



# The benefit of long-term high resolution wind data for electricity system analysis



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## ABSTRACT

Future energy systems rely increasingly on the wind power supply. Understanding its characteristics is essential for the functioning of future electricity systems. Critical low wind situations may endanger the security of supply. So far, historical observations of wind power production are limited to few recent historical years and may not suffice to quantify the expected overall wind contribution, its variability, and its regional balancing effects for future electricity systems. With a novel long-term high-resolution wind power production dataset (hourly on a  $6 \times 6$  km grid for 20 years) we derive new insights. First, we find advantages of our high-resolution dataset compared to previous studies. Second, we find a strong variation in annual wind production (variation of up to 14% for Germany). And third, we find a potential benefit from electricity exchange with neighboring countries in low wind conditions (for Germany in 81% of the low wind situations). The results are highly relevant for further investigation on the level of secured capacity or to identify optimal power transmission capacities within energy market modeling.

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## 1. Introduction

Weather dependent renewable energies, in particular wind energy, has recently gained an increasing importance for energy systems all over the world. For instance, the European wind capacity share raised from 6% (41 GW) in 2005 to 16.7% (154 GW) in 2016 [1]. Thus, for understanding future energy systems, the overall wind power contribution, its short- and long-term variability as well as its regional balancing effects are crucial. Especially regarding energy system reliability the unique characteristics of wind power production, such as low wind situations, play an important role.

This encounters at least two major challenges. First, available historical wind power production data is insufficient for future predictions. Due to the rapid expansion of wind employment, extensive long-term observations are scarce. Therefore, simulations of wind power time series using current and expected future wind

park fleets are required. However, this is leading to the second issue - the lack of meteorological observations with sufficiently high spatio-temporal resolution at the long-term scale, matching with operation sites to perform such simulations.

Recently a number of studies are making use of wind datasets from various reanalysis products in order to deal with these issues [2–6]. However, most of these studies are limited in the sense of spatial coverage (single countries), coarse spatial resolutions or the level of details concerning the conversion from wind energy to electricity generation. For instance, Staffell and Pfenninger [6] apply NASA's Modern-Era Retrospective Analysis (MERRA) in combination with a country based calibration to European wind parks calculating long-term wind power time series. Although the temporal resolution (hourly) of the MERRA reanalysis is sufficient for most energy related applications, the accuracy of the wind dataset might suffer from its coarse horizontal grid spacing (approximately 50 km in Europe) since important local effects happen at sub-grid scales.

In this article, we face these challenges by applying a novel wind power model to a unique high resolution wind dataset. The hourly and  $0.055^\circ \times 0.055^\circ$  (approximately  $6 \times 6$  km in Germany) resolution dataset is obtained from the brand-new reanalysis product of the Consortium for Small-scale Modeling (COSMO-REA6). In

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combination with a location specific European wind park portfolio of 2014, we generate a high resolution wind power database on an advanced level of details. Since the COSMO reanalysis contains long-term time series of 20 years, we are able to capture the broad range of variations, in particular the long-term variability of wind speed and hence electricity generation. In addition we apply a country based calibration to our model results using bias corrections triggered by historical time series.

We focus on three main insights from this approach. First, we have a closer look at advantages of our higher spatial resolution compared to other previous studies which rely on coarser reanalysis products. Second, by using long-term data we are able to analyze the variability and occurrence frequency of extreme events in the wind power sector. This leads to the question whether it is reasonable to define representative years as it is common in many energy studies. Third, we investigate regional balancing effects induced by wind power generation, on a European scale, as well as on a national scale (Germany). This highlights once more the advantages from extending electricity grids to reap the benefits from balancing effects. The dataset can be applied in further high-detailed energy market models and cost-benefit analyses.

The paper is structured as follows: In Section 2 we develop and apply the model to simulate wind power time series. The modeling results are further analyzed in Section 3 with respect to annual variation and balancing effects. We finally conclude in Section 4.

## 2. Methodology

In this section, the methodology is presented. Due to the high-resolution in time and space, the model has the potential to outperform existing wind datasets with a coarser resolution. Since wind speeds are highly dependent on regional effects (surface roughness, landmass, etc.) a high resolution is crucial to derive detailed data which is necessary for follow-up analysis in e.g. electricity dispatch and investment models, transmission grid expansions, as well as security of supply analysis.

