OPTIMAL SITING FOR MARINE RENEWABLES ENERGY INSTALLATIONS ALONG THE CALIFORNIAN COAST USING A MARINE SPATIAL PLANNING APPROACH

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Abstract

In this study the optimal siting and the environmental impact of Marine Renewable Energy Installations is analysed through a spatial planning approach in two areas in the Pacific Ocean along the North and Central California coast. The environmental background for the two areas is considered through set of multiple indicators. Environmental indicators are aggregated into environmental impact indexes that constitute the basis for evaluating the site suitability for Marine Renewable Energy Installations.

Keywords: Marine Spatial Planning; Environmental Impact Assessment; Marine Renewable Energy Installations.

1. Introduction

The increasing awareness of the cumulative effects of human activities on the marine ecosystem and the rapid development of the offshore renewable energy sector has led to an increased requirement for Marine Spatial Planning (MSP) to fulfill the need of a holistic and integrated approach to management (Backer, 2011). In the near future, marine renewable energy installations (MREIs) are likely to become a large part of the future energy mix worldwide (Brooke, 2003; Callaway, 2007). Ecosystem-based management (EBM) and Marine Spatial Planning are widely being pursued as strategies to achieve the sustainable flow of marine ecosystem services (Douvere and Ehler, 2008; Ehler and Douvere, 2009). One important incentive for this development has been the awakening to a potential future shortage of space in coastal seas, partly a result of the rapidly expanding interest in offshore wind-power developments. Among the renewable energy resources also wave energy is rapidly growing, having a potential which in some cases is comparable to that of wind or photovoltaic energy (Brooke, 2003). In addition, recent studies suggest to combine offshore wind turbines and wave energy converters (Stoutenburg et al., 2010). Combining renewable energy resources with low temporal correlations has been shown to reduce the aggregate power output variability of renewables, reduce the operational requirement for reserve and regulating power and reduce the requirement for generation capacity to maintain power system reliability (Wan et al., 2003; Milligan et al., 2001; Wangdee et al., 2006). With wind, and wave energy resources, many coastal areas of the world will be able to use resource diversity to reduce the variability of renewable power and lower the system integration costs of renewables (Stoutenburg et al., 2010). The overall development, is likely to result in further transformation of our coastal seas. California's offshore wind resource is high (Jiang et al., 2008; Dvorak et al., 2010), but currently it remains undeveloped because of the deep water off California's coast. Similarly, California has a good wave energy resource especially in the north (Wilson and Beyene, 2007). Recently has been proposed that resource diversity may be used along the Californian coast to manage the variability of renewable power and lower the system integration costs of renewables (Fusco et al., 2010; Stoutenburg et al. 2010). In such a complex framework, quantitative MSP criteria are requested to evaluate the sustainability of conflicting human activities in the perspective of minimizing the overall environmental impacts.

2. Methods

2.1 Study areas

2.1.1 Northern California coast Site

The first case study concerns the area of Cape Mendocino on the California's Northern coast (NCA) (Figure 1), where both wind and wave energy potential is quite high (Stoutenburg et al., 2010; Jiang et al., 2008; Dvorak et al., 2010) but it remains still undeveloped because of its deep waters. Studies on the meteorology of winds off the California's coast identified the best condition for MREI development in proximity of prominent capes (Dvorak et al., 2010). Unlike most of land based wind farms which peak at night, the offshore winds near Cape Mendocino coast are consistently fast throughout the day and night during all four seasons. Due to this availability of resources, the relative shallow water (< 100m) and the proximity of the city of Eureka, Cape Mendocino is considered a suitable site for the location of wind turbines (Dvorak et al., 2010) but also the co-location of wind and wave energy devices (Stoutenburg et al., 2010). This resource diversity approach may be used to manage the variability of renewable power and lower the system integration costs of renewable (Fusco et al., 2010).

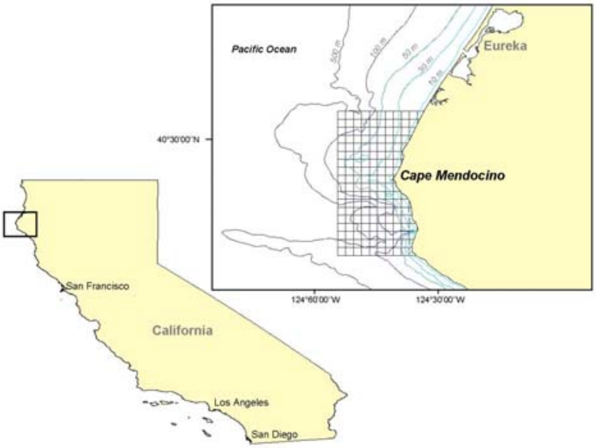

Figure 1. Northern California coast (NCA) sites. The analysis grid is shown in the panel.

