2000 network in order to define marine protected areas in the Greek marine environment, which were excluded for the deployment of HOWiWaES.

Based on all the above, it is obvious that up to now many researchers have used several environmental criteria in offshore wind and wave energy siting applications for satisfying environmental constraints and accounting for environmental considerations in the relevant decision making process. There has been, however, no study so far incorporating directly the EIA of such projects into the site selection process in terms of using an explicit siting criterion that expresses in quantitatively terms the potential environmental impacts of these projects throughout their whole life cycle.

EIA is nowadays considered a modern tool of developed societies for the achievement of appropriate compromises between development and environment, aiming at the inclusion of environmental concerns in decision-making and ultimately at promoting a more sustainable development [42,43]. An EIA enables the assessment of the environmental impacts of a project occurring during the planning phase of its life cycle, and includes impact assessment, as well as mitigation and prevention measures throughout the whole project's life cycle. The EIA methodologies that have been developed and applied so far are numerous and include, among others, the Rapid Impact Assessment Matrix (RIAM) [44–49]. RIAM has been widely used by environmental impact assessment proponents and include, in its simplest form, a grid-like table, where the characteristics of the environment are presented in one axis and the activities of the project under review in the other. Interactions of the activities and the environment are indicated in the corresponding cells and the entries can indicate the type, the importance, the size, the nature, as well as other features of the impact. Pastakia and Jensen [46] developed in their study the RIAM in an effort to incorporate subjective judgments into the EIA process. RIAM includes four environmental components (Physical/Chemical (PC), Biological/Ecological (BE), Sociological/ Cultural (SC) and Economic/Operational (EO)) and five impact assessment criteria (importance of condition, magnitude of change/effect, permanence, reversibility and cumulative). RIAM was partially modified by Ijäs et al. [50] adding a sixth impact evaluation criterion (susceptibility of the target environment) to the evaluation framework. Vagiona [51] created an EIA tool inspired by RIAM that includes five impact evaluation criteria and eighteen environmental components, and attributes an Environmental Performance Value (EPV) to every project.

Motivated by the significant advantages of integrating the EIA aspect within the site selection process of an offshore renewable energy project, in terms of adequately assessing environmental impacts throughout the whole project's life cycle and, therefore, supporting social acceptance, this paper presents a methodological framework for evaluating marine areas in Greece towards the identification of the most adequate sites for HOWiWaES, with special focus on the HOWiWaES' environmental impact assessment evaluation. The present paper advances the site selection decision making process in the case of offshore renewable energy projects and fills relevant existing research gaps by introducing, for the first time, EPV as an evaluation criterion. Analytical Hierarchy Process (AHP) is performed to hierarchically rank 12 predefined siting alternatives, which are fully harmonized with utilization restrictions, economic, technical and social constraints. AHP is applied considering eight evaluation criteria related to economic, technical and socio-political factors, additionally to EPV. The pairwise comparisons of the evaluation criteria are obtained from a group of stakeholders/experts through a questionnaire survey. A Geographic Information Systems (GIS) database is used as a metric tool for determining the relative weights of each siting alternative with respect to all evaluation criteria, except of the EPV, which is calculated through the deployment of an innovative EIA tool developed in the present paper. The rest of the paper is organized in three parts. First, a thorough description of EPV is given, and the environmental components, as well as the features of impacts considered in this research, are presented and described. The second part addresses the methodological framework followed for selecting the most adequate site for HOWiWaES in Greece, incorporating EIA. The third part is concerned with the results of the application. The procedure adopted for selecting the most adequate site for HOWiWaES in Greece is described in detail, so that it can be easily repeated and applied on any study area and at any spatial scale.

2. Calculation of EPV

EPV is introduced as an evaluation criterion to assess the environmental performance of a HOWiWaES' project at each examined site. Its calculation is based on an integrated and uniform methodology for attributing environmental performance values in projects initiated by [51]. In this paper, an innovative and modified, compared to [51], tool that evaluates the impact significance through the whole project's life cycle (construction, operational and decommissioning phase) is proposed and implemented. More specifically, EPV is determined through the implementation of the following four successive steps: (i) Definition of key environmental components (Step 1), (ii) Weight of importance attribute to each environmental component for two different time conditions (existing and potential) (Step 2), (iii) Evaluation of the impact significance of the project in its main life cycle phases (construction, operation and decommissioning) (Step 3) and (iv) Calculation of EPV (Step 4).

In Step 1, all aspects of the abiotic, natural and anthropogenic environment that might be affected by a proposed project or activity should be defined. In the present research, eighteen environmental components are totally considered, defined as follows: climate, bioclimate, morphology, aesthetics-visional features, geology, tectonics, soils, natural environment, land uses, built environment, historical and cultural environment, socio-economic environment, infrastructures, atmospheric environment, acoustic environment-noise, vibrations, electromagnetic fields, surface waters and groundwater. All the above components cover all aspects of the natural and anthropogenic environment that should be considered in an EIA study.

In Step 2, all eighteen environmental components are qualitatively evaluated, using a five-point scale (1: non-important, 2: slightly important, 3: moderately important, 4: very important, 5: extremely important) and those that are the most urgent and critical for ensuring sustainability of the area are identified. The evaluation is performed twice; once for the existing conditions and once for the future conditions, by attributing a qualitative weight, w_{kj}, $k = 1$ (existing conditions), $k = 2$ (future conditions), $j = 1, \ldots, 18$, to each j-th environmental component. Existing conditions refer to the present/existing state of the environment of the study area, while future conditions pertain to the state of the environment that will be formed due to other scheduled projects and activities, without considering the effects of the proposed project. The latter time conditions ensure that the potential dynamic changes performed in the environment are considered.

For implementing Step 3, specific environmental impact assessment criteria are taken into account, which are distinguished into: (i) Primary Criteria (PC) that include nature of impact (PC1) and magnitude of impact (PC2), and (ii) Secondary Criteria (SC) that include permanence of impact (SC1), reversibility of impact (SC2) and confrontability of impact (SC3). The scaling of these environmental impact assessment criteria is presented in Figure 1. Based on the scaling of this figure and inspired by the environmental score provided by [46], the impact significance of the project, a_{kij}, $k = 1, 2$, $i = 1, \ldots, 3$, $j = 1, \ldots, 18$, is calculated using the following equation:

$$a_{kij} = (\mathrm{PC1}_{kij}) \times (\mathrm{PC2}_{kij}) \times \{(\mathrm{SC1}_{kij}) + (\mathrm{SC2}_{kij}) + (\mathrm{SC3}_{kij})\} \tag{1}$$

where, $k = 1, 2$ denote existing and future conditions respectively, as described in Step 2, $i = 1, \ldots, 3$, corresponds to the three basic phases of a project's life cycle, namely, construction phase ($i = 1$), operational phase ($i = 2$) and decommissioning phase ($i = 3$), while $j = 1, \ldots, 18$, denotes the jth environmental component, as described in Step 1. Based on [46], it is noted that in Equation (1) the values of PC are multiplied in order to ensure that different nature and different magnitude of impact will always lead to different results. On the other hand, the values of SC are summed up to a single number, so that the combined importance of all individual SC can be taken into account. From a physical point of view, positive and negative a_{kij} values denote that the proposed project at the k-th time conditions and during its i-th phase has a positive and a negative respectively impact on the j-th environmental component, while zero values of a_{kij} denote neutral effect (nor negative nor positive impacts) of the project on this component. Larger positive a_{kij} values correspond to more significant positive impacts, while the existence of larger absolute a_{kij} values in the negative range denotes more significant negative impacts.

