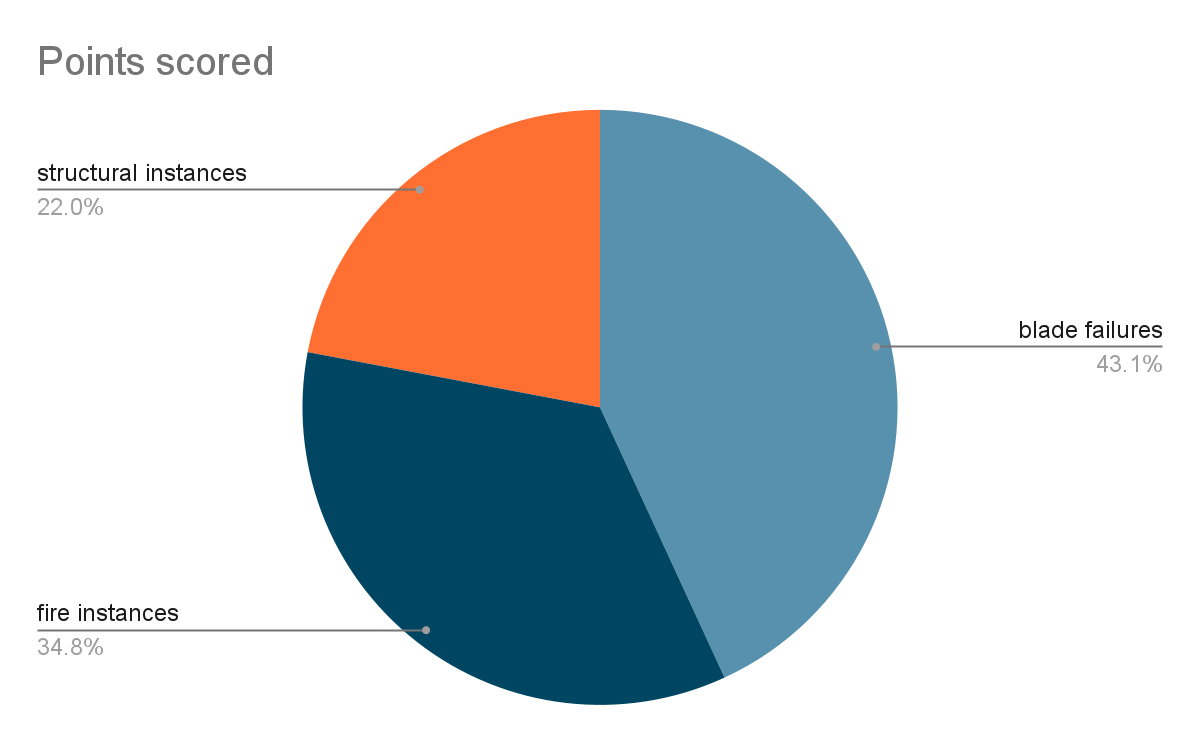
**NOTES**

**RISK TO OFFSHORE WIND TURBINES**

Resource: Windstorm risk assessment for offshore wind farms in the North Sea

During December 2011, 150-mph winds hit Scotland and Northern England, causing one turbine worth €2.2m in Ardrossan to burst into flames.7 This is not an isolated event with a total of 370 blade failures, 299 fire incidences, and 189 structural instances reported

Globally.9



According to Diamond,7 the total cost of installation of a 5-MW offshore wind turbine is approximately $14.2 million. This price varies depending on water depth as the foundation costs approximately $4.7 million of the total installation cost.7

Rose et al11 present a probabilistic model to show that in vulnerable areas of the Atlantic and Gulf Coastal waters of the United States, hurricanes could destroy nearly half the turbines in a farm in a 20-year period. Their study does not consider actual wind farms but focuses on four potential locations.

