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A decision support system for the optimal exploitation of wind energy on regional scale

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ABSTRACT

Wind is a promising sustainable energy resource that can help in reducing the dependence on fossil fuels. Models and tools can be effectively used to assess the resource availability, the possible exploitation, and the environmental impact. The aim of this work is to propose an Environmental Decision Support System (EDSS) for the sustainable design of wind power plants both in terms of the site selection over a regional territory and of the optimal technology to be installed. Specifically, the proposed EDSS is suited to territories with a complex orography (such as several regions of the Mediterranean coasts), and for the installation of plants in the class of power between 500 kW and 1000 kW. The different EDSS modules are applied to a specific case study, supporting the decision maker on the exploitation of wind power plants in the Savona District, Liguria Region, Italy.

1. Introduction

Sustainable energy systems can be defined as systems that can provide energy services to the present generation while ensuring that similar levels of energy services can be provided for future generations [1]. The limited availability of fossil fuel resources makes urgent the adoption of suitable strategies in the energy sectors in order to prevent an economic and social emergency that, in the absence of adequate strategies, will arrive sooner or later. In trend towards the diversification of the energy market, wind power is probably the most promising sustainable energy resource.

The wind is a clean and inexhaustible resource available all over the world. Recent progress in wind technology has led to cost levels comparable, in many cases, with conventional methods of electricity generation. Moreover, the number of wind turbines coming into operation increases significantly year after year. Produced energy from wind resources in the European Union (EU15) increased from 417 TOE to 7680 TOE in ten years (1996–2007, Eurostat).

Generation of electricity by wind energy has the potential to contribute to a country's economic growth, especially in developing countries and to reduce environmental impacts caused by the use of fossil fuels to generate electricity because, unlike fossil fuels, wind energy does not generate atmospheric contaminants or thermal pollution, thus being attractive to many governments, organizations, and individuals.

As electric power demand increases, it will be necessary to evaluate locations for renewable energy generation [2]. Geographic information systems (GIS) have had an increasingly fast development in the last two decades. A GIS is a system that is able to capture, store, process, analyze and present geo-spatial data and information [3]. The selection of the most adequate location for wind plants is a major and very important task. GIS are often coupled with software systems that integrate models, or databases or other decision aids, in a way that decision makers can be supported in the decisions on a territory and on the related environmental issues. These set of systems are commonly referred to as Environmental Decision Support Systems [4].

In literature, there are several examples of EDSS applied to the exploitation of renewable energy systems. Aran Carrion et al. [5] developed an EDSS based on multi-criteria analysis and GIS, taking into account environment, orography, location, and climate factors, for selecting optimal sites for grid-connected photovoltaic power plants. Rodman and Meentemeyer [2] developed an analytic framework using a GIS to evaluate site suitability for wind turbines and to predict the locations and extent of land available for feasible wind power development.

Cavallaro and Ciraolo [6] demonstrated that the multi-criteria analysis can provide a valid tool to aid decision making for achieving targets relating to more sustainable green energy. The

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geo-spatial multi-criteria analysis is a suitable technique to take into account—at an early stage of the design process—a wide variety of environmental and administrative factors and assign corresponding weights [3]. Several factors, such as technological limitations, environmental conditions, administrative and logistic conditions, have to be taken into account in order to support the decision for best location [3]. Amy et al. [7] showed that some of the factors like policy support, new technologies, and financial mechanisms do accelerate opportunities of adopting wind power from suitable wind farm. However, some factors such as the disparity of different parties and uncertainty of land usage do have negative impacts.

The aim of this work is to propose an EDSS for the sustainable design of wind power plants (WPPs) as regards the identification of the proper sites over a regional territory and the optimal technology to be installed in those sites. Specifically, the proposed framework is suited to territories with a complex orography (such as several regions of the Mediterranean coasts), and for the installation of plants in the class of powers between 500 kW and 1000 kW. The different modules of EDSS are exemplified in a case study, supporting the decision maker on the exploitation of wind power plants in the Savona District, Liguria Region, Italy.

