A study of the variation in offshore turbulence intensity around the British Isles

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prevailing wind farm analysis

MAINSTREAM RENEWABLE POWER

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Abstract

Offshore met mast installation is expensive and time-consuming, so remote sensing devices are increasingly employed as a cheaper and quicker alternative. However, turbulence intensity measurements from remote sensing cannot be directly related to measurements provided by cup anemometers. Turbulence intensity is a key input to wake models and a significant driver of turbine loading, and therefore impacts wind farm energy yield, turbine selection, and capital expenditure.

This study investigates the variation and drivers of turbulence intensity around the British Isles, to determine whether on-site turbulence intensity measurements are required for proposed offshore wind farms.

The work has been carried out by Prevailing for the Carbon Trust's Offshore Wind Accelerator and Mainstream Renewable Power.

Methods

8 publicly available datasets have been analysed from offshore met masts in the Irish Sea and North Sea (Figure 1). Data was sourced from The Crown Estate's Marine Data Exchange and Energieonderzoek Centrum Nederland's Wind op Zee website.

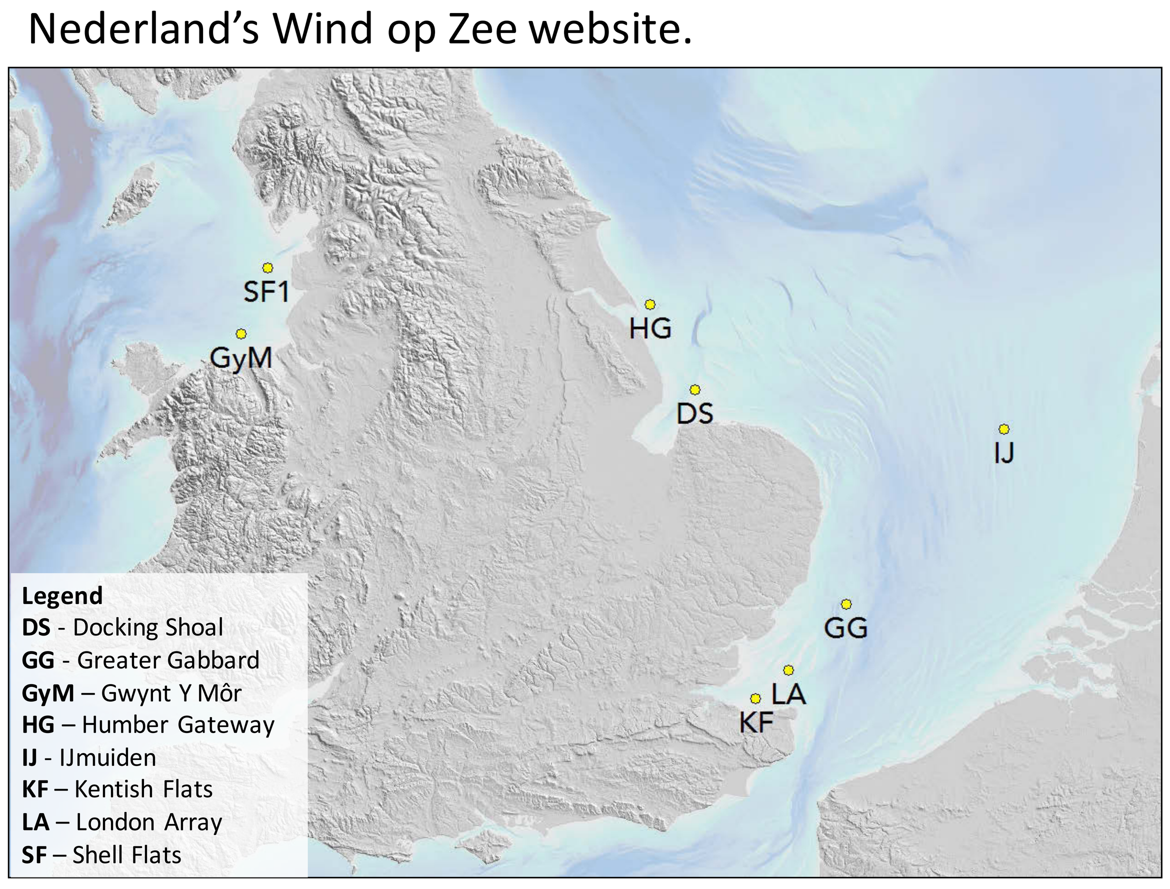

Figure 1. Locations of masts used in the analysis

The measured wind data was processed and cleaned using industry standard methods. Wind speed data at all masts was extrapolated to a height of 87 m using measured shear and seasonally-balanced datasets. Various turbulence intensity metrics were derived. Combined air and sea temperature data were only available at the IJmuiden mast.

The variation of these metrics were analysed as functions of wind speed, wind direction, distance to the coast, presence of significant terrain upwind, season and temperature.

There were a number of issues with the datasets used due to a lack of installation and maintenance information, poor data coverage and equipment malfunctions at some masts. Consequently the data processing undertaken does not meet financial-grade analysis standards. Nevertheless, the resultant datasets are deemed of acceptable quality to provide robust turbulence intensity metrics for the purposes of this study.

Results

Mean turbulence intensity metrics were observed to be very consistent across all datasets (Figure 2). Similarly, distributions of mean turbulence intensity as a function of wind speed (Figure 3) and turbulence intensity probability distributions (Figure 4) are in good agreement. Sensitivity tests using an Eddy Viscosity wake model show that the use of the highest or lowest turbulence intensity distributions results in relatively

Results (continued)

small wake loss differences of approximately 0.3 % for a typical offshore wind farm, significantly lower than the uncertainty in the wake modelling itself.

