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A new approach to assess wind energy potential

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Abstract

To meet the increasing global demand for renewable energy, such as wind energy, an increasing number of wind parks are being constructed worldwide. Finding a suitable location requires a detailed and often costly analysis of local wind conditions. Plain average wind speed maps cannot provide a precise forecast of wind power because of the non-linear relationship between wind speed and production. We suggest a novel, globally feasible approach to assess the local wind energy potential: First, meteorological reanalysis data are applied to obtain long-term low-scale wind speed data at specific turbine locations and hub heights. Second, the relation between wind data and energy production is for the first time determined via a five parameter logistic function using actual high-frequency energy production data. The resulting wind energy index allows for a turbine-specific estimation of the expected wind power at an unobserved location. A map of the wind power potential for Germany exemplifies our approach.

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1. Introduction

Because of increasing energy demand worldwide and the willingness to reduce greenhouse gas emissions, renewable energies, such as wind energy, are rapidly growing: The global cumulative installed capacity of wind energy increased from 6 GW in 1996 to 318 GW in 2013 and is expected to reach 596 GW in 2018 [1].

Planning a new wind farm begins with the search for a suitable location. Besides suitable surface conditions and legal aspects, geographical wind conditions and timing are also important. There are many studies which pertain to deriving detailed long-term wind speed maps for individual countries (e.g., U.S. [2] and Germany [3]). These maps of long-term average wind speeds are a rough indicator for average local wind conditions, but they are inadequate for deriving the expected wind energy production because of the non-linear relationship between wind speed and production. To overcome this problem, a long record of high-frequency wind speed at the turbine location and hub height is required. Then, the wind

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power production can be estimated by transforming the high-frequency wind speed to wind power production via a wind power curve (e.g., [4]). For example, Dahmouni et al. [5] estimate the net energy output at one location in Tunisia by measuring the wind every 10 minutes in different heights and combining it with the power curve provided by the turbine producer. The wind power curve given by the turbine producer requires high-frequency mast wind speed to derive production. However, from the perspective of installing a turbine at a new location, long-term high-frequency measurements of wind speed at various locations and heights are very time-consuming and costly and can hardly be conducted.

As an alternative to the power curve, the wind power density (WPD) is often applied, which is the amount of energy that can be extracted out of the wind from a physical viewpoint. For example, Karsli and Geçit [6] derive the wind power potential of one location in Turkey from hourly wind measurements via the WPD. This approach is also applied in [7] using the Weibull analysis and in [8] and [9] using meteorological reanalysis data. Gunturu and Schlosser [8] criticize, however, that the WPD overestimates the real on-site production and should be used only as an illustrative point. Hence, the linkage between wind speed at a higher scale (e.g., hourly averages) and true production deserves further investigation, and the expected energy production at potential locations has to be derived using different tools.

In this paper, we propose a new way to estimate the long-term wind energy potential of a new location by applying a wind energy index, which mainly consists of two steps: First, we derive lower scale wind speed data at the turbine location at hub height by processing meteorological reanalysis data. These data are available throughout the world at low spatial and temporal scales, so our approach is feasible globally. Second, we estimate an analytic production function based on real production data, which converts the meteorological reanalysis data into production data. Based on local wind speed data derived for an unobserved location, this production function provides an estimate of the turbine's low-scale energy production. By aggregating the estimated production to a larger time scale and long-term historical data, the proposed wind energy index is able to assess the long-term wind energy potential for any location.

2. Methods

2.1. Framework

To measure the potential of wind power production at a specific location, we develop a quantitative and objective wind energy index that represents the actual wind energy production of a certain turbine type. To obtain such an index, there are several necessary steps.

First, the type of database to calculate the wind energy index has to be chosen. Whereas production data are difficultly available and not always reliable, wind speed are easily to obtain. An innovative wind speed dataset that has been recommended in the wind power analysis is reanalysis data, such as the Modern-Era Retrospective Analysis for Research and Applications (MERRA) data provided by NASA [10]. MERRA reanalysis data reconstruct the atmospheric state by integrating data from different sources, such as conventional and satellite data [8,11]. They offer a complete worldwide grid of wind data at a spatial resolution of 1/2° latitude and 2/3° longitude (about 45 km × 54 km in Germany) and an hourly temporal resolution since 1979. The wind data consist of a northward and an eastward wind component at three different heights (2 m, 10 m and 50 m above ground).

The wind speed data have to be horizontally interpolated to the turbine location and vertically extrapolated to the turbine height. The wind speeds at the four nearest MERRA grid points are interpolated to the turbine's location weighted by their horizontal distance (inverse distance weighting). The vertical extrapolation is performed using the log wind profile (e.g., [8]):

$$V_z = \left(\frac{u_*}{\kappa}\right)\log\left[\frac{(z-d)}{z_0}\right] \tag{1}$$