2.1.2 Central California coast site

The second case study attains the area between Point Arguello and Point Conception on the South Central coast region of California (CCA) (Figure 2) off the coast of Vanderberg Air Force Base (VAFB) and near the city of Lompoc. The area is considered suitable by the P&GE (Pacific Gas and Electric Company) for wave energy power projects development in waters between 10 to 100 meters of depth. Data collected form the National Oceanic and Atmospheric Administration National Data Buoy Centre (NDBC) close to Point Arguello (station ID:46011) show significant wave action with monthly average wave height ranging form 1.2 to 2.7 meters. Analysis of the 28 year data set shows and average wave power density of approximately 27 kW/m.

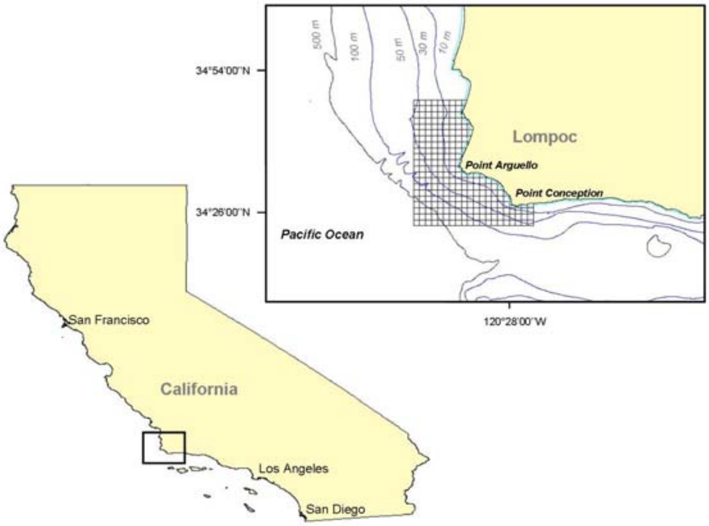

Figure 2. Central California coast (CCA) sites. The analysis grid is shown in the panel.

2.2 Data preparation for the analysis

A grid is created for the two study areas for the purpose of the spatial analysis. Several indicators of environmental vulnerability and pressures are taken into account. The potential implications in terms of habitat loss or degradation due to the direct (e.g. noise production, sea bottom modification) or indirect impacts (e.g. changes induced by habitat alterations) of MREIs has been gridded and used for the analysis.

The area of Cape Mendocino (NCA) was divided into 174 cells of 2x2 kilometres grid size (Fig. 2). The size of the grid was decided according to the dimensions of the multi-leg turbine wind park (138 km2, 300RE power 5M5.0MW wind turbines, total project rated capacity of 1500MW) proposed by Dvorak and colleagues (2010) for the Cape Mendocino area.

The area of Point Arguello (CCA) was divided into 269 cells of 2x2 kilometres grid size (Figure 3). In this case the size of the grid was decided according to the dimensions of the Wave connection project proposed by P&GE (Pacific Gas and Electric Company, www.pge.com) for a multi WEC devices project (approximate dimensions of the project: 5 km wide in the northeast south west direction by 25 km long in the northwest south east direction, WEC devices capacity of 150 kW to 4 MW, optimal operation between 10 to 100 m of depth).

The environmental vulnerability spatial data were extracted from the California Department of Fish and Wildlife Marine Region GIS Lab server (http://dfg.ca.gov/marine/gis/). The server provide an updated wide variety of marine related spatial data with the purpose to support conservation decisions according to California Marine Life Management Act (MLMA) and the California Marine Life Protection Act (MLPA, 1999). The following set of environmental indicators were extracted, gridded and used for the analysis in both the study areas.