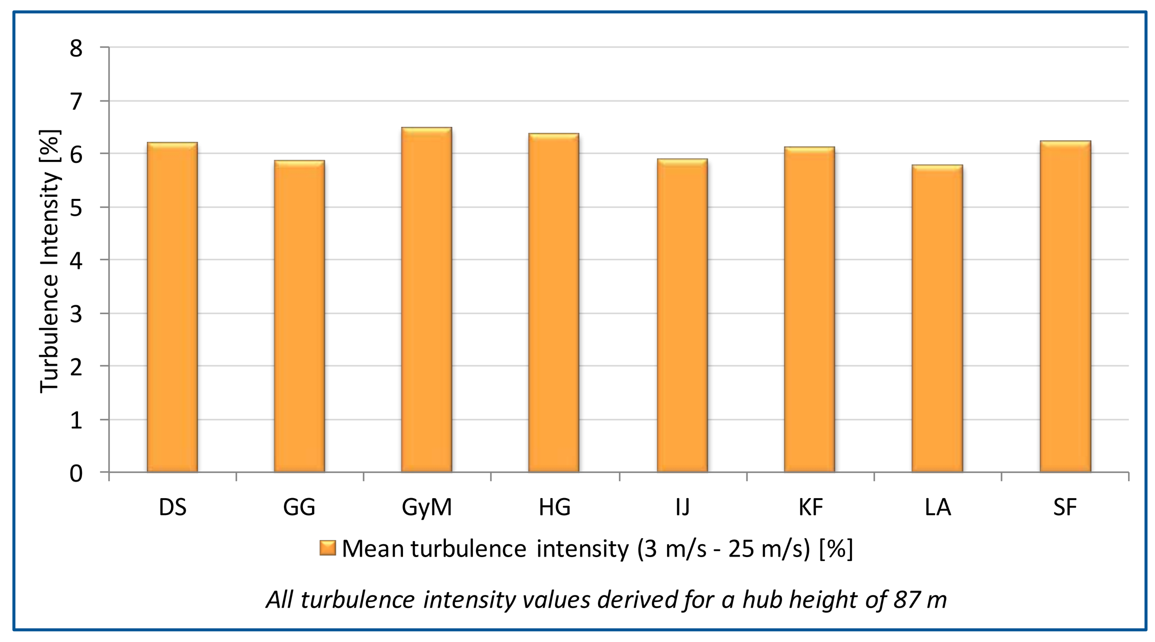

Figure 2. All-directional turbulence intensity

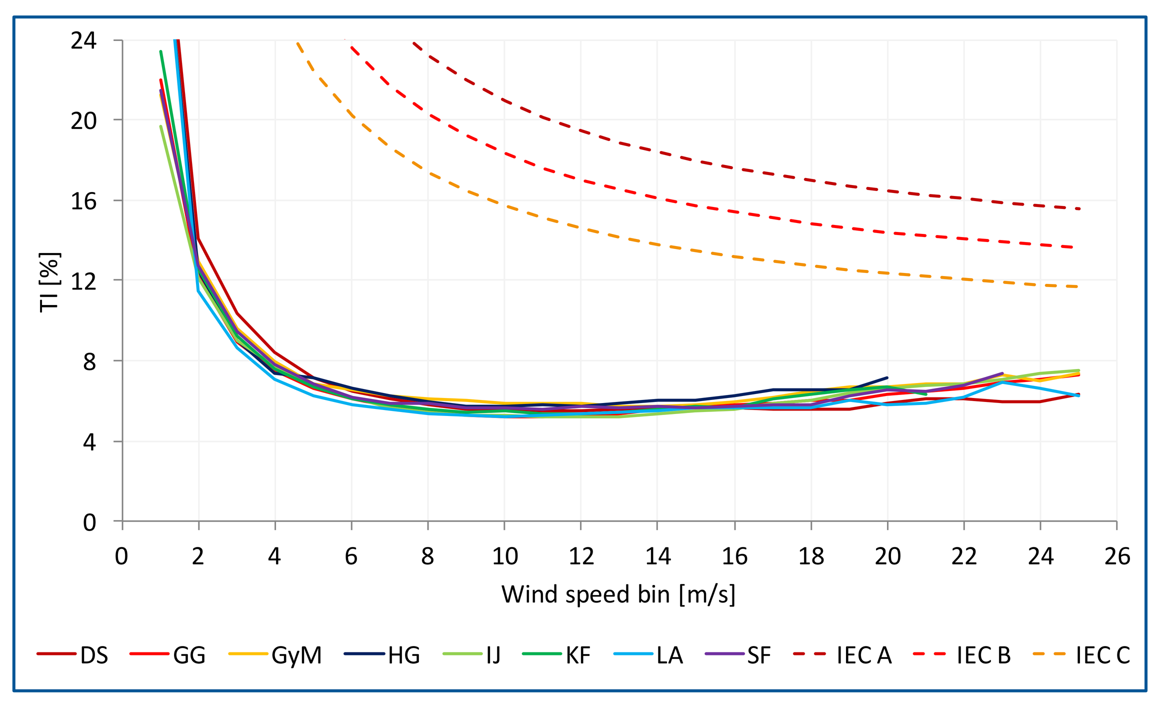

Figure 3. Mean turbulence intensity vs wind speed

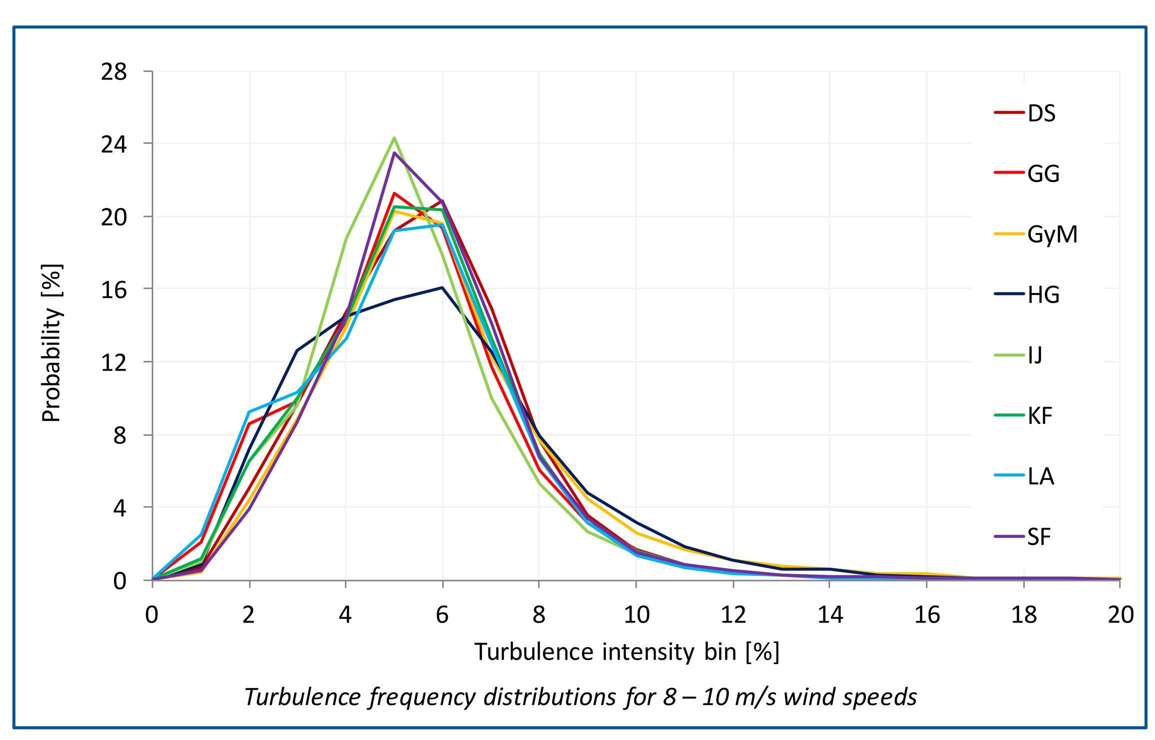

Figure 4. Turbulence intensity frequency distributions

For all the locations considered in this study, fetch (distance to coast) is generally greater than 10 km, and no clear trend in turbulence intensity due to coastal proximity was observed (Figure 5). The exception to this is for locations with significant terrain upwind – increased turbulence intensity was observed at Gwynt y Mor due to the presence of the Snowdonian mountains, which is consistent with findings of another study[1].

