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Economic performance indicators of wind energy based on wind speed stochastic modeling

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HIGHLIGHTS

- We propose a new and different wind energy production indicator.
- We compute financial profitability of potential wind power sites.
- The wind speed process is modeled as an indexed semi-Markov chain.
- We check if the wind energy is a good investment with and without incentives.

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ABSTRACT

We propose the computation of different wind energy production indicators and financial profitability of potential wind power sites. The computation is performed by modeling the wind speed process as an indexed semi-Markov chain to predict and simulate the wind speed dynamics.

We demonstrate that the indexed semi-Markov chain approach enables reproducing the indicators calculated on real data. Two different time horizons of 15 and 30 years are analyzed. In the first case we consider the government incentives on the energy price now present in Italy, while in the second case the incentives have not been taken into account.

1. Introduction

Renewable energy is becoming a big player in the world energy productions. Already in 2009, the world renewable energy generating capacity was 26% compared to 66% deriving from fossil fuel [1]. In Europe, on account of the 120 GW of installed wind turbines, 284 TW h of electricity are produced per year. Even though the installed capacity in Europe grows with a mean of 3% per year [2], producers have to deal with many problems related to renewable energy. In the case of wind farms, one of the most important hurdle, is the intrinsic volatility of wind speed that requires accurate evaluation of wind speed data before installing wind turbines. Due to its random behavior [3] and the intrinsic difficulty of storage [4], many researchers are still working on the quantification of available energy and performances estimation of wind projects [5–8].

Frequently, in the literature, indicators closely related to the method of life cycle assessment (LCA) are used (see for example reviews by [9,10]). The influence of site specific parameters on the environmental performance of wind energy converters has been addressed in particular by [11], the issue of site specific LCAs is further discussed in [12]. These methods are very important when assessing large-scale wind projects, where marginal factors can cause relevant economic variations.

We focus our work on the micro-generation of energy from the wind speed. In this scenario, the main important aspects are essentially the satisfaction of the electrical power demand and the return on investments for owners. Wind speed modeling plays an important role in the micro-generation of electrical power from wind speed. In fact, it can accurately describe the process in terms of its intrinsic volatility and fluctuations, which can cause the not fulfilment of the electrical power demand. Furthermore, good stochastic modeling can give information on the production of energy over the short-term, reproduce time lag autocorrelation and it can also be used to forecast the produced energy for short time scale.

Accurate probabilistic models permit the forecast of future wind speed and energy production (see for example [13–15]). At

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the basis of this approach is the evidence that past values of the wind speed keep informations about present value and future values. Many scholars have proposed new models that can allow the prediction of wind speed minutes, hours or days ahead. Many of these models are based on neural networks [16], autoregressive models [17,18], Markov chains [19–24], hybrid models where the previous mentioned models are combined [25–29] and other models [30–34]. All of these models try to catch, from the past, information on the future. Often, these models are either focused on specific time scale forecasting, or synthetic time series generation. In a previous series of papers [35–37], we applied different semi-Markov models to wind speed modeling and we demonstrated that the semi-Markov framework out performs the Markov models and should therefore be preferred in the modeling of wind speed.

The approach we propose here is based on an indexed semi-Markov chain (ISMC) model that we advanced in [38] and applied to the generation of synthetic wind speed time series. In [38] we demonstrated that the ISMC model is able to accurately reproduce the statistical behavior of wind speed. The ISMC model is a non-parametric model because it does not require any assumption on the form of the distribution function of wind speed. Furthermore, we showed that it is able to forecast wind speed at different time scales without loosing the goodness of forecasting which is almost independent from the time horizon [39].

The main purpose of this paper is to present a profitability analysis of wind energy production through economical and financial indexes.