2. System architecture

Wind park planning is founded on a multi-criteria decision making process. Therefore, the selection of suitable sites should be carried out using a multi-criteria planning tool attempting to consider in cooperation the economic, technical, environmental and social issues. The selection of final location for the wind parks installation must be discussed among all decision makers involved in the planning process. In general, environmental and social criteria are subject to a number of good practice rules relating to wind farm installation in accordance with the regional government framework.

The proposed architecture of the DSS is reported in Fig. 1 and is made by the following modules:

- a GIS module to evaluate eligible sites according to several criteria;
- a wind analysis module, based on statistical analysis of historical wind speed data;
- a module for the modelling of the exploitable wind energy according to analysis of the available medium-size technologies;
- a module, Decision Support System, implementing a mathematical model to support the optimal decision as regards the technology to be adopted in the eligible sites;
- a model to assess the environmental impact of the proposed methodologies.

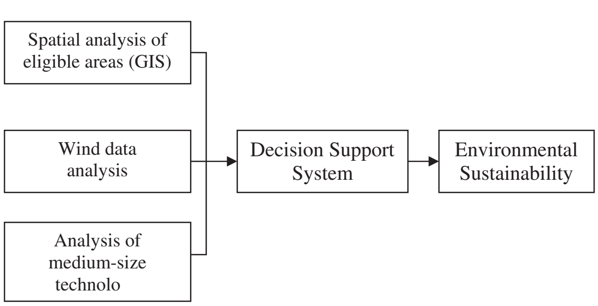

Fig. 1. The sub-models to be taken into account for wind turbine modelling.

2.1. GIS module

According to regional and territorial regulations, environmental as well as work constraints, some restrictions to WPP settling may be adopted, discarding areas with features that are not adequate to the exploitation of wind energy. In addition, the spatial information regarding the eligible areas from a regulation viewpoint should be intersected with areas where wind can be effectively exploited from an energy viewpoint.

An example of a work condition which causes some restrictions to WPP settling is related to high slope areas which should be excluded since impeding accessibility to the vehicles carrying the WPP components. Examples of environmental constraints are the migratory routes or environmental protected areas where a WPP may represent a source of environmental impact. On the other hand, the WPP installation in urbanized areas and in the neighbourhood of the airports should be protected by adequate buffer areas for reasons of safety and visual impact.

Commonly, the following spatial information should be used:

- provincial and municipal boundaries;
- slopes;
- airports, port areas, the urban and industrialized areas;
- sites of interest, the special protection areas and protected areas;
- high and medium voltage electric supply network;
- network traffic main road.

Adequate selection criteria to identify eligible areas are:

1. Maximum slope 10%;
2. Maximum distance from the power supply of 1000 m;
3. Maximum distance from the main road network of 1500 m;
4. Area not classified as protected and interest areas;
5. Distance from the migratory routes of wild greater than 1500 m;
6. Distance from urban greater than 1000 m;
7. Distance from airports greater than 2500 m.

2.2. The wind analysis module

The study of wind speed statistical distribution, and of related characteristic parameters, is essential in wind resource assessment and they require a monitoring campaign [8]. So, for a specific eligible site, wind speed data should result by a direct monitoring campaign on the field, or, alternatively, by some interpolation or other modelling Kriging of data coming from wind monitoring stations in the neighbourhoods. In this work, a direct monitoring campaign on the site is taken into account.

Specific attention should be given to the knowledge of statistical characteristics, availability, diurnal variation, and prediction of wind speed. In the literature, probability density functions (PDF) are used to describe wind speed data. Weibull and Rayleigh functions are commonly used for wind speed studies for energy production. According to Justus et al. [9], from a practical point of view, the two parameters Weibull PDF is the most suitable for wind speed distribution. It has been employed for many different case studies around the world for the evaluation of wind energy potential [10–13]. This distribution has also been used in the construction of a variety of models: estimation of the energy output and capacity factor of wind turbines [14,15], performance assessment of autonomous wind energy systems [16], definition of wind characteristics as a function of height [17], wind speed time series