Environmental vulnerability indicators:

- Marine Protected Areas presence (Federal and State MPA);

- Marine mammals critical habitats (pinnipeds haul out or rookeries and sea otter habitats);

- Sea birds colonies;

- Vulnerable fish ranges: leopard shark (*Triakis semifasciata*) and rock fish (i.e. Bocaccio rockfish, *Sebastes paucispinis).*

Data on MPA consider the borders of both Federal and State Marine Protected Areas present in the two study areas updated to December 2012 (Fig. 3a-4a). Data on vulnerable fish species range (Fig. 3b- 4b) indicate the home range of the Bocaccio rock fish, (depth range between 0 and 480 m) and leopard shark, (depth range between 0 and 90 m) both classified as "Least concern" in Red List of International Union for the Conservation of Nature (IUCN). In the area of Cape Mendocino (NCA), Sugarloaf Island has been designated as critical habitat for the Steller sea lion (*Eumetopias jubatus*) (Fig. 3a) by the Federal government according to Endangered Species Act (ESA) (**http://www.nmfs.noaa.gov/pr/laws/esa/**). Critical habitat includes the marine zone extending 0.9 km (3,000 feet) seaward from the mapped point. In the area of Point Arguello (CCA) marine mammal habitats are mostly localized in the area of VAFB (Vandernberg Air Force Base- First Cove). Species of concern include principally the Pacific harbor seals (*Phoca vitulina richardsi*), but also California sea lions (*Zalophus californianus*). In addition the area of Point Conception represent a critical habitat for southern sea otter (*Enhydra lutris nereis*) species of *Mustelidae* protected under the Marine Mammal Protection Act (Fig. 4a). Four seabird colonies where identified within the Cape Mendocino study area (*i.e.* Three brothers, Seamboat Rock, False Cape Rock and Sugraloaf Island) (Fig. 3a) while eight seabird colonies were identified in the Point Arguello study area (*i.e.* Point Conception site, Point Arguello site, Rocky point, Destroyer Rock, North Honda, Purisma Point, Mainland Rock, St. Antonio Creek) (Fig. 4a).

Human pressure indicators:

- Ecosystem-stressor scores (Tenk et al., 2010).

To quantify the human pressure to marine ecosystem in the regions a vulnerability score was taken from Tenck and colleagues (2010) where a quantitative and repeatable assessment of relative vulnerability across ecosystems to any ongoing or emerging human activity (stressor) is provided. Marine ecosystems (substrates) in the areas includes kelp (K), rocky reef (RR), shallow soft (SS), rock intertidal (RI), soft shelf (SSh), soft slope (SSl), hard shelf (HSh), hard slope (HSl) and canyons (C). Stressor categories include multiple potential pressures such as: aquaculture, benthic structures (*e.g.* oil rigs), climate change (sum of ocean acidification, sea temperature change, UV change), habitat alteration, direct human impact (trampling), fishing (demersal, pelagic and recreational), invasive species, nutrient input, ocean dumping, pollution inputs, sediment input and shipping.

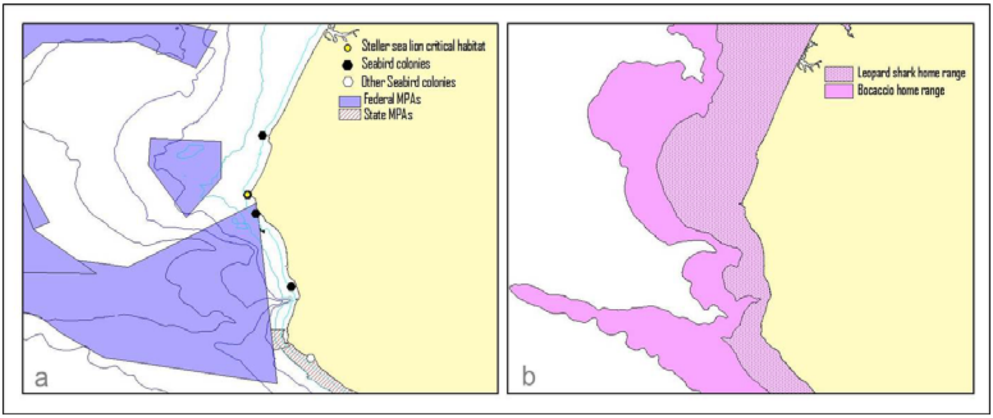

Figure. 3. NCA - Northern California coast site: Maps of Environmental vulnerabilities: a) Federal MPA borders (light blue), State MPA border (red lines) Steller sea lion critical habitat (yellow circle), Sea birds colonies inside (black circles) and outside the study areas (white circle); b) Leopard shark (pink dots) and Bocaccio rockfish (pink) home ranges.