We beginning by presenting a comparison between the energy produced by real wind speed and that obtained by implementing the ISMC model through Monte Carlo simulation. Then, we advance a new indicator that quantifies the utilization degree of a wind turbine. This indicator is defined as the *Satisfying Power Demand Percentage* (SPDP) and measures the fraction of time in which the wind turbine satisfies the electrical power demand. It can be interpreted as a degree of utilization of the wind turbine. We compute these indicators for real and synthetic data. Finally, we consider two financial indicators of the cash flow, namely, Semi-Elasticity and Relative Convexity. We compute these indicators on the cash flow generated by selling the electricity produced by a wind turbine. The cash flow sequences are unknown and random because they depend on the future values of wind speed. Furthermore, the cash flows are subject to the interest rate risk. This is an important component that affects the operation risk of producing wind energy. The computed financial indicators allow managing such risks.

The paper is presented as follow: First, we show our research methodology, the database used and the technical details of the commercial wind turbine. Second, the ISMC model is shortly described as the theoretical support of the empirical application. Third, a real data application is executed involving the proposal of a new index and the computation of classical financial indicators in our stochastic framework.

2. Research methodology and materials

The research methodology is summarized in Fig. 1. We use real wind speed data, described here below, to set the stochastic model that is described in the next section. Then, through Monte Carlo simulations, we generate synthetic time series of wind speed. Both time series, real data and synthetic data, are converted into energy by means of the power curve of the chosen wind turbine. We then suppose that the produced energy is sold in the market at two different prices (with and without government incentives). The sale produces cash flows on which we compute two important financial indicators, namely, Semi-Elasticity and Relative Convexity. To the best of our knowledge, we are the first to use and apply these financial indicators to wind energy investments.

For the analysis conducted in this paper we use a free database of a weather station situated in Italy at N45°28′14,9″–E9°22′19,9″ and at 107 m of altitude. The data of the L.S.I. -Lastem station are downloadable at www.lsi-lastem.it/meteo/page/dwnldata.aspx. The database is composed of more than 230,000 data with a sampling frequency of 10 min. The period of sampling starts from 25/10/2006 until 28/06/2011, almost five years. The station uses a combined speed-direction anemometer at 22 m above the ground. Since we need to test the model for the energy production of a commercial wind turbine, we transpose our database at the turbine rotor altitude using a well known relation, see e.g. [40]:

$$v_h = v_{rif}\left(\frac{h}{h_{rif}}\right)^{\alpha} \quad \alpha = \frac{1}{ln\frac{h}{z_0}} \tag{1}$$

where v_h is the wind speed at the height h of the wind turbine hub and v_{rif} is the value of the wind speed at the height h_{rif} of the instrument. In our application $h = 50$ m and $h_{rif} = 22$ m. The symbol z_0 denotes a parameter that takes into account the morphology of the area near the wind turbine. For a region without buildings or

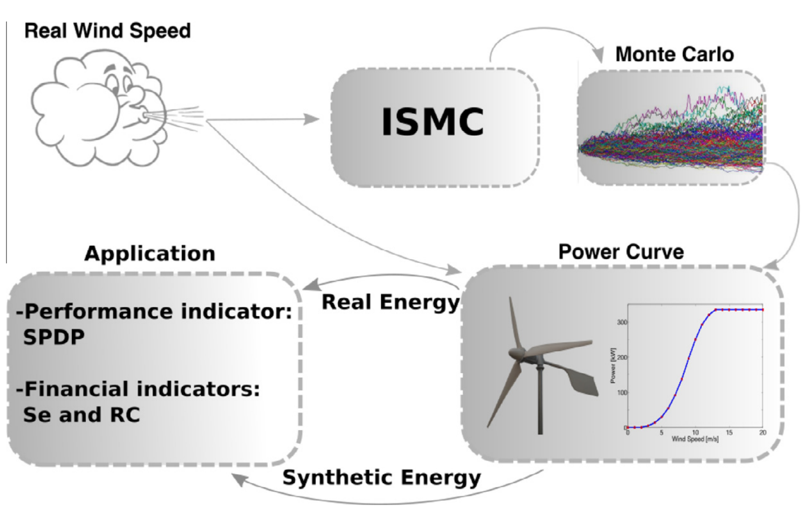

Fig. 1. Scheme of the research methodology adopted.