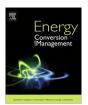
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Development of a statistical bivariate wind speed-wind shear model (WSWS) to quantify the height-dependent wind resource



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ABSTRACT

The goal of this study was to develop a statistical bivariate wind speed-wind shear model (WSWS). The development of WSWS is based on near surface wind speed data available from 397 measurement stations distributed over Germany, as well as on ERA-Interim reanalysis wind speed data available in 1000 m above ground level (a.g.l.). These data were used (1) to calculate empirical distributions of wind speed in 1000 m a.g.l., (2) empirical distributions of the wind shear exponent, and (3) to fit theoretical distributions to the empirical wind speed and wind shear exponent distributions. It was found that the four parameter Johnson SB distribution reproduces the shape of the wind speed in 1000 m a.g.l. empirical distributions best. The four parameter Dagum distribution provided good fits to the empirical wind shear distributions. The parameterized wind speed and wind shear marginal distributions were then linked by 16 joint copulas. Goodness-of-fit evaluation of the joint copulas demonstrates that the Gaussian-Gaussian copula reproduces the empirical bivariate wind speed-wind shear distribution most accurately. By using WSWS it is possible to continuously calculate the wind speed probability density function in hub heights between 10 m a.g.l. and 200 m a.g.l. This allows WSWS to be applied to virtually any power curve for computing the wind energy yield and capacity factor in the analyzed hub height range. A one-time site-specific parametrization of WSWS is sufficient for a comprehensive height-dependent exploitation of the available wind resource.

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1. Introduction

The current global electricity consumption is mainly covered by conventional fuels [1]. However, it is essential to find appropriate substitutes for conventional fuels. First, their utilization is strongly connected with greenhouse gas emissions, which cause climate change [2]. Second, emission of air pollutants by combustion processes can impair human health [3]. Moreover, the peaking of fossil fuels is anticipated in the next decades [4]. It is expected that wind energy will be one important substituent for conventional fuels and plays a major role in the future energy mix [2].

Wind turbines are used to convert the kinetic energy of the airflow first into mechanical and then into useful electric energy [5]. The countries with largest installed wind energy capacity in 2016 were China (168,690 MW), the USA (82,184 MW) and Germany (50,018 MW) [6]. From these three countries Germany has by far the highest wind turbine density with 0.076 wind turbines/km² and an average capacity of \sim 1.68 MW per onshore wind turbine. At the end of 2016, a total of 27,270 onshore and 947 offshore wind

turbines were installed in Germany [7] and the share of renewable energies in the electricity consumption was 31.7% corresponding to a gross electricity production of about 188 billion kWh [8]. In the same year, wind energy covered 13.0% of Germany's gross electricity consumption. According to the German Renewable Energies Act in the version issued 2014, Germany aims to further increase the share of renewable energies until 2025 to 40–45% and until 2035 to 55–60%. To achieve these goals, a massive installation of new wind turbines is necessary.

Prior to installation of wind turbines accurate wind resource assessment is necessary [9-11]. Wind resource assessment can be carried out by connecting wind speed (x) and characteristics of the land surfaces [12]. Often, the wind power density function is used as an important indicator for the available wind resource [13]. It is estimated by

$$P(x) = \frac{1}{2}\rho x^3 f(x) \tag{1}$$

where ρ is the air density. Accordingly, P increases with the cube of x, which means that a rather small error in the assessment of x leads to a large estimation error of the available wind resource. The mean wind power density (\bar{P}) is often used as a qualitative magnitude to

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Nomenclature

Ass.l. above ground level Ass.l. above ground level Ass.l. above ground level Ass.l. above sea leved Ass.l. above sea level Ass.l. above sea leve	Acronym	c	MOM	moment method
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