Site selection of hybrid solar/wind renewable energy systems: A case study from Andros, Greece

Bili A.[1], Vagiona D.[2,*]

[1] School of Spatial Planning and Development, Faculty of Engineering, Aristotle University of Thessaloniki, 54124 Greece
[2] School of Civil Engineering, Faculty of Engineering, Aristotle University of Thessaloniki, 54124 Greece
*corresponding author, e-mail: dimvag@plandevel.auth.gr, Tel +30 2310 99595

Abstract
The combination of two or more forms of Renewable Energy Sources at the same spatial scale is a highly promising sector, resulting in an increase in the number of installations of hybrid RES systems. In Greece, where abundant resources such as wind and sun are available, the combination of these two renewable forms of energy can contribute to reducing dependence on conventional energy resources, as in hybrid power systems the weakness of a source is offset by the forces of the other. The purpose of this paper is the development of a methodology for selecting suitable sites for the installation of Hybrid Wind and Solar Energy Systems (HWSES) using Geographic Information Systems (GIS). The implementation focuses on the island of Andros, Greece, and the proposed methodology includes the exclusion of areas defined by the Greek legislation and the international experience for both forms of energy. The site selection corresponds to a multi-dimensional process, which includes multiple criteria such as wind speed, solar radiation, distance from settlements, technical infrastructure, environmental and cultural interest and slope. Finally, the areas occupied by wind and solar farms in different licensing stages are excluded from the areas that are available for HWSES siting.
Keywords: site selection, Hybrid Wind and Solar Energy Systems, Geographical Information Systems, exclusion criteria, Andros

1. Introduction

According to Nakata et al. (2005), renewable energy produced by the wind and the sun is interrupted, so it would be difficult to predict a stable energy supply using only one source of renewable energy. The combination of two or more RES in a hybrid system often helps to overcome this constraint, while reducing dependence on conventional energy resources as in hybrid power systems, the failure of a source is offset by the forces of the other sources (Hongxing et al., 2009).

2. Methodology

In this study, the proposed methodology for the site selection process of HWSES is consisted of three steps: i) suitable locations for wind turbines and solar–PV power plants are identified separately ii) these priority sites are overlaid to obtain feasible locations for HWSES and iii) the areas that are already proposed for wind and solar-PV applications in different licensing stages are excluded from the areas considered appropriate from the previous two steps.

2.1 Exclusion of unsuitable areas for wind farm siting

Initially, the areas that don't comply with the restrictions of the national legislation are excluded. According to Article 6 of the Special Framework of Spatial Planning and Sustainable Development for Renewable Energy Resources (SFSPSD-RES) the areas considered incompatible regarding the installation of wind farms, are the following:

- Point areas: ports, the heliport, bathing waters, archaeological sites, listed cultural monuments, monasteries, antennas
- Linear areas: road network, high-voltage electricity grid
- Extensive areas: Sites of Community Importance (SCIs) and Special Protection Areas (SPAs) of the Natura 2000 network, Areas of Outstanding Natural Beauty (AONBs), settlements, high-productivity farmland.

Rivers and lakes were also excluded (Aydin et al., 2010; Zhou et al., 2011; Phuangpornpitak and Tia, 2011).
In order to specify the minimum distances of wind farm siting areas from incompatible zones the restrictions proposed in the SFSPSD-RES and the extensive literature review (e.g. Noorollahi et al., 2016; Ouammi et al., 2012; Zhou et al., 2011) are compared and the most strict distance limit is finally selected. Wind farms should be installed in a distance that exceeds 1000m from areas of environmental interest; 1500m from bathing waters; 2000m from the coastline; 3000m from archaeological monuments and historical places of high importance; 1000m from cultural monuments and historical sites; 500m from monasteries; 1000m from big settlements and 500m from small ones; 1500m from traditional settlements; 130m from roads and the electricity grid; 600m from antennas; 2500m from the heliport, 130m from high-productivity farmland, 500m from quarries and mines and 1000m from tourism-related facilities.
Moreover, a high wind velocity is the primary criterion which an area has to fulfill in order to be considered suitable for the installation of a wind park. As a result, in this study the exclusion limit is selected to be 6m/sec (Gorsevski et al., 2013; Noorollahi et al., 2016). Thus, after the exclusion of incompatible areas and the buffer zones as well as areas with wind velocity lower than 6m/sec, appropriate areas for windfarm installation are defined.

2.2 Exclusion of unsuitable areas for solar-PV siting

According to SFSPSD-RES and literature review the following areas should be excluded from the solar-PV farm siting process:

- Point areas: ports, the heliport, archaeological sites of great importance, listed cultural monuments
- Linear areas: road network, high-voltage electricity grid, rivers
- Extensive areas: Sites of Community Importance (SCIs) and Special Protection Areas (SPAs) of the Natura 2000 network, Areas of Outstanding Natural Beauty (AONBs), settlements, high-productivity farmland.

Combining SFSPSD-RES and restrictions found in the literature solar-PV farms should be installed in a distance that exceeds 1000m from areas of environmental interest and the coastline; 300m from lakes and rivers; 3000m from archaeological sites; 1000m from cultural monuments and historical sites; 500m from monasteries; 500m from settlements; 1000m from traditional settlements; 100m from roads; 130m from high-productivity farmland and 1000m from tourism-related facilities. Areas with slope of terrain more than 10% are also excluded as solar energy technologies require rather mild slopes in order to utilize sunlight (Bravo et al., 2007) At last areas with solar radiation lower than 1400 kW/m^2 are also excluded (Merrouni et al., 2016).

2.3 Exclusion of existing wind and solar-PV farm infrastructures

From the areas that are considered compatible for HWSES siting from Steps 1 and 2, the areas where wind or solar farms either exist or have been proposed as suitable for siting are excluded. According to Greek standard environmental commitments the areas that are located within 150m of the perimeter of existing renewable energy facilities in operation, are also excluded from the suitable for HWSES siting areas.

3. Case study

The proposed methodology for the site selection of HWSES is applied to a Greek Island, Andros which is located at the Aegean Sea and has high wind and solar capacity the most time of the year. Currently, there is only 1 operating wind farm in Andros and 49 wind and solar applications at different licensing stages. Fig. 1 shows the suitable areas for HWSES siting in the island of Andros. As shown, the northern part of the island which has relatively high wind energy potential and also high solar radiation values is suitable for HWSES siting.

4. Conclusions

One major problem associated with stand-alone renewable energy systems is the discontinuous energy generation due to changing weather and climatic conditions. In order to maintain stability in electricity production, two or more renewable energy systems should be integrated into a hybrid system. Currently, there are no operating HWSES in Greece. The goal of this study is to develop a GIS-based methodology to identify the preferred locations for HWSES siting.

The proposed methodology takes into account the Greek legislation and also numerous criteria for both wind and solar-PV siting applications from all over the world and attempts to combine them, making this methodology a complete and ready-to-use tool. The implementation of this methodology unveiled that less than 20% of the total area of Andros is suitable for HWSES siting.

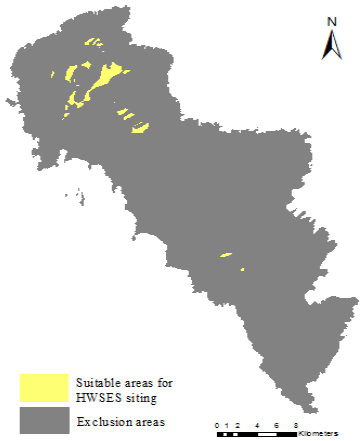

Figure 1. Proposed HWSES siting locations

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