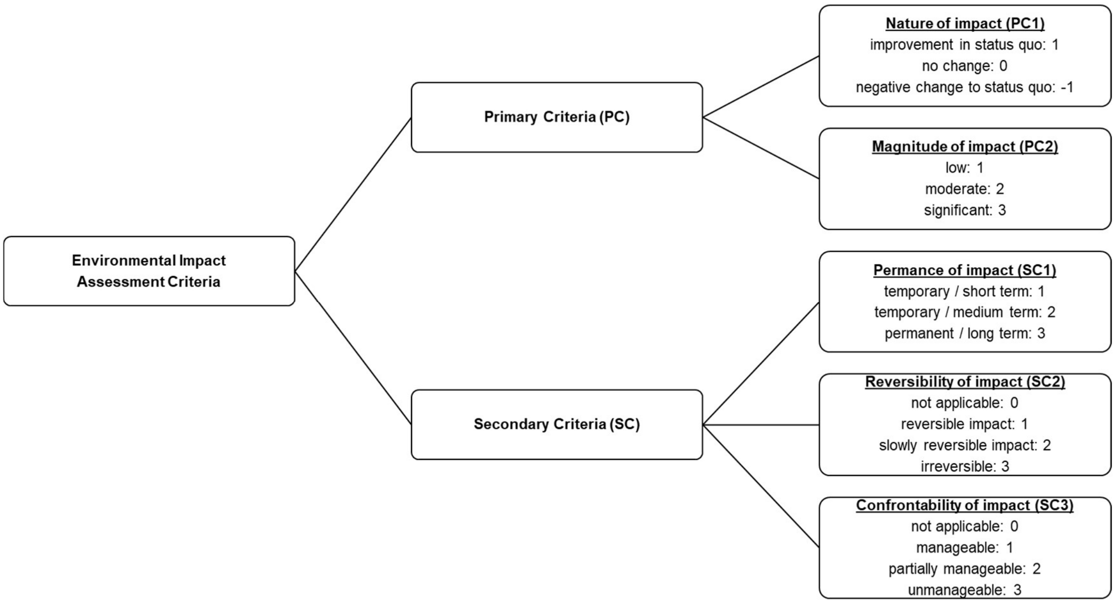

Figure 1. Environmental Impact Assessment (EIA) criteria and their scaling.

Finally, in Step 4, EPV of the examined project is derived using the weighted sum model. Six different alternatives are considered during the life time of the project, by combining the existing and the future conditions of the key environmental components (Step 2) with the impact significance for the construction, the operational and the decommissioning phase of the project (Step 3). The total score, A_{kij}, of each j-th, $j = 1, \ldots, 18$, environmental component for given time conditions ($k = 1$ or $k = 2$) and for each i-th, $i = 1, \ldots, 3$, relevant alternative, corresponding to the construction phase ($i = 1$), the operational phase ($i = 2$) and the decommissioning phase ($i = 3$) of the project at these time conditions, is calculated as follows:

$$A_{kij} = \frac{a_{kij} w_{kj}}{\sum\limits_{j=1}^{18} w_{kj}} \tag{2}$$

In Equation (2), w_{kj}, $k = 1, 2$, $j = 1, \ldots, 18$, is the qualitative weight of the j-th environmental component in the existing ($k = 1$) and future ($k = 2$) conditions, as defined in Step 2, and a_{kij}, $k = 1, 2$, $i = 1, \ldots, 3$, $j = 1, \ldots, 18$, is the impact significance as obtained from Equation (1). From a physical point of view, Equation 2 expresses quantitatively the relevant impact significance of the project on a j-th environmental component compared to the rest seventeen components at given k-th time conditions and for a specific i-th phase of the project. The EPV is, finally, derived by the aggregation (sum) of all the environmental components' scores for all the six different alternatives described above.

Based on these alternatives and using the scaling of the EIA criteria (Figure 1), EPV ranges from 54 (extremely positive impacts) to −162 (extremely negative impacts), as shown in Table 1.

Table 1. Relation of Environmental Performance Value (EPV) to impact range bands.

Impact Range Bands	Description	EPV
Extremely positive impacts	positive, significant, long term impacts	54
Significant positive impacts	positive, significant, medium term impacts	36
Moderate positive impacts	positive, moderate, medium term impacts	24
Positive impacts	positive, low, long term impacts	18
Slight positive impacts	positive, low, short term impacts	6
No change-status quo	no impacts	0
Slight negative impacts	negative, low, short term, reversible, manageable impacts	−18
Negative impacts	negative, low, long term, reversible, manageable impacts	−30
Moderate negative impacts	negative, moderate, long term, reversible, manageable impacts	−60
Significant negative impacts	negative, moderate, long term, irreversible, unmanageable impacts	−108
Extremely negative impacts	negative, significant, long term, irreversible, unmanageable impacts	−162

3. Methodology

3.1. Study Area

The study area is defined by the coastline and the other geographical boundaries of the Greek marine area (Figure 2a) and includes 12 eligible siting alternatives of HOWiWaES that are derived as a result of the application of exclusion siting criteria in [41]. The above mentioned exclusion criteria refer to [41]: (i) utilization restrictions (Military Exercise Areas (MEA), Areas to be licensed for Exploration and Exploitation of Hydrocarbons (AEEH), Areas where Offshore Renewable Energy Projects (AOREP) are planned to be or have been installed, Marine Protected Areas (MPA)), (ii) economic and technical constraints (Wind Velocity (WV) < 6 m/sec, Wave Energy Potential (WED) < 5 kW/m, Water Depth (WD) > 500 m) and (iii) social implications (Distance from Shore (DS) < 25 km). The proposed decision alternatives fulfill all the above exclusion criteria and are depicted in Figure 2b.

The twelve eligible marine areas, covering a total area of 2536.29 km^2, are grouped into three categories according to the corresponding values of WV, WEP and WD (Table 2).

