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GIS-based spatial decision support system for the optimum siting of offshore windfarms

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Abstract: The development of Renewable Energy Sources (RES) as an alternative to fossil fuels has gained significant ground in the last years with the EU aiming at 27% energy production from RES until 2030. However, the lack of suitable land based RES sites due to various constrains (aesthetic nuisance, environmental impacts, etc.) has led to the development of offshore windfarms sites. Currently available software packages for wind farms siting take into consideration only wind power, cost and potential energy production but they do not give to the users the capability to simultaneously evaluate various candidate sites; instead, the users have to pre-select a site and then analyze the data. Nevertheless, this procedure is complex and crucial factors must be considered (environmental, socio-economic, spatial planning) and a software that would analyze critical data and compare the candidate sites would contribute remarkably to the evolution of offshore windfarms siting. The current study is aiming to the development of a holistic methodology for the optimum siting of offshore windfarms that will be implemented through a web-based GIS software. The whole process could be briefly depicted by the following steps: exclude sites that do not fulfil the criteria, asses the candidate sites through an analytical hierarchical process, form energy scenarios for every candidate site and then select the optimum. This software will be a precious decision support system for the stakeholders.

Key words: GIS-based software, Offshore Wind Farms, Siting, Analytic Hierarchical Process, Public Participation

1. INTRODUCTION

Raise of green energy (tidal, wind and solar) and implementation of renewable energy technologies is a way towards independency from fossil fuel oils. Each form of renewable energy is characterized by advantages, drawbacks and different impacts on natural and anthropogenic environment. Wind energy is a rapidly evolving RES and also the most exploited because humans have been harvesting endless amounts of energy for hundreds of years with different types of windmills. Nowadays, there is a trend towards offshore wind farms (OWF) due to their various advantages comparing to onshore wind farms. As there are no geographical obstacles at the open sea OWFs can be extended spatially causing only slight acoustic and optical disturbance. OWF's construction and maintenance costs are high and their affection on the marine environment certain but as they exploit the moving air above the oceans their operating speed is higher and this means higher efficiency and electricity production (Miller and Spoolman, 2009).

Greece's wind potential is rich and classified among the most promising in Europe, with onshore air velocities exceeding 8 m/sec. To site an OWF involves a series of different factors such as financial, social, ecological and technological and many methods for applying multi-criteria analysis at coastal areas have been proposed, targeting at finding suitable RES for best siting and energy production. However, none of them focuses on an approach that ensures the compatibility and complementarity of regional planning and marine spatial planning for sustainable development (Wimmler et al., 2015). The combination of RES in inland and maritime areas has not been studied sufficiently and especially in Greece where most of the researches until now concerns the inland.

Also, through a literature investigation there is a major failure regarding participatory planning in Greece. Specifically, a few researches include the perspective of local residents and stakeholder engagement in a comprehensive sustainable energy-planning project. Siting RES without the public acceptance and institutions can lead to severe reactions and finally to the cancellation of the project. Therefore, the acceptance of the proposed project by local residents and operators should be one of the most important criteria for any type of RES siting.

The core idea of this study is the development of a GIS-based software tool that will implement the proposed methodology. A similar tool is the Geospatial toolkit of National Renewable Energy Laboratory (NREL), USA and is distributed totally free. It is a GIS-based software with graphic user interface and constitutes a tool for searching the ideal site of wind and solar farms. The user has the ability to select from a list of criteria. This tool can be used in many countries but not in Greece. Another tool is Energy Zones Mapping Tool (EZMT), which is online and identify potential areas for siting various RES, including marine areas. The user can choose between various RES, select the criteria and get the final map with the eligible areas. This tool is feasible to be implemented by any user without requiring a subscription, but can be applied only within the US.

As it was noted, there is only one software for offshore and onshore RES siting and its use is restricted to United States only. Therefore, the proposed software is highly innovative because it is generic and so it can be used without geographical restrictions, it implements a holistic methodology including several criteria (social, economic, environmental and technical, etc.) in the framework of marine Spatial Planning and it incorporates the participatory planning and stakeholder engagement aiming at sustainable development.

2. THEORETICAL FRAMEWORK

2.1 Offshore wind farm trend

According to EWEA, there are 1371 offshore wind turbines installed in Europe seas with a total capacity of 3812.6 MW approximately. These wind turbines are located in 53 OWF in 10 European countries producing 14 TWh covering the 0.4% of the total consumption in European Union.