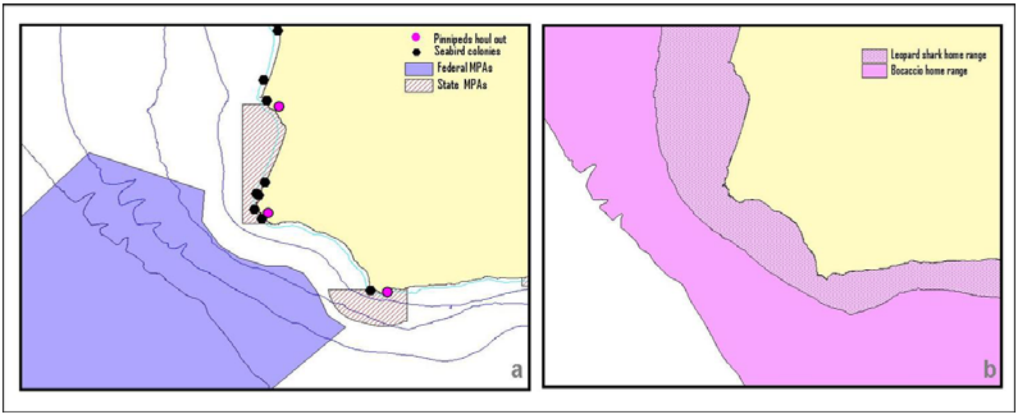

Figure. 4. CCA Central California coast site: Maps of Environmental vulnerabilities: a) Federal MPA borders (light blue), State MPA border (red lines) Marine mammals critical habitat (pink circle), Sea birds colonies inside (black circles) b) Leopard shark (pink dots) and Bocaccio rockfish (pink) home ranges.

3. Results and Discussion

Due to the local scale characteristic of the two study areas and the complexity of the ecosystems the impact of the human pressures on marine ecosystem was evaluated in terms of ecosystem–stressor interaction. Therefore, a matrix of ecosystem-stressor scores for 13 stressors affecting the areas and the 9 ecosystems (substrates) identified in costal and offshore areas, was attributed to each of the cell of grids. Vulnerability scores for every ecosystem-stressor combination are provided in Table 1.

Table 1. Ecosystem-stressor scores for stressors and ecosystems, modified from Teck et al., 2010.

Stressors	**Costal ecosystems**				**Offshore ecosystems**				
	K	**RR**	**SS**	**RI**	**SSh**	**SSl**	**HSh**	**HSl**	**C**
Aquaculture: finfish (predators)	0.2	1	0	0.2	0.9	0.5	0.7	0	0
Benthic structures (e.g. oil rigs)	1.6	1.7	1.4	0.9	2.2	1.4	2.4	2.3	2.3
Climate change	6.5	6.1	1.2	8.1	4.3	4	4.6	4.6	4.3
Coastal engineer.: habitat alteration	1.4	1.1	0.6	1.7	0.2	0	0	0	0
Direct human impact: trampling	0.1	0.2	0.3	1.6	0.1	0	0	0	0
Fishing	4.7	6.8	3	2.9	5	4.8	5.2	6.8	4.6
Invasive species (from ballast, etc.)	2.4	1.8	1.3	2.6	0.7	0	1.5	0	0
Nutrient Input	0.9	1	0.3	0.9	1	0	1.2	0	1
Ocean dumping: marine debris	0.8	0.9	0.4	0.9	0.8	0.9	1	1	0.6
Ocean pollution (from ships/ports)	0.9	1	0.4	1.3	0.8	0	1	1.3	0.9
Pollution Input	3.7	4.1	2.5	4.5	4.4	4	3.6	0.7	3.8
Sediment Inputs	1.5	1.1	1.4	2.3	0.3	0	0	1	1.4
Shipping (commercial, cruise, ferry)	0	0.3	0	0.2	0.3	0	0	0	0