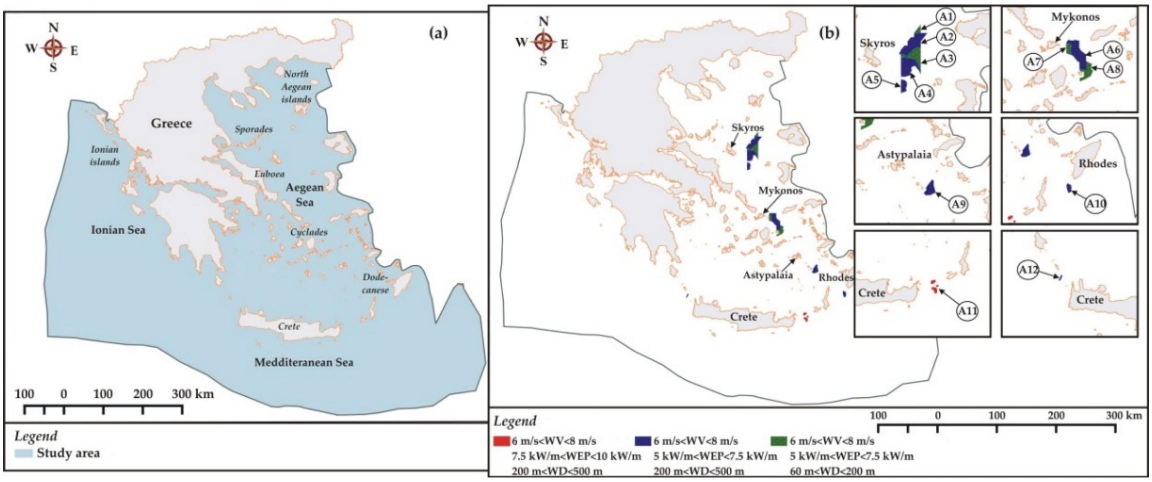

Figure 2. (**a**) Study area; (**b**) Eligible marine areas for Hybrid Offshore Wind and Wave Energy Systems (HOWiWaES) siting in Greece [41].

Table 2. Characteristics of eligible siting alternatives for the deployment of Hybrid Offshore Wind and Wave Energy Systems (HOWiWaES) in Greece.

Category	WV (m/sec)	WEP (kW/m)	WD (m)	Siting Alternative ID	Area (km^2)	Location
Category 1	6–8	7.5–10	200–500	A11	81.32	East (E) of Crete
Category 2	6–8	5–7.5	200–500	A2	467.33	East-North-East (ENE) of Skyros
				A4	427.7	South-East (SE) of Skyros
				A5	113.19	South-South-East (SSE) of Skyros
				A6	516.86	East-South-East (ESE) of Mykonos
				A9	192.32	South-East (SE) of Astypalaia
				A10	86.56	South-West (SW) of Rhodes
				A12	21.12	North-West (NW) of Crete
Category 3	6–8	5–7.5	60–200	A1	45.77	North-East (NE) of Skyros
				A3	283.27	East (E) of Skyros
				A7	88.37	East (E) of Mykonos
				A8	212.48	South-East (SE) of Mykonos

3.2. HOWiWaES Concept for Deployment

The evaluation of the various siting alternatives incorporating EIA requires the selection of a specific HOWiWaES concept, which could be potentially deployed for the realization of the relevant offshore renewable energy project. For this purpose, in the present paper the Semi-submersible Flap Combination (SFC) concept consisting of a semi-submersible floating 5 MW offshore wind turbine with three flap-type wave energy converters is selected [52,53]. The existence of water depths larger than 200 m at the majority of eligible offshore areas (A2, A4, A5, A6, A9, A10, A11, A12) has primarily triggered the selection of this specific floating concept. Moreover, considering that nowadays HOWiWaES presents a new, currently developing technology, the SFC concept is selected since: (i) its specific technical and functional characteristics are available in the literature and (ii) its effective performance (in terms of dynamic behavior, structural integrity and power production) under normal and extreme environmental conditions compared to other HOWiWaES concepts has been numerically and experimentally verified and proved in the framework of the EU Project Marina Platform.

3.3. Methodological Framework for Identifing the Most Adeqaute Site

The identification of the most adequate site for HOWiWaES in Greece, as well as the preference order of eligible sites, are performed through AHP (Figure 3). AHP presents one of the most popular multi-criteria analysis methods on sustainable energy planning, since it is characterized by simplicity, flexibility and ability to consider in a common framework both quantitative and qualitative criteria [54,55].

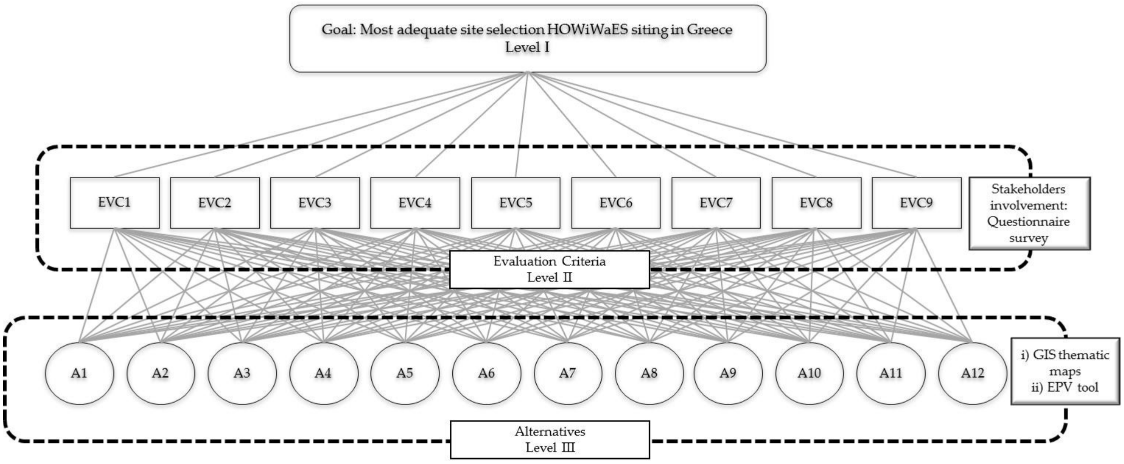

Figure 3. Levels of Hierarchy for selecting the most adequate site for HOWiWaES.

The decision modeling in this paper consists of building a hierarchy to analyze the decision. The first level of the hierarchy includes the goal of the study (Level I), the second level (Level II) presents the evaluation criteria, while the third level (Level III) defines the ranking of the decision alternatives based on the evaluation criteria defined in Level II.