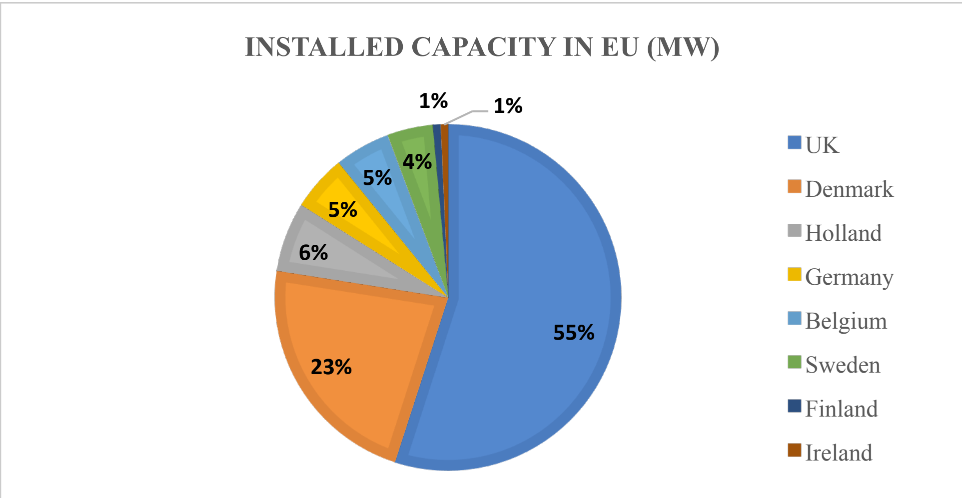

Figure 1. Installed capacity in EU (EWEA, 2013)

Southern countries of EU have not installed so many wind turbines (Figure 1) as the sea depth constitutes a limiting factor for offshore wind farms development. Until today, wind turbines in OWF are installed on the seabed with 4 different type of foundation: gravity (20%), monopile (75%), tripod and jacket that are ideal for seas with depth more than 40 meters.

As a result of technology evolution, the distance of OWF from shore and their installation depth are both increasing: in 2011, the average depth of installation was about 23 meters and the average distance from shore was about 23 km while for current projects the average depth is 25 m and the average distance is 33 km. A large number of wind turbines constructors (41) have announced their will to develop new models for offshore projects and that means that the offshore wind energy will be one of the most significant sectors for development and investment globally. New models will have capacity more than 5 MW. The aim of two companies, Vestas and Alstom, are turbines of 7 MW and 6 MW capacity, respectively, while Siemens has already test a new model with 6 MW capacity in Denmark (EWEA, 2013).

The development of OWF further from shore and in deeper seas seems to be a cost-effective solution if it is combined with high capacity wind turbines and for this reason, development of offshore wind turbines constitutes a basic of European energy policy.

Although there are not any installed offshore wind turbines in the Greek seas due to the complexity of their geomorphological characteristics (Xaviaropoulos, 2012) the significant offshore wind velocity could contribute to the development of RES in Greece. Moreover, given the current market trend of installing bigger turbines into deeper waters it is concluded that to install offshore wind turbines in Greece it may be now feasible. According to National Renewable Energy Action Plan (NREAP) the offshore renewable energy target for Greece for 2020 is 1500 MW (EWEA, 2013).

2.2 Siting criteria

The siting of an OWF may provoke potential spatial conflicts with other resources exploitation sites. So, the optimum siting of offshore wind farms should take into consideration technological, ecological and social parameters because the limitation of their negative effects will maximize the overall value of the wind farm development. Based on this concept, evaluation of candidate areas have been successfully used in wind farm macro-siting analysis, considering the best wind farm location within a region, through marine spatial planning analysis (MSP). MSP has been shown to substantially increase the overall value of the area with little to no cost for the wind farm developers (O’Reilly et al., 2012).

The siting criteria that must be taken into account have been selected through a bibliography and legislation research and are presented in the following Table 1 (Vagiona et al., 2012; Vasileiou et al., 2017; Ministry of Environment & Energy, 2011; O’Reilly et al., 2012).

Table 1. Siting criteria

Field of interest	Factors	Exclusionary	Mitigable	Constraint
Environment	National parks, NATURA2000, Marine Protected Areas, RAMSAR etc.	x		yes / no
Military	Fire zone, submarine zone, training zone, airport, etc.	x		yes / no
Navigation	Cables, signalization, channels		x	yes / no
Radars	Harbors, safety navigation, military		x	yes / no
Economics	Fisheries		x	yes / no
	Economic Exclusion Zones	x		yes / no
Technical	Wind velocity	x		> 6 m/s
	Water depth	x		< 500 m
	Distance from shore	x		> 3 km
	Proximity to a local electrical grid with high voltage capacity		x	220-400 kV / 220 kV / 150kV / 66kV
Tourism	Saturated		x	yes / no
Other	Distance from shore	x		> 6 km
	Shipping route density		x	low / high traffic
	Licensed areas for exploration and exploitation of hydrocarbons	x		yes / no

2.3 Decision making through Analytical Hierarchical Process

Decision analysis using the Analytical Hierarchical Process (AHP) has three concepts: a) structuring the complex decision problem as a hierarchy of goal, criteria and alternatives, b) pair-wise comparison of elements at each level of the hierarchy with respect to each criterion on the preceding level and c) vertically synthesizing the judgments over the different levels of the hierarchy (Vagiona et al., 2012). AHP is selected for a multi-criteria analysis, as it uses a ratio scale, which, contrary to methods using interval scales (Kainulainen et al., 2007), requires no units in the comparison (Ishizaka and Labib, 2009). At each node of the hierarchy, a matrix collects the pairwise comparisons, performed according to information generated from the corresponding maps (Karanikolas et al., 2011).