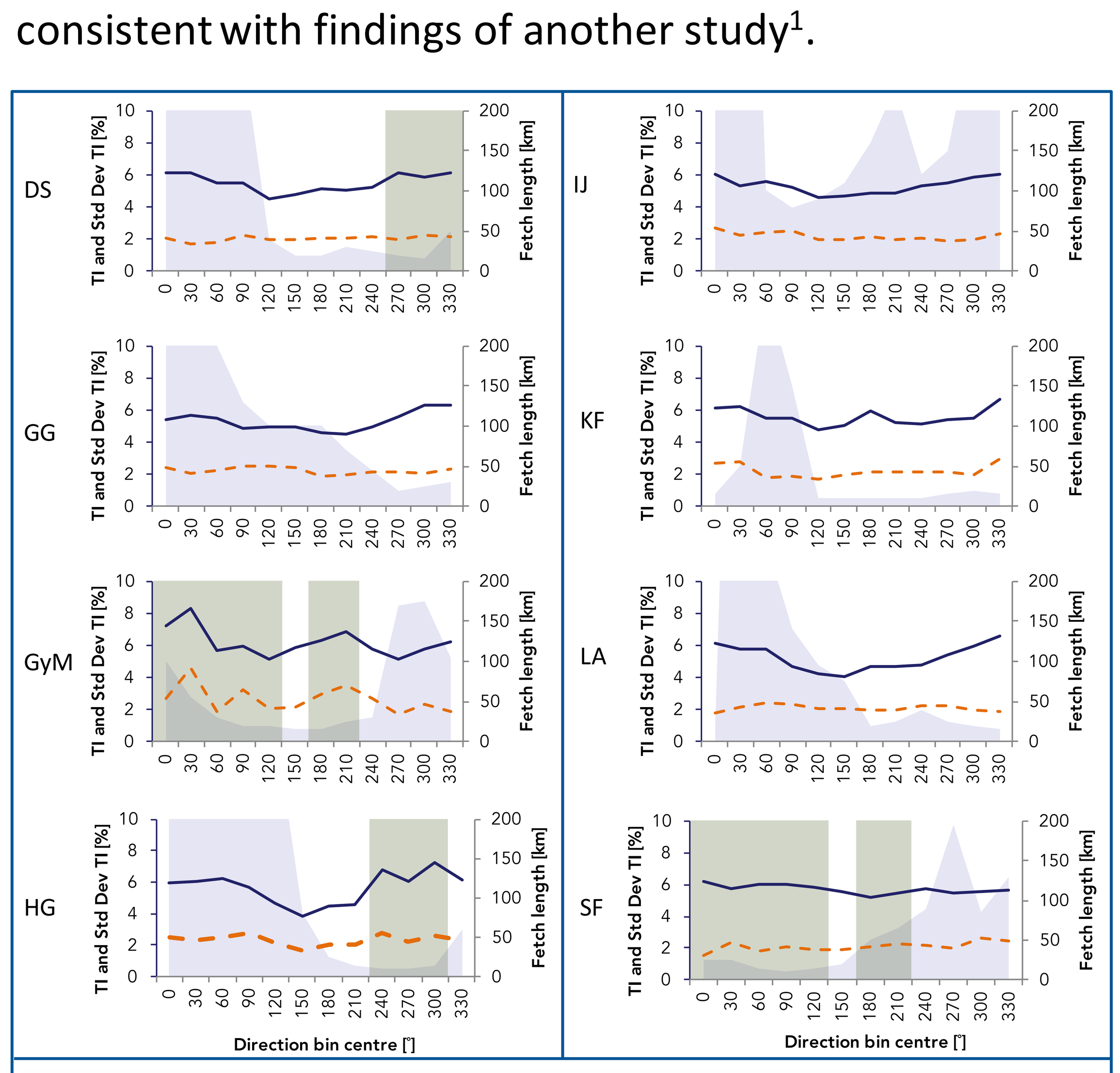

Figure 5. Turbulence intensity vs wind direction with fetch and presence of complex terrain upwind

Results (continued)

A clear seasonal variation was observed (Figure 6), with lowest turbulence intensity during spring at most masts. This suggests that the slower warming of the sea, compared to land, creates a stable boundary layer resulting in lower turbulence. This effect was investigated further using the IJmuiden mast, where both air and sea temperature data are available (Figure 7). For this dataset, a clear correlation was observed between turbulence intensity and the sea-air temperature difference, supporting the stable springtime boundary layer hypothesis.