In the present investigation a total of nine evaluation criteria are used, including: EVC1: Wind Velocity (WV), EVC2: Wave Energy Potential (WEP), EVC3: Water Depth (WD), EVC4: Distance from Shore (DS), EVC5: Connection to Local Electrical Grid (CLEG), EVC6: Population Served (PS), EVC7: Shipping Density (SD), EVC8: Distance from Ports (DP) and EVC9: Environmental Performance Value (EPV). These criteria are related to economic, technical, socio-political and environmental factors that have an impact on the decision for the implementation or not of a HOWiWaES project. The evaluation criteria (Table 3) used in the present paper have been defined based on a detailed literature review, data availability and the main features of the examined Greek marine environment that can significantly affect the decision to implement a HOWiWaES project.

Table 3. Evaluation criteria for HOWiWaES siting in Greece.

Evaluation Criteria	Description
EVC1: Wind Velocity (WV)	Mean WV (10 m above the mean water level) exceeding 6 m/s is considered. Larger WV corresponds to higher preference.
EVC2: Wave Energy Potential (WEP)	WEP exceeding 5 KW/m is considered. Larger WEP corresponds to higher preference.
EVC3: Water Depth (WD)	WD ranges between 0 m and 500 m are considered. Smaller WD corresponds to higher preference.
EVC4: Distance from Shore (DS)	DS ranges between 25 m and 200m are considered. Smaller DS corresponds to higher preference.
EVC5: Connection to Local Electrical Grid (CLEG)	The proximity to a local electrical grid with high voltage capacity is assessed. Closer proximity corresponds to higher preference.
EVC6: Population Served (PS)	The PS in terms of covering energy demands at a mean distance smaller than 100 km from the centroid of an eligible marine area (where one or more ports exist) is considered. Larger PS corresponds to higher preference.
EVC7: Shipping Density (SD)	Qualitative assessment based on the existence of navigation routes and traffic volume (low, moderate, high). Lower SD corresponds to higher preference.
EVC8: Distance from Ports (DP)	DP ranges from 50 m to 100 m. Smaller DP corresponds to higher preference.
EVC9: Environmental Performance Value (EPV)	EPV defines the HOWiWaES impacts on natural and anthropogenic environment during construction, operational and decommissioning phase. Larger EPV corresponds to higher preference.

3.4. Tools and Techniques Used in the AHP

To achieve the identification of the most adequate site for HOWiWaES in Greece, the AHP, a widely applied multi-criteria decision making method, is used. Priority vectors (relative weights/priorities) in each level of hierarchy are derived from pairwise comparisons, which are implemented by using a numerical nine-point scale developed by [56,57]. The input for the pairwise comparisons is obtained either from subjective opinion such as preference (Level II) or from actual measurements (Level III).

In the present paper, the relative weights of the evaluation criteria with respect to the goal (Level II) are retrieved based on a questionnaire survey conducted on relevant stakeholders, as well as experts in the field of renewable energy sources management, during December 2016 and January 2017. For this purpose, more than 100 questionnaires were sent by e-mail to relevant authorities. The questionnaire consisted of four parts. The first part included a brief description of the applied methodology for the identification of the most adequate site for HOWiWaES in Greece, the second part described the evaluation criteria, while the third part explained the fundamental nine-point scale measurement utilized for assessing the advantage of one criterion over the others on a single scale. In the fourth part, the pairwise comparison matrix that had to be completed was provided. Some example questions of the questionnaire are as follows: (i) Please note how many years you have been working in the energy sector; (ii) Please define your specific expertise with Renewable Energy Resources; (iii) Using a numerical nine-point scale (1 = equally dominant to 9 = extremely more dominant), please provide the pairwise comparisons for the nine evaluation criteria (EVC1-EVC9). The experts were identified from public authorities related to energy management (e.g. Department of Administration Energy Development Licenses and Natural Resources), industry experts and private companies in the energy sector, as well as from Research Institutes and Universities.

On the other hand, in the third level of hierarchy the relative weights of the decision alternatives with respect to the first eight evaluation criteria (EVC1–EVC8, Table 3) are retrieved based on measurements performed in the GIS environment. GIS is defined "as a system of hardware, software, and procedures to facilitate the acquisition, management, manipulation, analysis, modeling, representation, and output of spatially referenced data to solve complex planning and management problems" [58–60]. Therefore, GIS enables the evaluation of the decision alternatives with respect to ECV1–EVC8 in a spatially accurate, systematic and robust manner, eliminating efficiently subjectivity in the relevant judgments. The GIS database was developed using the open source software package Quantum GIS (QGIS). Finally, the last evaluation criterion (EVC9, Table 3) is assessed through the calculation of EPV described in Section 2.

4. Results and Discussion

4.1. Priority Vector of Evaluation Criteria

As mentioned in Section 3.4, for deriving the priority vector (relative weights) of the evaluation criteria with respect to the desired goal, the required pairwise comparison of these criteria was implemented by relevant experts through a questionnaire survey.

A total of 17 experts (approximately equal to 20% of the total sample) participated finally in this survey, by appropriately filling the comparison matrices of the evaluation criteria. Based on these matrices, the relative weights of the evaluation criteria with respect to the goal were calculated. These weights are shown in Figure 4. It can be seen that WV and WEP are the top two choices among the examined evaluation criteria, followed by EPV.

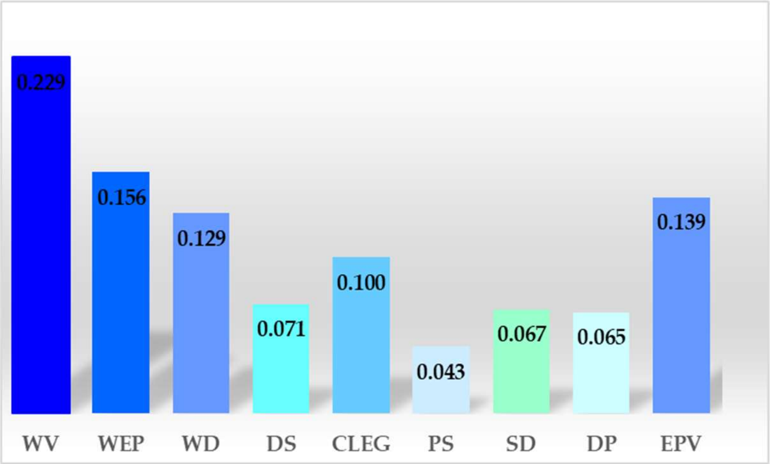

Figure 4. Relative weights of evaluation criteria with respect to the goal (Level II).

4.2. Relative Weights of Siting Alternatives

The relative weights of the alternatives with respect to each criterion separately are derived through the pairwise comparison of all the alternatives, with respect to each evaluation criterion. As the present model includes twelve siting alternatives, eleven comparisons are required for each evaluation criterion. The relative weights of the decision alternatives with respect to the first eight evaluation criteria (EVC1–EVC8) are shown in Table 4 [41].