2.4 Stakeholder engagement and public participation

Stakeholder engagement and public participation are a means of achieving:

- Participatory democracy
- Transparency in decision-making process
- Community empowerment and support
- Reduced conflict over decisions between decision-makers and public groups, and between the groups.

If the public participation is to be effective it requires that citizens be informed and aware of the topic or issue of concern. They must also be willing and able to be involved in the process, which typically involves investing significant personal time (Yee, 2010).

Spatial planning should be based on a participatory, synthetic and comprehensive series of negotiations, but also needs to be a flexible process which is possible to be modified depending on each areas' needs, requirements and characteristics. Public participation in spatial planning usually is leading in exchanging personal views on certain topics. Stakeholders involved are often able to bring different levels of knowledge to the table, an approach very useful due to the fact that planning activities require different areas of expertise and knowledge. Local society is also regarded to be a valuable source of information to evaluate the priorities on which planning policies should be based on (Lazoglou et al., 2015).

3. SOFTWARE ARCHITECTURE

The aim for this software is to create a support decision system for OWF siting that will be possible to be used by someone not necessarily an expert. It is GIS-based and all the results are presented on thematic maps at GIS environment permitting the user to navigate on the map as well as to export the map to a shapefile. The interface was tried to be user friendly without requesting too many inputs but the user is also given the possibility to parameterize the factors or add more of them. The methodology that is implemented through the software is divided into two phases: exclusion and assessment. It should be noted that stakeholders' engagement and public participation are included in the exclusion phase and at assessment phase, respectively.

First of all, there is a database with two categories of criteria: exclusion criteria and assessment criteria. The user is asked to decide if he will use the criteria with the defined parameters. In case that user does not agree with the parameters or the legislation is different from Greece's, it is feasible to edit the database of criteria. The user also can edit the impact factor of each criteria. The criteria have already defined impact factors that have been provided by implementing an AHP at Greek stakeholders. If user agrees with theses impact factors continues to the next step. Otherwise, it is suggested to implement a new AHP and insert his impact factors. Thus, each criterion has an

Impact Factor (IF). At the next step, it is asked to load the needed data in shapefile format. The needed data are the following: wind velocity, bathymetry, land uses, protected areas, special uses and other data. The output is a thematic map in GIS environment and the shapefile overlapping provides with a new map in which unsuitable areas have been excluded. So, there are "n" eligible areas. Each eligible area has an index indicating the satisfaction of each exclusion criterion (EC). There is a process at the background that scores (SC) the fulfilment of each criterion. The index is calculated by the following equation for each eligible area:

$$EPSI_n=SCEC_1*IFEC_1+SCEC_2*IFEC_2+SCEC_3*IFEC_3+SCEC_4*IFEC_4+SCEC_5*IFEC_5+SCEC_6*IFEC_6 \quad (1)$$

The best value for the index is 1. Then, the eligible areas are evaluated using the assessment criteria. At this phase, it is suggested to implement a crowdsourcing process to investigate the public acceptance for each eligible area. An index of satisfaction is also produced

$$APSI_n=SCAC_1*IFAC_1+SCAC_2*IFAC_2+SCAC_3*IFAC_3+SCAC_4*IFAC_4+SCAC_5*IF\ AC_5+SCAC_6*IFAC_6 \quad (2)$$

A total satisfaction index is also calculated for each area. This process reveals out the most suitable area based on all the criteria, exclusion and assessment.

$$TSI_n = APSI_n + EPSI_n \quad (3)$$

Then, a type of Offshore Wind Turbine (monopile, gravity, tripod et-c) is selected for each suitable area and energy scenarios are produced and for each one of them critical values such as the available area (m^2), the satisfaction of each criterion through TSI and the potential energy that can be produced are calculated. Then An index is also considered, a median installed cost (€/MW). These scenarios are the final output and the user has acquired valuable knowledge on some suitable areas, the cost and the potential energy. It should be noted that it is possible that for one area two energy scenarios to be produced because at deeper waters more than one Offshore Wind Turbine (OWT) type can be installed. At this case, the cost may be a crucial factor. The software's architecture is briefly depicted at the following figures.

