Department for
Energy Security
& Net Zero

Wind load factor methodology note

DESNZ SICE Methodology to Estimate Net Load Factors for Renewable Wind Technologies

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Introduction

This report outlines a methodology for estimating net load factors for offshore wind and onshore wind generation.

The methodology uses satellite data and wind power curves to simulate the load factor of existing sites in Great Britian on an hourly basis. These simulated load factors are then calibrated against real generation data, to correct for errors in the simulations and additional losses.

The load factors of larger turbines positioned at representative future sites for onshore and offshore wind are then simulated, and the calibration factors from existing data are used to convert the simulated load factor to a prediction of net load factor.

1 Simulating load factors

1.1 Data source

The weather data source used for this modelling is ERA5, published by the ECMWF[1]. ERA5 has hourly data at a spatial resolution of 0.25 ° x 0.25 °, which translates to approximately 30x20km at UK latitudes. ERA5 is widely used by industry and academia and was assessed as appropriate for the use case presented here.

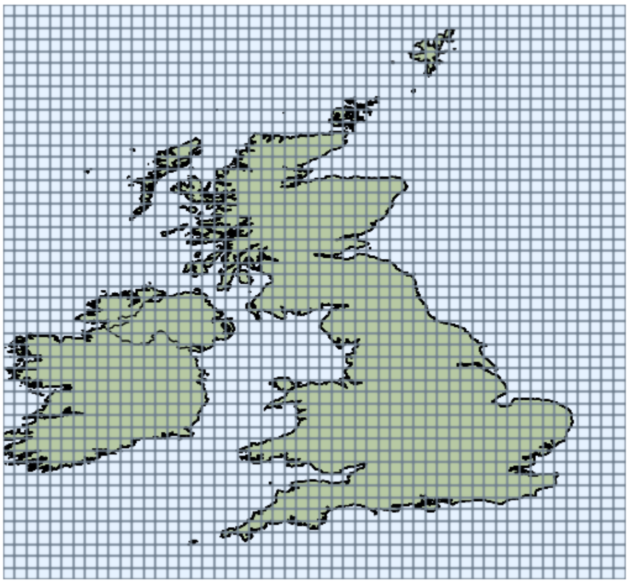

Figure 1: The ERA5 grid squares over the UK

For predicting the output of wind farms, wind speed data at a height of 100m is used.

1.2 Wind speed adjustment

The windspeed in ERA5 has two components, north and east, which can be combined to find the total wind speed magnitude.

To model the wind speed at the various heights, the wind profile equation is used.

$$u = u_r \left(\frac{z}{z_r}\right)^{\alpha}$$

Where *u* is the windspeed, *z* the height, α a coefficient which can vary based on atmospheric conditions, and the *r* subscript indicating ERA5 data points. The value for alpha used is 1/7, a common approximation for neutral stability conditions[2].

[1] https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5
[2] https://doi.org/10.1175/1520-0450(1978)017%3C0390:OTUOPL%3E2.0.CO;2

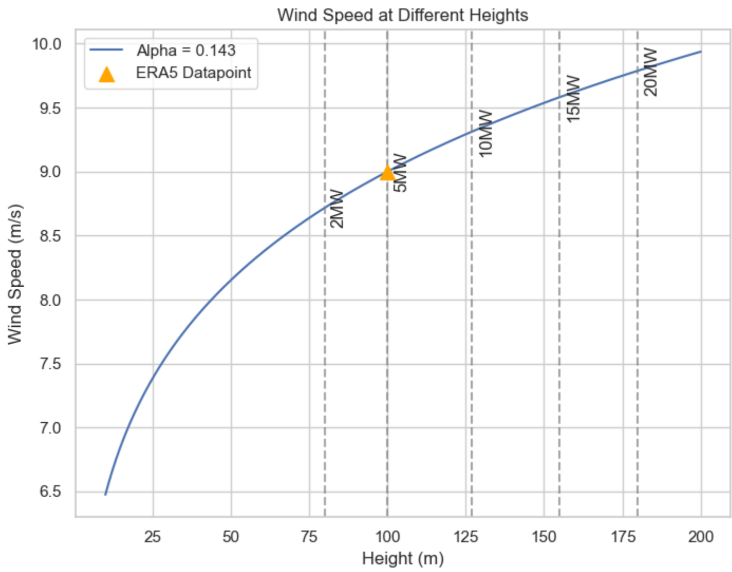

Figure 2: Wind height adjustment using the wind profile equation

1.3 Power curves

A power curve describes the relationship between wind speed and the power generated by a wind turbine.

The power curves used for this work were provided by industry, at 0.5MW increments up to 20MW. The power curves assume that turbine's fundamental performance will not increase as turbine sizes increase. The power curves have been compared to other power curves provided from different sources and show good agreement.

1.4 Errors and losses

Using the ERA5 wind speeds and the power curves does not account for any of the losses which wind farms will be subject to. The resulting load factor can therefore be thought of as a prediction of the **gross load factor**. This prediction will have some error, from several sources.

The most material source of potential error will relate to variation in wind speed within grid cells. ERA5 grid cells are approximately 30x20km in size. There will be substantial variation in the wind speeds of different locations within that cell, due to local topology, which means that the aggregation necessary to make the analysis tractable will necessarily not pick up the level of output variation that a siting study for an individual wind farm might take into account. Tthe wind speed prediction should be taken as an average across that grid square. This will be most applicable for onshore wind, and offshore wind sites close to the shore. However, the largest and most significant offshore wind sites are further out to sea, where the ERA5 data are likely to be a close fit.