The relative weights of the decision alternatives with respect to the last evaluation criterion (EVC9) are derived considering the corresponding EPVs. In order to achieve an efficient EIA, it deemed necessary to consider not only the energy conversion devices themselves, but also additional required activity, notably subsea cables and electrical sub-station and boat operations [31]. Activity at all phases of the project's life cycle (construction, operational and decommissioning phase) should be considered. Table 5 summarizes the impacts of a HOWiWaES project on natural and anthropogenic environment, while Table 6 shows the 12 × 12 pairwise comparison matrix of the twelve siting alternatives of HOWiWaES with respect to EVC9. It is noted that in Table 5, the symbols "X" and "-" denote respectively existence and non-existence of impact.

Table 4. Relative weights of decision alternatives A1–A12 with respect to EVC1–EVC8.

Decision Alternative	EVC1	EVC2	EVC3	EVC4	EVC5	EVC6	EVC7	EVC8
A1	0.063	0.071	0.150	0.026	0.035	0.018	0.104	0.014
A2	0.063	0.071	0.050	0.041	0.035	0.021	0.022	0.029
A3	0.063	0.071	0.150	0.030	0.035	0.012	0.022	0.016
A4	0.063	0.071	0.050	0.065	0.035	0.012	0.022	0.018
A5	0.063	0.071	0.050	0.034	0.035	0.045	0.022	0.029
A6	0.188	0.071	0.050	0.113	0.092	0.077	0.104	0.164
A7	0.063	0.071	0.150	0.127	0.092	0.120	0.104	0.188
A8	0.063	0.071	0.150	0.144	0.092	0.083	0.104	0.248
A9	0.063	0.071	0.050	0.024	0.044	0.041	0.240	0.120
A10	0.063	0.071	0.050	0.139	0.092	0.198	0.047	0.045
A11	0.188	0.214	0.050	0.133	0.219	0.071	0.104	0.055
A12	0.063	0.071	0.050	0.124	0.194	0.301	0.104	0.072

Siting alternatives A1 and A5 present the highest EPV, as they impose slight negative impacts, mainly due to their restricted area, acoustic environment, vibrations and electromagnetic fields (during operational phase), as well as surface waters and groundwater (throughout the whole project's life cycle). In addition, they are located far away from the shoreline, avoiding any serious impact on visual features. The impacts of the deployment of HOWiWaES in these areas on the natural environment are considered moderate in all the three phases of the project's life cycle.

Table 5. Main environmental impacts associated with HOWiWaES developments.

Environmental Components		Construction Phase	Operational Phase	Decommissioning	Potential Impacts
Climate		-	-	-	-
Bioclimate		-	-	-	-
Morphology		-	-	-	-
Aesthetics-visional features		X	X	-	Disruption from tall structures (near shore wind farms)
Geology		-	-	-	-
Tectonics		-	-	-	-
Soils		-	-	-	-
Natural environ-ment	Seabirds	X	X	-	Disturbance and emigration, collision fatalities
	Fish/ marine mammals	X	X	X	Displacement or loss of habitat due to noise, electromagnetic emissions and vibrations
Land uses		-	-	-	-
Built environment		-	-	-	-
Historical and cultural environment		-	-	-	-
Socio-economic environment		X	X	X	Minor restriction of shipping routes, minor impacts on tourism activities
Infrastructures		-	-	-	-
Atmospheric environment		X	X	X	Low air pollutant emissions (construction, maintenance, disposal)
Acoustic environment-noise		-	X	-	Increased underwater sound levels
Vibrations		-	X	-	Increased vibrations
Electromagnetic fields		-	X	-	Emission of electromagnetic fields
Surface waters and groundwater		X	X	X	alteration of flows, Pollution from increased vessel traffic, sediment redistribution

Table 6. Pairwise comparison matrix and relative weights of siting alternatives (A1–A12) with respect to EVC9 (EPV).

Decision Alternative	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Relative Weights
A1	1	6	4	7	1	9	3	6	4	3	3	3	0.207
A2	1/6	1	1/3	2	1/6	4	1/4	1	1/3	1/4	1/4	1/4	0.029
A3	1/4	3	1	4	1/4	6	1/2	3	1	1/2	1/2	1/2	0.060
A4	1/7	1/2	1/4	1	1/7	3	1/5	1/2	1/4	1/5	1/5	1/5	0.021
A5	1	6	4	7	1	9	3	6	4	3	3	3	0.207
A6	1/9	1/4	1/6	1/3	1/9	1	1/7	1/4	1/6	1/7	1/7	1/7	0.013
A7	1/3	4	2	5	1/3	7	1	4	2	1	1	1	0.093
A8	1/6	1	1/3	2	1/6	4	1/4	1	1/3	1/4	1/4	1/4	0.029
A9	1/4	3	1	4	1/4	6	1/2	3	1	1/2	1/2	1/2	0.060
A10	1/3	4	2	5	1/3	7	1	4	2	1	1	1	0.093
A11	1/3	4	2	5	1/3	7	1	4	2	1	1	1	0.093
A12	1/3	4	2	5	1/3	7	1	4	2	1	1	1	0.093

The siting alternative A6 comes last in the hierarchy ranking of EPV as the deployment of HOWiWaES in East-South-East of Mykonos might cause negative effects on: (i) visional features (construction and operational phase), (ii) acoustic environment, vibrations and radiation (operational phase), (iii) natural and socio-economic environment (construction, operational and decommissioning phase) and (iv) surface waters and groundwater (construction, operational and decommissioning phase). Siting alternatives A7, A10, A11 and A12 occupy the second position in the hierarchy, presenting the same EPV.

4.3. Hierarchy Ranking of Siting Alternatives

Considering the evaluation of alternatives A1–A12 with respect to the EVC1–EVC9 evaluation criteria, coupled with the involvement of the selection criteria as derived from the questionnaire survey, all alternatives are evaluated as shown in Figure 5. This figure illustrates the importance (percentage %) of the various alternatives in satisfying the primary goal (most adequate HOWiWaES siting) and forms the basis for the prioritization of the candidate sites.

The siting alternative A11 (East of Crete) presents the highest score (14.1%) and it is, therefore, considered as the most adequate HOWiWaES site in the Greek marine environment, followed by alternatives A7 (East of Mykonos) and A12 (North-West of Crete) (preference percentage equal to 10.1%). The last position in the hierarchy (4.6%) is covered by the siting alternative A4 (South-East of Skyros).

The candidate area A11 presents the top choice for the deployment of HOWiWaES in the Greek marine environment, as it is characterized by: (i) the highest values of wind velocity (7–8 m/s), (ii) the highest values of wave energy potential (7.5–10 kW/m), (iii) the smallest proximity to local grids of high voltage capacity, (iv) moderate EPV equal to −16 and (v) short proximity to the shore.