4. CONCLUSIONS

The present paper is depicting a holistic methodology that can be implemented through an open architecture software and can be used as a precious tool for supporting decision process. The methodological framework is based on GIS and AHP combination, incorporating public acceptance and stakeholders' expertise, for the identification of the most appropriate marine areas for OWF siting. Many approaches concerning this topic have been presented in the past but the implementation of the proposed methodology through a software is really innovative as there in not similar software. Another pioneering component of this approach. Additional innovative elements is the integration of public participation, the fact that the software is open so any user, expert or not, can parametrized it by adding or editing the criteria and their parameters. This generic character of the software permits its implementation worldwide. Last but not least, the software is based on GIS and its outputs are in "shapefile" format so it is possible to be used with every GIS software for further analysis. It should be noted that it is not a tool that provides the final decision but it significantly helps to the investigation for an OWF potential use. It is obvious that a further analysis even in a micro-scale analysis is needed should a stakeholder or an investor aims at finding the final area of siting an OWF.

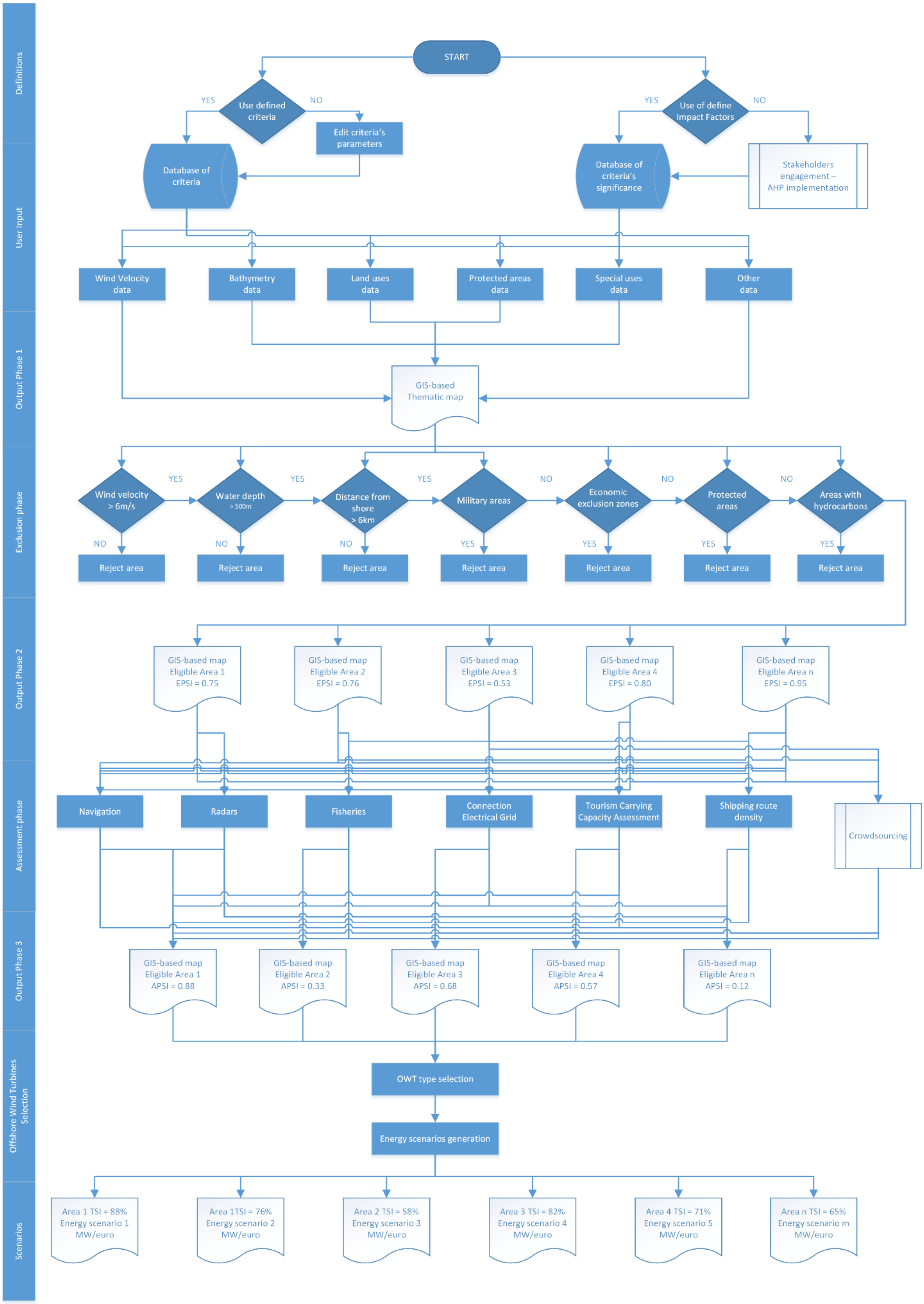

Figure 2. Workflow of software

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