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Validation of Danish wind time series from a new global renewable energy atlas for energy system analysis

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ABSTRACT

We present a new high-resolution global renewable energy atlas (REatlas) that can be used to calculate customised hourly time series of wind and solar PV power generation. In this paper, the atlas is applied to produce 32-year-long hourly model wind power time series for Denmark for each historical and future year between 1980 and 2035. These are calibrated and validated against real production data from the period 2000 to 2010. The high number of years allows us to discuss how the characteristics of Danish wind power generation varies between individual weather years. As an example, the annual energy production is found to vary by ±10% from the average. Furthermore, we show how the production pattern change as small onshore turbines are gradually replaced by large onshore and offshore turbines. Finally, we compare our wind power time series for 2020 to corresponding data from a handful of Danish energy system models. The aim is to illustrate how current differences in model wind may result in significant differences in technical and economical model predictions. These include up to 15% differences in installed capacity and 40% differences in system reserve requirements.

1. Introduction

In 2020, Danish wind power is expected to cover about 50% of the Danish electricity consumption on average [1]. This means that fluctuations in the wind will clearly dominate many technical and economical aspects of the power system. For this reason, it is of obvious importance to use an accurate representation of the future wind power in models of the future power system. But to the best of our knowledge, there is currently no consensus on how to select and validate a good forecast of future wind power generation time series for the different energy system models of e.g. Denmark.

In this paper, we present and apply a new global high-resolution renewable energy atlas (REatlas) to model hourly Danish wind power generation for all years between 1980 and 2035. The model is based on a detailed representation of historical and future configurations of Danish wind turbines. With a simple calibration of the wind speed-to-power conversion, we show how historical wind power production for Denmark during the period 2000 to 2010 can be reproduced.

The calibrated model is then used to convert 32 years of weather data to hourly model time series for turbine configurations representing each year from 1980 to 2035. These are available for download in the Python npy-format [2]. To the best of our knowledge, this study represents the most detailed model calculations of future Danish wind power generation available in the scientific literature.

The time series are used to forecast future characteristics of Danish wind power generation, and to show how past and future wind power generation from a particular turbine configuration varies between individual weather years. In addition, we compare and discuss wind power time series for 2020 from different Danish energy system analysis tools to illustrate how large and important differences in the prediction of technical and economical characteristics of the future power system can be caused by differences in the wind power time series. We are not aware that such a comparison has been carried out previously.

The REatlas used in this study is global and can be applied to generate hourly time series of both wind and solar PV power generation. It is based on a state-of-the-art global 32-year-long meteorological data set from the American weather service NOAA, and it meets a number of design goals for state-of-the-art and next

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generation energy system modelling (see Section 3.1). In this paper, we present the detailed implementation of the REatlas for the first time.

The development of the REatlas is motivated by a need for an efficient and configurable wind and solar PV conversion tool. As an example, it has been optimised in software and hardware for very fast repeated wind or solar PV conversions with different technologies and/or geographical capacity assignments. Among other things, this makes it possible to make predictions of the consequences of development in wind or solar technologies, different renewable energy strategies, and even optimisation of strategies with respect to multiple objectives. It also allows for easy sensitivity analysis.

Other wind or solar atlas with high temporal resolution, e.g. hourly, do not allow the user to modify the input parameters for the conversion to wind or solar power. Instead, specific technologies have been preselected, and only the resulting time series are available (examples are [3–5]).

The paper is organised as follows: Previous, related studies are briefly discussed in Section 2. In Section 3, the REatlas is described. Section 4 is concerned with validation of model wind power time series for Denmark 1980 to 2035. Section 5 contains a discussion of wind power time series for 2020 from a handful of different models of the future Danish power system. Finally, the paper is concluded in Section 6. Further details on the REatlas software and hardware implementation can be found in Appendix A.

2. Previous studies

The time series presented in this paper are based in reanalysis data from state-of-the-art climate data. This approach offer many advantages for the generation of wind power time series. In particular, multiple decades of consistent global weather records are available in this form, and it contain consistent spatial and temporal correlations. Furthermore, many other weather fields relevant for either weather-driven power generation or demand modelling are included in the climate models. Examples are solar irradiation and temperature, which are both relevant for solar energy production as well as heating or cooling demands.