Finally, an overall Ecosystem-Stressor Score (Fig. 5b and 7b) was calculated for every cell of the grid covering the two study sites, based on the dominant ecosystem (*e.g.* about 70% of the cells contains at least 1 ecosystem in both the areas) or, in case of multiple ecosystems contained within the same cell (*e.g.* Kelp and Shallow Soft ecosystems), by summing the scores (Fig. 5a-7a). Then, the environmental vulnerability was evaluated in every grid cell by summing, the presence of Marine Protected Areas, the presence of marine mammals critical habitats, the proximity to seabird colonies and the fish home range. In this way, Classes of Vulnerability (from 0 to 4) were obtained in both the study areas (Fig.6a and 8a). Finally, Cumulative Impact Indexes were calculated by multiplying the Ecosystem-Stressor Score by the Classes of Vulnerability:

$$\text{Cumulative Impact} = \text{Ecosystem-Stressor Score} \times \text{Vulnerability Classes} \quad [1]$$

The cumulative impacts index normalized to 1 (where 1 represent the higher impact expected), is shown in Figure 6b for the Northern California (NCA) site and in Figure 8b for the Central California (CCA) site. Based on this analysis higher values of the index (from 0.6 to 1) are localized within the 50 m depth contour in front of the NCA site ,to the South of Cape

Mendocino. On the other hand, the northern part of the NCA study area was identified as the one with the lowest potential cumulative impact (values lower than 0.2). The analysis of the CCA site outlined higher cumulative impacts (values > 0.6) close to shore within the 10 m depth contour in proximity of the three prominent capes. However hot spots areas with cumulative impact values between 0.2 and 0.6 are localized in deeper waters within the 100 m depth contour.

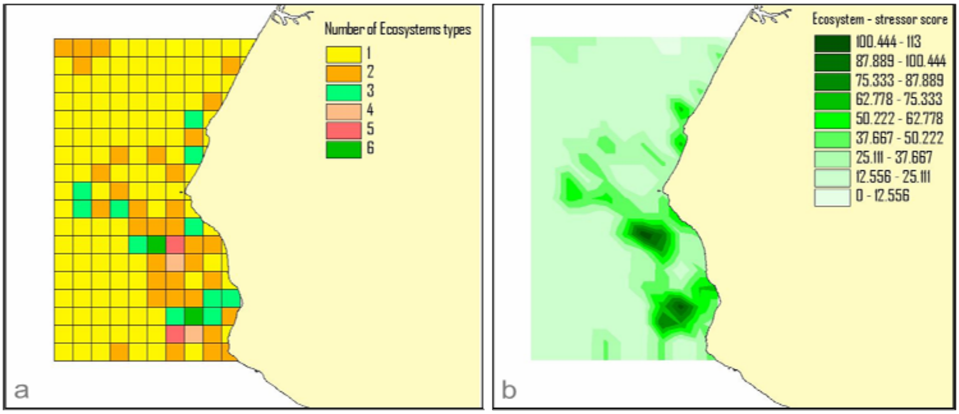

Figure 5. NCA a) Map of number of Ecosystem type per cell and b) Overall Ecosystem-Stressor Score

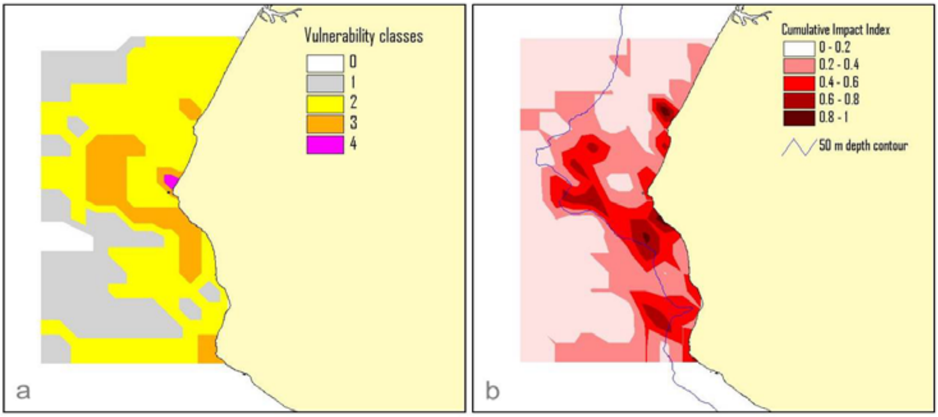

Figure 6. NCA a) Map of Vulnerability classes and b) Cumulative impact Index, 50 m depth contour is shown.