### 2.1. A model for high resolution wind power production

We develop a method to accurately estimate spatially and temporally high resolution wind power production time series for given installed wind park capacities in a certain domain. The method is implemented in the Renewable Energy Output Model (REOM). To calculate the power output  $P_{out}$  of a single wind turbine at a known location for given instantaneous wind speeds at hub height  $v_{hub}$  the following equation, also called power curve, is used:

$$P_{out} = \begin{cases} 0 & v_{hub} < v_{in} \\ \frac{1}{2} \pi R^2 c_p \rho_{hub} \cdot v_{hub}^3 & v_{in} \leq v_{hub} < v_r \\ C & v_r \leq v_{hub} < v_{out} \\ 0 & v_{hub} \geq v_{out} \end{cases} \quad (1)$$

The rotor diameter  $R$ , efficiency  $c_p$ , capacity  $C$ , cut-in wind speed  $v_{in}$ , cut-out wind speed  $v_{out}$  as well as rated wind speed  $v_r$  are determined by the specific turbine type. The cut-in wind speed is the speed, where a turbine starts to generate power output. At rated wind speeds it produces at maximum (capacity) level and for wind speeds above the cut-out it stops due to technical limitations and security issues. The wind speed  $v_{hub}$  and air density  $\rho_{hub}$  from equation (1) need to be known at the turbine's hub height, since both quantities vary substantially with height.

Due to the cubic dependency of the power output by the wind speed at hub height in equation (1), it is crucial to have highly

accurate wind input data. The wind input data is obtained from reanalysis data on a pre-defined grid. Two steps are necessary to get the wind speed at the specific turbine location and hub height. First of all, wind speeds are horizontally interpolated from adjacent grid points to the exact specific wind park location using the inverse distance weighting method. Second, wind speeds need to be vertically interpolated, respectively extrapolated to the adjacent hub height. Reproducing the vertical wind profile is a challenging task due to the complexity of atmospheric stability conditions [7–9]. In this paper, we use a vertical interpolation between the first six model layers obtained from the reanalysis data by a 3rd order fit.

### 2.2. Application of REOM: generation of a European long-term dataset

A wind park dataset is necessary to provide information about geographical coordinates, commission dates (production start dates), hub height, rotor diameter as well as the specific power curve characteristics (cut-in, cut-out, rated speed and capacity) for every single wind park in Europe. We use an extract of the worldwide database for wind turbines and power parks from *The Wind Power*<sup>1</sup> [10], last updated in April 2016. In order to be able to compare different years of weather and hence wind power production, we use the European wind power park fleet of the end of 2014 as the basis for our long-term wind power production simulations. After filtering out parks without a detailed location, production status or commission date information, 15 400 European parks contributing to an overall installed capacity of 119.85 GW for 2014 are left. However, some parameters are still lacking to different extents. For instance, for more than half of all parks in Europe the rotor diameter is unknown and for roughly 40% the exact hub height is lacking. In these cases default values are set, obtained by the mean of the particular parameter and country. In the Appendix Figs. A1 and A2 show the distribution of installed capacity in Europe for 2014 and Table A1 summarizes the parameter availability.

Imprecise wind input, due to the cubic dependency in equation (1), results in highly inaccurate wind energy outputs. Since wind speed is highly variable in time and space it is desired to use temporal and spatially high resolution wind input data. Reanalysis products are an approach to solve the lack of high resolution and homogeneously distributed data. They are systematic approaches to generate long-term datasets on a defined homogeneous grid for climate research by combining an assimilation scheme for historical observations with a certain atmospheric circulation model. Several reanalysis datasets are available for different historical periods, spatial domains and resolutions. However most of these products have a coarse horizontal resolution [6], e.g. ERA-Interim with approximately 80 km in Europe, due to their global coverage and computational limits. This might be a problem especially in mountainous regions, where the meteorological model is not able to reproduce the underlying terrain and capture wind speed variations adequately [11]. To reduce these inaccuracies we use the novel high resolution reanalysis dataset COSMO-REA6 from the Climate Monitoring Branch of the Hans Ertel Center for Weather Research (HErZ-TB4) funded by the German Weather Service (DWD). It provides hourly wind data between 1995 and 2014 in Europe on a 0.055° (approximately 6 km) horizontal grid spacing with 40 different vertical layers. For more details about the reanalysis model and dataset see Bollmeyer et al. [12].

Staffell and Pfenniger [6] point out that a key factor for

<sup>1</sup> [www.thewindpower.net](http://www.thewindpower.net).

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