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Wind speed spatial estimation for energy planning in Sicily: Introduction and statistical analysis

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Abstract

The exploitation of the renewable energy sources plays a key role for achieving the CO_2 emissions reduction targets established by the Kyoto Protocol, as well as for facing the shortage of world fossil fuels reserves.

In countries like Italy, with an high potential in terms of wind power generation, an efficient energy planning based on renewables is a very complex task. It encompasses many aspects: the resource availability assessment, the compliance with environmental and legislative constraints and last, but not least, the technical aspects linked to the safe integration to the grid of the intermittent power generated by the wind farms.

This paper is the first part of a study addressing the first of the aforementioned issues. The wind measurements recorded in several stations of Sicily (Italy) were used for the spatial modelling of the wind fields over the region.

A statistical analysis of the wind data has allowed the estimation of the parameters of the wind probability distribution function, that is a Weibull, as predicted by theory.

In the last sections of the paper the results of some traditional deterministic and geostatistical interpolation techniques are shown. In the companion paper the maps of the estimated wind fields have been obtained by using the results of the statistical investigation accomplished here and coupling neural and geostatistical techniques. For a comprehensive evaluation of the forecasting accuracy of this neural kriging approach, those maps have to be compared with the maps showed in this paper.

Keywords: Neural networks; IDW; Kriging; Weibull; Sicily; Wind

1. Introduction

In 1997 the Commission of the European Union published its White Paper on renewable sources of energy [1], setting the goal of doubling the share of renewable energy in the EU from the 1997 level (less than 6%) to 12% by 2010. At the World Summit on Sustainable Development in Johannesburg (September 2002), it was agreed that the contribution of renewables to world energy use should be substantially increased "with a sense of urgency." Intermittent renewables can reliably provide 10–30% of total electricity supplies in the area covered by an adequately strong power grid if operated in conjunction with fuel-based power generation.

One of the targets of the White Paper was to increase EU electricity production from renewable energy sources from 337 TWh in 1995 to 675 TWh in 2010. Within this target, the goal for wind power was an increase in installed capacity from 2.5 GW in 1995 to 40 GW by 2010, which could produce 80 TWh of electricity and save 72 Mt of CO_2 per year [2].

In order to foster a large-scale penetration of renewables, make progress towards the objective of doubling the EU renewable energy sources share by 2010 and ensure a coordinated approach throughout the Community, the Commission proposed a campaign for the take-off of renewables. Within this campaign, were set the indicative

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targets of 1,000,000 PV systems, 10,000 MW of installed large wind farms and 10,000 MW of biomass-fuelled power installations to be reached by 2010 [1].

In 2001 the European Commission launched a directive [3] to promote an increased use of electricity produced from renewable energy sources and to create a basis of a future community framework in support thereof. The directive includes a proposal on share of renewable energy technologies (RETs) in the individual member states by 2010, with the aim to comply with both Kyoto bindings and the 12% RET share in EU electricity market stated in the White Paper. Although not legally binding, it seems that the national targets are generally accepted among the member states. Moreover, even if the directive does not indicate which instruments should be used to meet the targets, among the most relevant ones there is the organization of an EU-wide market for tradable green certificates (TGCs).

In 2002, the Green Paper "Towards a European Strategy for the Security of Energy Supply" [4] was published, where the Kyoto Protocol commitments and the target of the White Paper on renewable energy sources were further pointed out.

By considering the progress made by the EU member states, the target set in the White Paper is likely to be achievable since in December 2004 there was about 34 GW of installed wind-turbine capacity in UE-15, compared with only 6.4 GW in 1998 and 300 MW in 1993. The distribution of wind-turbine capacity is interesting, with Germany accounting for about 48% of the UE-15 total and Spain having approximately 24% in 2004. The average capacity of wind-power generators has increased in Germany, for example, from 473 kW in 1995 to 1395 kW in 2002. By following this trend, the average energy output has increased from about 400 to almost 900 $kWh/(m^2 yr)$. Generation costs have decreased by approximately a factor of ten in Denmark and investment costs by 35% in Germany during the period 1990–1999. Hitherto, cost reduction has been achieved through the up-scale of turbine sizes but economies of scale and additional learning will have important effects in the future with increasing production volumes. Further technology-related cost reductions can be expected through the use of flexible blades, flexible hubs and variable-speed generators that lead to lower weight and lower machine costs. Furthermore, by following a life cycle approach,[1] interesting energy and environmental performances of wind farms have been showed [6]. In particular, the energy and environmental payback times of a wind farm resulted to be lower than 1 year and the primary energy output 40–80 times higher than the energy consumed during its whole life cycle. These values are sensibly lower compared to the environmental burdens of fossil-fuelled power plants and to other renewable energy sources.

Concerning Italy, it still has a strong dependence on fossil fuels, accounting in December 2004 for 3.3% of the UE-15 total (with 1.1 GW of installed wind-turbine capacity). Especially in the south part (including the main islands), Italy can rely on the availability of quite strong winds, even if the anemometric data concerning the Italian nation are not very detailed so far.

In this framework, it is apparent that boosting the exploitation of wind energy is an important challenge in order to achieve the goal of the Kyoto protocol. However, wind energy generation is difficult to manage, because of the irregular nature of the wind flows. It is easily understandable how a reliable wind forecasting model, simple enough to use and capable of giving fast answers, is important for energy planning purposes. In the field of spatio-temporal wind speed forecasting, the scientific literature counts several applications of neural and geostatistical models, which are often coupled [7–12].

The spatial mapping of the wind speeds over the region is here accomplished by using a well known geostatistical interpolator and has to be taken only as a first approximation result. It can be used as a comparison term with the results of the neural network residual kriging (NNRK) approach described in the companion paper.

1.1. Problem description

The work is based on the wind data recorded in about 3 years in 29 different anemometric stations spread in the Sicily region and operated by the regional meteorological service for the agriculture council (SIAS). The data supplied by SIAS are the values, recorded at 10 m above the ground level (a.g.l.), of

(1) hourly mean wind direction (°);
(2) hourly mean wind speed (m/s);
(3) hourly maximum wind speed (m/s).

In Fig. 1 the locations of the 29 anemometric stations are marked with little squares.

Starting from the wind time series, for each site the experimental data were fitted by a two-parameter Weibull distribution, whose parameters (*shape* and *scale*) were determined through the maximum likelihood (ML) technique. Afterwards, the spatial interpolation over the whole territory was accomplished by the application of geostatistical techniques to the theoretical mean values of the previously determined Weibull distributions.

An accurate data preprocessing was necessary because of the presence of several null values in the data arrays, many of which were probably not due to wind-calm periods but to faults of the probes. In order to avoid the harmful effect of these null values on the statistical interpretation of the data, the data base underwent the following operations: if there was only one zero recorded value, it was substituted

[1]The Life Cycle Assessment (LCA) is a standardized methodology to compute the overall environmental burden of a system, including all the contributes throughout its whole life cycle, from the extraction of raw materials to the end-life disposal [5].