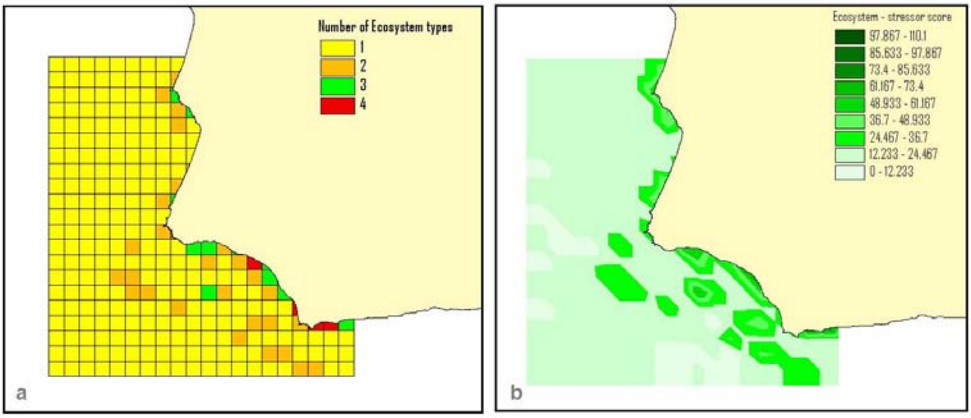

Figure 7. CCA a) Map of number of Ecosystem type per cell and b) Overall Ecosystem-Stressor Score

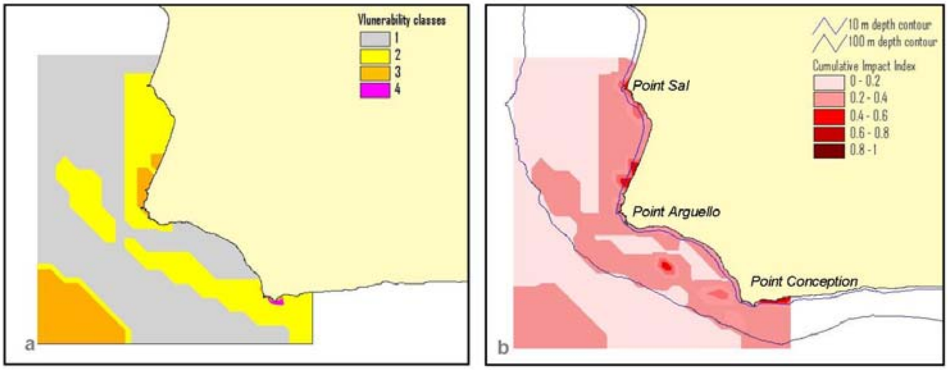

Figure 8. CCA a) Map of Vulnerability classes and b) Cumulative impact Index, 10 and 100 m depth contours are shown.

Concerning the NCA site, the area northern Cape Mendocino presents the lowest potential index (< 0.2). Due to the considerable area required within the 50 m depth contour for the installation of a wind park (according to one proposed by Dvorak et al, 2010, about 138 Km^{2}) and considering the consequent habitat alteration, wind energy is not considered the optimal alternative in term of environmental sustainability. According to the wave energy availability in the northwest facing coast north to Cape Mendocino (Stoutenburg et al., 2010), offshore floating wave energy devices (i.e. Pelamis Wave Energy Converter) are probably the best alternative. Concerning the Wave Connect Project in CCA site, developed by the Pacific Gas and Electronic, the proposed location (between Point Conception and Point Arguello) is not considered appropriate in term of environmental sustainability. A better location for the installation of WECs could be localized in the off shore waters (within the 100 m of depth) between Point Arguello and Point Sal in the northern part of the study areas (Impact score < 0.2). According to the wave energy availability this solution can be considered as an alternative location able to minimize the environmental impact of WEC project in the area.

4. Conclusions

In this study a Marine Spatial Planning approach has been used to provide quantitative criteria that may support the identification of the optimal sites for MREIs in two areas along the Californian coast (Cape Mendocino, NCA and Point Arguello, CCA). In the perspective of the management of conflicts between human uses and their environmental sustainability, different pressure indicators have been aggregated and overlaid to the environmental vulnerability, obtaining maps of cumulative impact. Such maps of potential impact, considered in context of energy resource availability and of the economic constrains, may suggest the optimal location of MREIs minimizing the environmental impact.

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