There will also be some error in the wind speed height adjustment and the power curves: both will be valid for average air density and turbulence conditions, but in non-average weather conditions will no longer be representative.

The prediction of the gross power output also does not account for any of the losses which wind turbines experience which reduce the amount of power they generate. These factors alter the “gross” outputs from an individual turbine operating perfectly to “net” outputs that reflect that turbines are not fully reliable, require maintenance downtime, and need engineering compromises on the electricity transmission systems to make them affordable.

Gross to net losses come from several sources. These include:

- Internal wake effects
- Electrical transmission losses
- Turbine performance: over time the efficiency of the turbines decreases slightly as the equipment ages.
- Availability (e.g. downtime due to maintenance)
- Environmental losses: local factors such as trees and hills may reduce the energy yield of a particular onshore turbine.
- Self curtailment due to noise constraints.

In addition to these losses, there are curtailment losses: a generator may not be able to sell their energy if the grid cannot transport that energy to demand centres (locational balancing curtailment), or if there is not demand for the energy (economic curtailment).

2. Calculating net load factor

The correction factor to go from simulated to net load factor is found through comparison to real generation data, instead of making assumptions around wind farm design and operation, as the chosen assumptions will have a major impact on the results. The comparison was made for 55 sites between the years of 2020 and 2023 (onshore and offshore sites were compared separately).

This correction should account both for systematic errors in the modelling and the losses which are not modelled.

The turbines which are being simulated for informing future policy decisions are not currently in operation in large enough scale for data to be available for comparison. The real data is from existing wind farms with smaller turbines, and the assumption is made that the correction from the modelled load factor to the net load factor for smaller turbines is the same as the correction for larger turbines.

Most of the losses will be subject to design or operational decisions. By using the adjustment from existing sites for future wind farms, we are assuming that the future design choice, performance and behaviour of operators does not alter compared with the traditional operating practices of the UK wind industry.

Many of the losses experienced are fairly consistent across different wind farms, although wake effects will vary significantly depending on the wind farm density and layout. The wake effects of specific sites can be simulated, but accurate modelling would require assumptions to be made around the layout of the site. Comparing the simulated load factor to real net load factors removes the need for assumptions.

It is also assumed that the relationship between the modelled gross load factor and the energy sold in the absence of curtailment is the same for real sites as it will be for future sites, using larger wind turbines.

2.1 Elexon data

Elexon is responsible for managing the Balancing and Settlement Code[3]. As part of this responsibility, they publish data from participants in the Balancing Mechanism. The Balancing Mechanism is the process by which energy is bought and sold to meet demand: any generator connected to the transmission grid is obligated to report information to Balancing Mechanism. The amount of energy sold by all of these generators is available on a half hourly basis. Each individual wind farm will be made up of one or more Balancing Mechanism Units (BMUs).

It is worth noting that none of the onshore sites analysed for this comparison are in England. This is because there are currently no large wind farms in England connected to the transmission grid and hence data is not published on a half hourly basis.

2.1.1 Curtailment data

To accurately analyse the differences between the modelled load factor and the real generation, we need to remove those hours where curtailment occurs. There are two significant types of curtailment for a wind farm: economic and locational balancing.

Economic curtailment occurs when the generator cannot recoup enough money to cover its short run marginal cost. The conditions for economic curtailment will depend on the subsidy regime which the generator is operating under, but for the purposes of this analysis we have excluded any hour where the Intermittent Market Reference Price (IMRP), the benchmark price which Contract for Difference (CFD) payment is based on, is below £0.

Locational balancing curtailment occurs when the transmission grid is too constrained for the energy sold by a generator to reach sources of demand. In these instances, generators will submit bids to the balancing mechanism indicating the price which they will have to be paid to turn off their generation. All hours where

[3] https://www.elexon.co.uk/bsc/bsc-and-codes/

locational balancing thermal curtailment occurs have been excluded from the comparison between simulated gross and real net load factor.

In the dataset studied, onshore wind is curtailed more often than offshore wind: some of the sites studied were curtailed more than 15% of the time. The majority of offshore sites studied experienced very little curtailment, with one exception, Moray East.

2.2 Simulated to real comparison

Due to the limited resolution of the ERA5 data, the real data will never be perfectly correlated with the simulated data. However, the real and simulated data for the majority of sites had a Pearson's correlation coefficient above 0.83, indicating a reasonably good correlation between the two. Offshore sites had higher R^2 values than onshore sites. The adjustment factors were found by taking the capacity weighted mean of the difference between the simulated and real load factors. This was done separately for the onshore and offshore load factors to account for the differences in errors and losses between the two.

2.3 Gross to net adjusted load factors

No statistically significant correlation between turbine size and the adjustment factor was found for the sites studied. For this reason, the adjustment factors for onshore and offshore sites were used for the future turbine sizes, despite the fact that no similarly sized turbines appeared in the studied sample.

3 Predicting future load factors

Many policy decisions require forward looking estimations of net load factor. The load factors of future turbines depend on the turbine sizes and their locations. Using the adjustment factors from historic data assumes that the unaccounted-for losses and errors will be the same for future sites as for those in the studied dataset.

For all estimations of future load factor, we have used historic weather data between 2000-2024.

The load factor methodology presented here represents an update on DESNZ's previous approach and is currently undergoing independent external peer review.