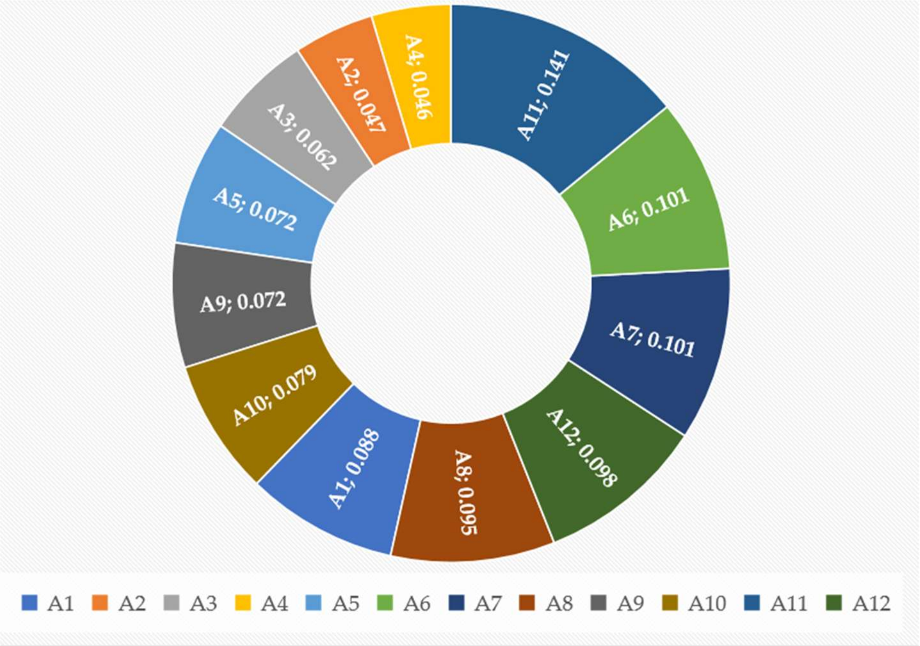

Figure 5. Final ranking of the siting alternatives for HOWiWaES in Greece.

Finally, it is worth to note that a sensitivity analysis on the AHP weights was carried out in order to show the impact of varying criteria weights to the final outcome. Four different scenarios were examined: (i) equal criteria weights (scenario 1), (ii) policy scenario focusing on economic/technical criteria (scenario 2), (iii) policy scenario focusing on socio-political criteria (scenario 3) and (iv) policy scenario focusing on environmental criteria (scenario 4). The results (not included here due to space constraints) revealed that under different policy scenarios, decision alternative A11 presents the most adequate area for the siting of HOWiWaES in the Greek marine environment, while decision alternative A4 the least adequate.

5. Conclusions

Considering the growing demand for energy and the shift to renewables worldwide, sustainable selection of energy investment projects is gaining increasing interest and importance at all policy levels. The overall aim of this study is to identify the most adequate locations for HOWiWaES developments within a study area (Greece) with emphasis on environmental considerations. The renewable energy site selection problem should involve different stakeholders (policy makers, proponents, regulation authority, investors and society) who can state different preferences and priorities relating to the various evaluation criteria. For this reason, relevant stakeholders and experts in the field of renewable energy sources management were involved in the decision making process. Using the pairwise comparisons of evaluation criteria provided by the experts, it has been possible to identify the appropriate and most suitable locations to host these types of infrastructures.

The integration of analytical tools such as GIS and multi-criteria decision analysis contributes to the effective solution of this multidimensional site selection procedure. Considering a set of evaluation criteria related to economic, technical and socio-political factors, and calculating the environmental performance value at an initial stage of planning, the viability of the proposed and applied methodological process was ensured. The selected evaluation criteria apply strict limitations aiming at the cost-effectiveness of HOWiWaES, the maximization of security, as well as the minimization of environmental impacts and local community reactions.

In this study, wind velocity, wave energy potential and environmental performance value presented the three evaluation criteria with the highest relative significance. The hierarchy problem was induced to 12 pre-defined eligible offshore areas for the siting of HOWiWaES in Greece. The marine area, located East of Crete, presents the most adequate area for the siting of HOWiWaES, mainly due to the simultaneous existence of the largest wind and wave energy potential, as well as its low environmental performance value. The high position in the hierarchy of the marine areas located East of Mykonos and North-West of Crete is attributed to important economic factors such as water depth (adequately satisfied in the second option) and proximity to a local electrical grid with high voltage capacity (adequately satisfied in the third option), as well as to slight environmental effects (adequately satisfied in both options).

As stated above, this paper aims to provide an insight for the site selection problem of renewable energy investments of HOWiWaES in Greece. Extending the above process to other areas worldwide and increasing the number of renewable technologies to be implemented could be included in possible future work. It would also be interesting to combine GIS techniques with other multi-criteria decision methods. The proposed approach can address different stakeholders, while it has a flexible design for considering the evaluation criteria and it is applicable to any candidate area for HOWiWaES deployment.

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References

1. Pineda, I.; Tardieu, P. (Eds.) Wind in Power 2017. Annual Combined Onshore and Offshore Wind Energy Statistics. 2018. Available online: https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf (accessed on 28 June 2018).
2. Pineda, I. (Ed.) Offshore Wind in Europe—Key Trends and Statistics 2017. 2018. Available online: https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2017.pdf (accessed on 24 July 2018).
3. Atcheson, M.; Garrad, A. Looking back. In *Floating Offshore Wind Energy: The Next Generation of Wind Energy*, 1st ed.; Cruz, J., Atcheson, M., Eds.; Springer International Publishing: Basel, Switzerland, 2016; pp. 1–2, ISBN 978-3-319-29396-7.
4. Magagna, D.; Uihlein, A. Ocean energy development in Europe: Current status and future perspectives. *Int. J. Mar. Energy* **2015**, *11*, 84–104. [CrossRef]