A number of recent studies use reanalysis data from atmospheric climate models such as ERA-40 [6] and CFSR (Climate Forecast System Reanalysis) [7] as a source of wind speeds. Most interesting are studies where the resulting wind power time series have been compared against historical records. Kiss et al. [8] appears to be first to compared nacelle measurements of wind speed and power generation from two turbines in Hungary to the ERA-40 reanalysis data set. They found a “satisfying agreement” with proper calibration of the conversion model. Other studies include: Hawkins et al. [9] who replicated monthly load factors for the UK from a reanalysis data set calculated with the WRF (Weather Research and Forecast) model. Kubik et al. [10] matched the global NASA reanalysis to half-hourly power output from wind parks located in Northern Ireland. Finally, Staffel and Green [11] used the NASA data set to investigated the performance of wind farms located in the UK (United Kingdoms).

3. Methodology: REatlas

The REatlas is a computer program, currently implemented in a mix between the Python and the C programming languages. It is used to calculate hourly generation profiles of wind and solar PV based on a 32-year-long global high-resolution data set from the American weather service NOAA [7,12]. Further input is the power curves of wind turbines and the efficiency curves and orientations of solar PV modules. The latter can have fixed orientations or single/dual-axis tracking of the sun. If the total production of a region, e.g. Denmark or Europe is needed, the distribution of installed capacity is also an input, and simple spatial distributions of turbines or PV panels, such as proportionally to generation potential, can be automatically generated. A simplified version of the REatlas implementation is shown in Fig. 1.

The REatlas is designed to satisfy a number of design goals. These are listed in Section 3.1. The input data is described in Sections 3.2 and 3.3, and the wind conversion algorithm is described in Section 3.4. Details on the solar PV conversion can be found in Ref. [13].

Furthermore, a combined software and hardware implementation and optimization of the REatlas is described in Section 3.5 with

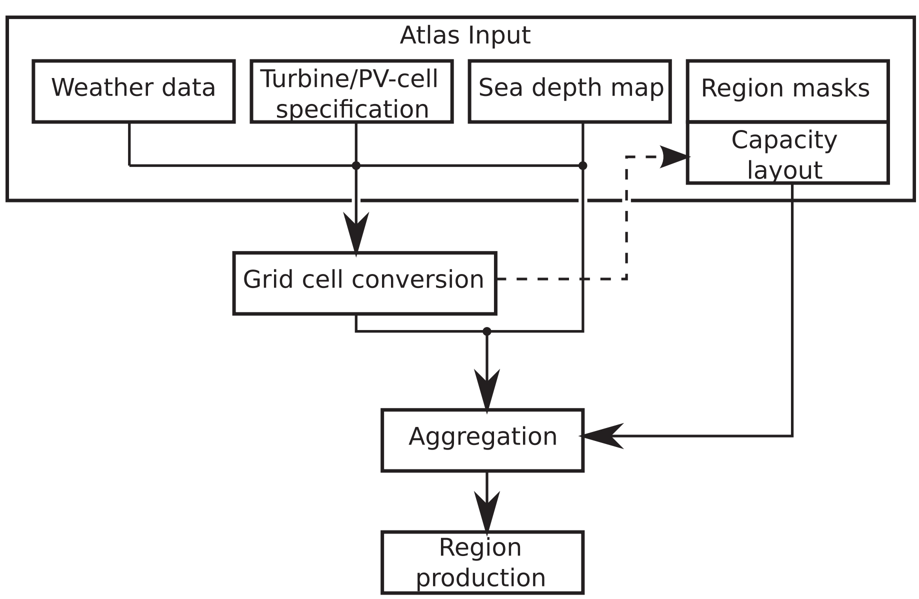

Fig. 1. Flowchart of the renewable energy atlas. The input data and parameters are first converted to hourly wind or solar PV power generation for each individual grid point. Then the production for a region is obtained by weighted aggregating over the grid cells within a region mask, which specifies the installed capacity for each grid point. A capacity layout proportional to the individual grid point capacity factors can be generated automatically, or a custom layout can be specified by the user.