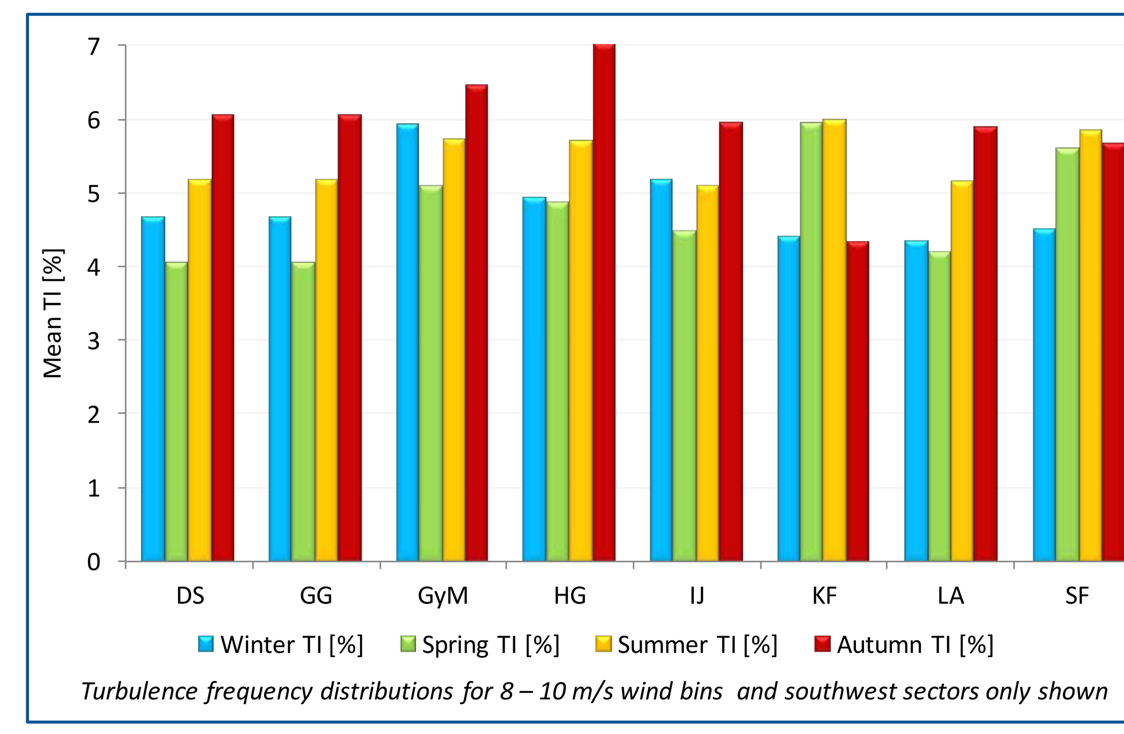

Figure 6. Turbulence intensity by season

	Wind speed [m/s]													
Air – water temp [ºC]	3	4	5	6	7	8	9	10	11	12	13	14	15	16
-8 (air colder than water)					8.8	8.4	8.1							
-7		13.6		10.7	9.5	7.9	6.8							
-6		14.0	11.0	10.6	9.3	8.2	7.4	7.4	7.3	6.9	7.1	7.1		
-5			11.0	10.3	8.6	7.8	7.0	7.7	7.1	6.8	6.5	6.8	6.8	6.4
-4	13.0	11.7	10.1	8.7	8.1	7.2	6.8	6.7	6.6	6.0	6.3	6.1	6.3	6.3
-3	12.1	10.8	8.1	7.3	6.6	6.1	5.9	5.8	5.8	5.9	5.7	6.3	6.2	6.2
-2	8.3	7.4	6.6	6.1	5.6	5.3	5.2	5.4	5.7	5.5	5.9	6.1	6.2	6.1
-1	6.9	5.7	5.2	5.2	5.0	5.2	5.1	5.3	5.3	5.6	5.9	6.0	6.2	6.2
0	6.0	5.5	4.8	4.2	4.3	4.3	4.3	4.6	4.6	4.7	5.3	5.8	5.6	5.8
1 (air warmer than water)	5.5	5.7	4.2	4.6	3.8	3.7	3.3	3.5	3.5	3.6	4.0	4.2	4.4	4.7
2	6.8	4.1	4.9	4.8	3.6	3.8	2.9	2.9	2.5	2.9	2.8	3.2	3.8	4.4
3				4.3	4.8	3.1	3.1	2.6	2.8		2.6			
4						2.8								

Data from IJmuiden mast only

Figure 7. Turbulence intensity vs wind speed and sea-air temperature difference

Conclusions

For the region and datasets considered in this study, the variation of turbulence intensity is observed to be more strongly connected to season than distance from the coast.

For sites more than 10 km from the coast, mean turbulence intensity and turbulence intensity distributions are very similar. Consequently, where a remote sensing device is employed on such sites, it is considered appropriate to use suitable off-site turbulence intensity measurements for wake modelling, energy yield analysis and representative turbulence intensity calculations.

Due to the observed seasonal variation in turbulence intensity, it is recommended that all turbulence intensity metrics for offshore wind farm energy yield assessment and turbine loading calculations are derived using seasonally balanced datasets.

References

1. "Characterization of Ambient Offshore Turbulence Intensity from Analysis of Nine Offshore Meteorological Masts in Northern Europe", Daniel Alexander Pollak, *DTU Wind Energy Master Thesis M-0056, 8 March 2014*