5. Antonio, F.D.O. Wave energy utilization: A review of the technologies. *Renew. Sustain. Energy Rev.* **2010**, *14*, 899–918. [CrossRef]
6. Malara, G.; Arena, F. Analytical modelling of an U-oscillating water column and performance in random waves. *Renew. Energy* **2013**, *60*, 116–126. [CrossRef]
7. Elhanafi, A.; Macfarlane, G.; Fleming, A.; Leong, Z. Experimental and numerical investigations on the hydrodynamic performance of a floating–moored oscillating water column wave energy converter. *Appl. Energy* **2017**, *205*, 369–390. [CrossRef]
8. Elhanafi, A.; Macfarlane, G.; Fleming, A.; Leong, Z. Experimental and numerical measurements of wave forces on a 3D offshore stationary OWC wave energy converter. *Ocean Eng.* **2017**, *144*, 98–117. [CrossRef]
9. Zhang, X.; Yang, J. Power capture performance of an oscillating-body WEC with nonlinear snap through PTO systems in irregular waves. *Appl. Ocean Res.* **2015**, *52*, 261–273. [CrossRef]
10. Sergiienko, N.Y.; Rafiee, A.; Cazzolato, B.S.; Ding, B.; Arjomandi, M. Feasibility study of the three-tether axisymmetric wave energy converter. *Ocean Eng.* **2018**, *150*, 221–233. [CrossRef]
11. Michailides, C. Power production of the novel WLC wave energy converter in deep and intermediate water depths. *Recent Patents Eng.* **2015**, *9*, 42–51. [CrossRef]
12. Zhang, X.; Lu, D.; Guo, F.; Gao, Y.; Sun, Y. The maximum wave energy conversion by two interconnected floaters: Effects of structural flexibility. *Appl. Ocean Res.* **2018**, *71*, 34–47. [CrossRef]
13. Buccino, M.; Vicinanza, D.; Salerno, D.; Banfi, D.; Calabrese, M. Nature and magnitude of wave loadings at Seawave Slot-cone Generators. *Ocean Eng.* **2015**, *95*, 34–58. [CrossRef]
14. Contestabile, P.; Iuppa, C.; Di Lauro, E.; Cavallaro, L.; Andersen, T.L.; Vicinanza, D. Wave loadings acting on innovative rubble mound breakwater for overtopping wave energy conversion. *Coast. Eng.* **2017**, *122*, 60–74. [CrossRef]
15. Han, Z.; Liu, Z.; Shi, H. Numerical study on overtopping performance of a multi-level breakwater for wave energy conversion. *Ocean Eng.* **2018**, *150*, 94–101. [CrossRef]
16. Martins, J.C.; Goulart, M.M.; Gomes, M.D.N.; Souza, J.A.; Rocha, L.A.O.; Isoldi, L.A.; dos Santos, E.D. Geometric evaluation of the main operational principle of an overtopping wave energy converter by means of Constructal Design. *Renew. Energy* **2018**, *118*, 727–741. [CrossRef]
17. Exo, K.M.; Huppop, O.; Garthe, S. Birds and offshore wind farms: A hot topic in marine ecology. *Bulletin* **2003**, *100*, 50–53.
18. Drewitt, A.L.; Langston, R.H.W. Assessing the impacts of wind farms on birds. *Ibis* **2006**, *148*, 29–42. [CrossRef]
19. Koschinski, S.; Culik, B.M.; Henriksen, O.D.; Tregenza, N.; Ellis, G.; Jansen, C.; Kathe, C. Behavioral reactions of free-ranging porpoises and seals to the noise of a simulated 2 MW wind power generator. *Mar. Ecol. Prog. Ser.* **2003**, *265*, 263–273. [CrossRef]
20. Wahlberg, M.; Westerberg, H. Hearing in fish and their reactions to sounds from offshore wind farms. *Mar. Ecol. Prog. Ser.* **2005**, *288*, 295–309. [CrossRef]
21. Thomsen, F.; Lüdemann, K.; Kafemann, R.; Piper, W. Effects of Offshore Wind Farm Noise on Marine Mammals and Fish, Biola. Hamburg, Germany on Behalf of COWRIE Ltd. Available online: https://www.researchgate.net/publication/228653581_Effects_of_Offshore_Wind_Farm_Noise_on_Marine_Mammals_and_Fish (accessed on 8 January 2018).
22. Öhman, M.C.; Sigray, P.; Westerberg, H. Offshore Windmills and the Effects of Electromagnetic Fields on Fish. *Ambio* **2007**, *36*, 630–633. [CrossRef]
23. Gill, A.B. Offshore renewable energy: Ecological implications of generating electricity in the coastal zone. *J. Appl. Ecol.* **2005**, *205*, 605–615. [CrossRef]
24. Petersen, J.K.; Malm, T. Offshore windmill farms: Threats to, or possibilities for, the marine environment. *Ambio* **2006**, *35*, 75–80. [CrossRef]

25. Wilhelmsson, D.; Malm, T.; Thompson, R.; Tchou, J.; Sarantakos, G.; McCormick, N.; Luitjens, S.; Gullström, M.; Patterson Edwards, J.K.; Amir, O.; et al. (Eds.) *Greening Blue Energy: Identifying and Managing the Biodiversity Risks and Opportunities of Off Shore Renewable Energy*; IUCN: Gland, Switzerland, 2010; 102p, Available online: https://www.actu-environnement.com/media/pdf/news-22257-etude-uicn.pdf (accessed on 8 January 2018).
26. Fayram, A.H.; de Risi, A. The potential compatibility of offshore wind power and fisheries: An example using bluefin tuna in the Adriatic Sea. *Ocean Coast Manag.* **2007**, *50*, 597–605. [CrossRef]
27. Langhamer, O. Artificial Reef Effect in relation to Offshore Renewable Energy Conversion: State of the Art. *Sci. World J.* **2012**, *2012*, 386713. [CrossRef] [PubMed]
28. Kaldellis, J.K.; Apostolou, D.; Kapsali, M.; Kondili, E. Environmental and social footprint of offshore wind energy. Comparison with onshore counterpart. *Renew. Energy* **2016**, *92*, 543–556. [CrossRef]
29. Wilson, B.; Batty, R.S.; Daunt, F.; Carter, C. *Collision Risks between Marine Renewable Energy Devices and Mammals, Fish and Diving Birds*; Report to the Scottish Executive; Scottish Association for Marine Science: Oban, UK, 2007; Available online: https://depts.washington.edu/nnmrec/workshop/docs/Wilson_Collisions_report_final_12_03_07.pdf (accessed on 8 January 2018).
30. Inger, R.; Attrill, M.; Bearhop, S.; Broderick, A.C.; Grecian, W.J.; Hodgson, D.J.; Mills, C.; Sheehan, E.; Votier, S.C.; Witt, M.J.; et al. Marine renewable energy: Potential benefits to biodiversity? An urgent call for research. *J. Appl. Ecol.* **2009**, *46*, 1145–1153. [CrossRef]
31. Woolf, D.K. Environment, Regulation and Legislation. Report of the Off-Shore Renewable Energy Conversion Platforms—Coordination Action (ORECCA) Project. 2011. Available online: http://www.orecca.eu/documents (accessed on 14 February 2018).
32. Stratigaki, V.; Troch, P.; Stallard, T.; Forehand, D.; Kofoed, J.P.; Folley, M.; Benoit, M.; Babarit, A.; Kirkegaard, J. Wave basin experiments with large wave energy converter arrays to study interactions between the converters and effects on other users in the sea and the coastal area. *Energies* **2014**, *7*, 701–734. [CrossRef]
33. Schillings, S.; Wanderer, T.; Cameron, L.; van der Wal, J.T.; Jacquemin, J.; Veumb, K. A decision support system for assessing offshore wind energy potential in the North Sea. *Energy Policy* **2012**, *49*, 541–551. [CrossRef]
34. Vagiona, D.; Karanikolas, N. A multicriteria approach to evaluate offshore wind farms siting in Greece. *Glob. Nest J.* **2012**, *14*, 235–243.
35. Mekonnen, A.; Gorsevski, P. A web-based participatory GIS (PGIS) for offshore wind farm suitability within Lake Erie, Ohio. *Renew. Sustain. Energy Rev.* **2015**, *41*, 162–177. [CrossRef]
36. Christoforaki, M.; Tsoutsos, T. Sustainable siting of an offshore wind park a case in Chania, Crete. *Renew. Energy* **2017**, *109*, 624–633. [CrossRef]
37. Zubiate, L.; Villate, J.L.; Torre-Enciso, Y.; Soerensen, H.C.; Holmes, B.; Panagiotopoulos, M.; Neumann, F.; Rousseau, N.; Langston, D. Methodology for site selection for wave energy projects. In Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden, 7–10 September 2009.
38. Nobre, A.; Pacheco, M.; Jorge, R.; Lopes, M.F.P.; Gato, L.M.C. Geo-spatial multi-criteria analysis for wave energy conversion system deployment. *Renew. Energy* **2009**, *34*, 97–111. [CrossRef]
39. Perez-Collazo, C.; Astariz, S.; Abanades, J.; Greaves, D.; Iglesias, G. Co-located wave and offshore wind farms: A preliminary case study of an hybrid array. *Coast. Eng. Proc.* **2014**, *34*, 1–10. [CrossRef]
40. Cradden, L.; Kalogeri, C.; Martinez Barrios, I.; Galanis, G.; Ingram, D.; Kallos, G. Multi-criteria site selection for offshore renewable energy platforms. *Renew. Energy* **2016**, *87*, 791–806. [CrossRef]
41. Vasileiou, M.; Loukogeorgaki, E.; Vagiona, D.G. GIS-based multi-criteria decision analysis for site selection of hybrid offshore wind and wave energy systems in Greece. *Renew. Sustain. Energy Rev.* **2017**, *73*, 745–757. [CrossRef]
42. Kørnøv, L.; Christensen, P.; Nielsen, E. Environmental impact assessment. In *Tools for Sustainable Development*; Kørnøv, L., Thrane, M., Remmen, A., Lund, H., Eds.; Aalborg Universitetsforlag: Aalborg, Denmark, 2007; pp. 353–374, ISBN 978-87-7307-797-9.
43. Larsen, S.V. Is environmental impact assessment fulfilling its potential? The case of climate change in renewable energy projects. *Impact Assess. Proj. Apprais.* **2014**, *32*, 234–240. [CrossRef]
44. Pastakia, C.M.R. The rapid impact assessment matrix (RIAM)—A new tool for environmental impact assessment. In *Environmental Impact Assessment Using the Rapid Impact Assessment Matrix (RIAM)*; Jensen, K., Ed.; Olsen & Olsen: Fredensborg, Denmark, 1998; pp. 8–18.

45. Hagebro, C. Flood damage assessment Dac La Province, Vietnam. In *Environmental Impact Assessment Using the Rapid Impact Assessment Matrix (RIAM)*; Jensen, K., Ed.; Olsen & Olsen: Fredensborg, Denmark, 1998; pp. 28–35.
46. Pastakia, C.M.R.; Jensen, A. The rapid impact assessment matrix (RIAM) for EIA. *Environ. Impact Assess. Rev.* **1998**, *18*, 461–482. [CrossRef]
47. Pastakia, C.M.R.; Bay, J. Initial environmental evaluation of alternative methods to conserve the Rupa Tal, Nepal. In *Environmental Impact Assessment Using the Rapid Impact Assessment Matrix (RIAM)*; Jensen, K., Ed.; Olsen & Olsen: Fredensborg, Denmark, 1998.
48. Shakib-Manesh, T.E.; Hirvonen, K.O.; Jalava, K.J.; Ålander, T.; Kuitunen, M.T. Ranking of small scale proposals for water system repair using the Rapid Impact Assessment matrix (RIAM). *Environ. Impact Assess. Rev.* **2014**, *49*, 49–56. [CrossRef]
49. Suthar, S.; Sajwan, A. Rapid impact assessment matrix (RIAM) analysis as decision tool to select new site for municipal solid waste disposal: A case study of Dehradun city, India. *Sustain. Cities Soc.* **2014**, *13*, 12–19. [CrossRef]
50. Ijäs, A.; Kuitunen, M.T.; Kimmo, J. Developing the RIAM method (rapid impact assessment matrix) in the context of impact significance assessment. *Environ. Impact Assess. Rev.* **2010**, *30*, 82–89. [CrossRef]
51. Vagiona, D. Environmental performance value of projects: An environmental impact assessment tool. *Int. J. Dev. Sustain.* **2015**, *10*, 315–330. [CrossRef]
52. Michailides, C.; Gao, Z.; Moan, T. Experimental study of the functionality of a semisubmersible wind turbine combined with flap-type Wave Energy Converters. *Renew. Energy* **2016**, *93*, 675–690. [CrossRef]
53. Michailides, C.; Gao, Z.; Moan, T. Experimental and numerical study of the response of the offshore combined wind/wave energy concept SFC in extreme environmental conditions. *Mar. Struct.* **2016**, *50*, 35–54. [CrossRef]
54. Ramanathan, R.; Ganesh, L.S. Energy resource allocation incorporating qualitative and quantitative criteria: An integrated model using goal programming and AHP. *Soc.-Econ. Plan. Sci.* **1995**, *29*, 197–218. [CrossRef]
55. Løken, E. Use of multicriteria decision analysis methods for energy planning problems. *Renew. Sustain. Energy Rev.* **2007**, *11*, 1584–1595. [CrossRef]
56. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill: New York, NY, USA, 1980.
57. Saaty, T.L. *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, Third Revised Edition*; RWS Publications: Pittsburgh, PA, USA, 2012; ISBN 0-9620317-8-X.
58. Carrion, J.A.; Estella, A.E.; Dols, F.A.; Toro, M.Z.; Rodriguez, M.; Ridao, A.R. Environmental decision-support systems for evaluating the carrying capacity of land areas: Optimal site selection for grid-connected photovoltaic power plants. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2358–2380. [CrossRef]
59. Tegou, L.I.; Polatidis, H.; Haralambopoulos, D.A. Environmental management framework for wind farm siting: Methodology and case study. *J. Environ. Manag.* **2010**, *91*, 2134–2147. [CrossRef] [PubMed]
60. Atici, K.B.; Simsek, A.B.; Ulucan, A.; Tosun, M.U. A GIS-based Multiple Criteria Decision Analysis approach for wind power plant site selection. *Util. Policy* **2015**, *37*, 86–96. [CrossRef]