*7 Diamond KE. Extreme weather impacts on offshore wind turbines: lessons learned. Nat Resources Env't. 2012;27:37.*

*9 Caithness Wind Farms. Summary of wind turbine accident data to 30 September 2017. 2017. Caithness Wind Farms.* [*http://www.caithnesswindfarms.co.uk/AccidentStatistics.htm*](http://www.caithnesswindfarms.co.uk/AccidentStatistics.htm)*.*

*11Rose S, Jaramillo P, Small MJ, Grossmann I, Apt J. Quantifying the hurricane risk to offshore wind turbines. Proc Natl Acad Sci. 2012;109(9):*

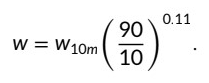
*3247-3252.*

As in Rose et al,11 to obtain the number of turbines damaged and accounting for replacement over a 20-year time period for each of the 38 wind farm locations, a series of Monte Carlo simulations were performed. From the energy developers' perspective, a 20-year time period is considered as it is the average time frame within which they own and operate the wind farm as stipulated in the power purchase agreement. The number of turbines Yrep that buckle with replacement in T years is modeled as a compound distribution with five parameters Yrep ∼ Compound Poisson (λ, a, b, α, β) where λ is the windstorm occurrence rate, a and b are the parameters of the LTW distribution, and α and β are the parameters of the log-logistic damage function. The simulation steps for each of the wind farm locations are as follows. Using a Poisson distribution simulate 10 000 20-year periods as to obtain the number of windstorm occurrences in each case. We considered

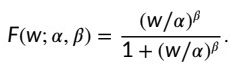
the rate of occurrence (λ) to be 1.515 as there were 50 recorded windstorms over a period of 33 years in and around the North Sea.

As in Rose et al,11 the total number of turbines buckled with replacement over the 20-year period was calculated as follows.

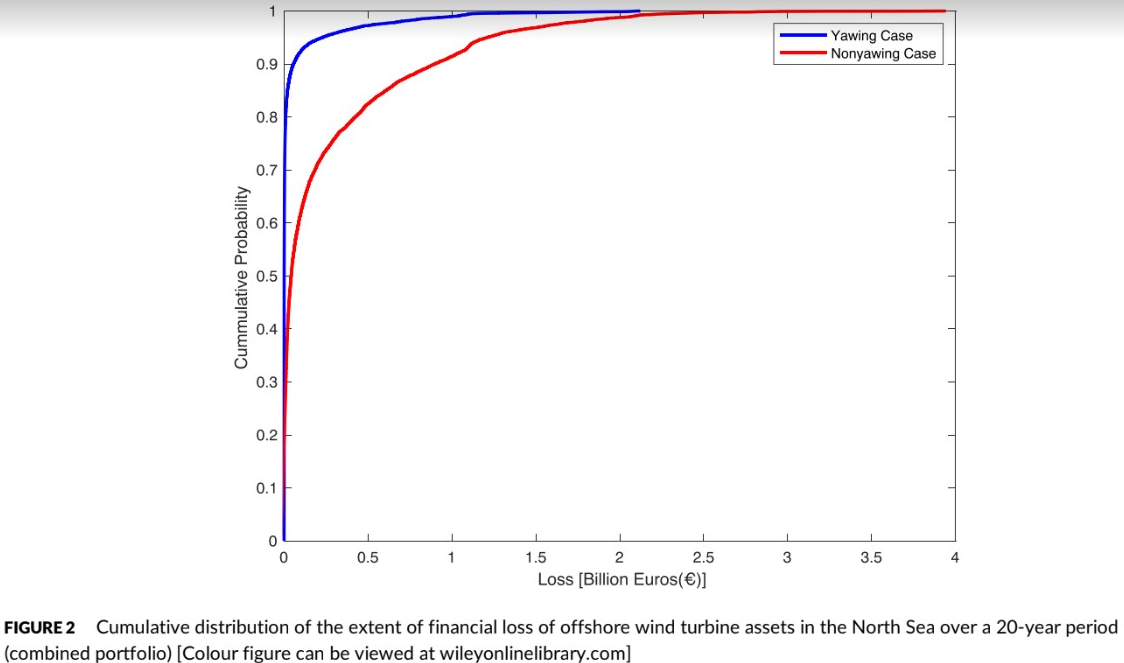
1. For each 20-year period, the maximum sustained wind speeds from the number of hurricane occurrences were drawn from the LTW distribution. The LTW distribution (a) scale and (b) shape parameters vary for each wind farm location. Table 1 shows the Weibull parameters for the different wind farm locations.
2. The obtained wind speeds were then scaled to hub height (90 m) using the equation below:

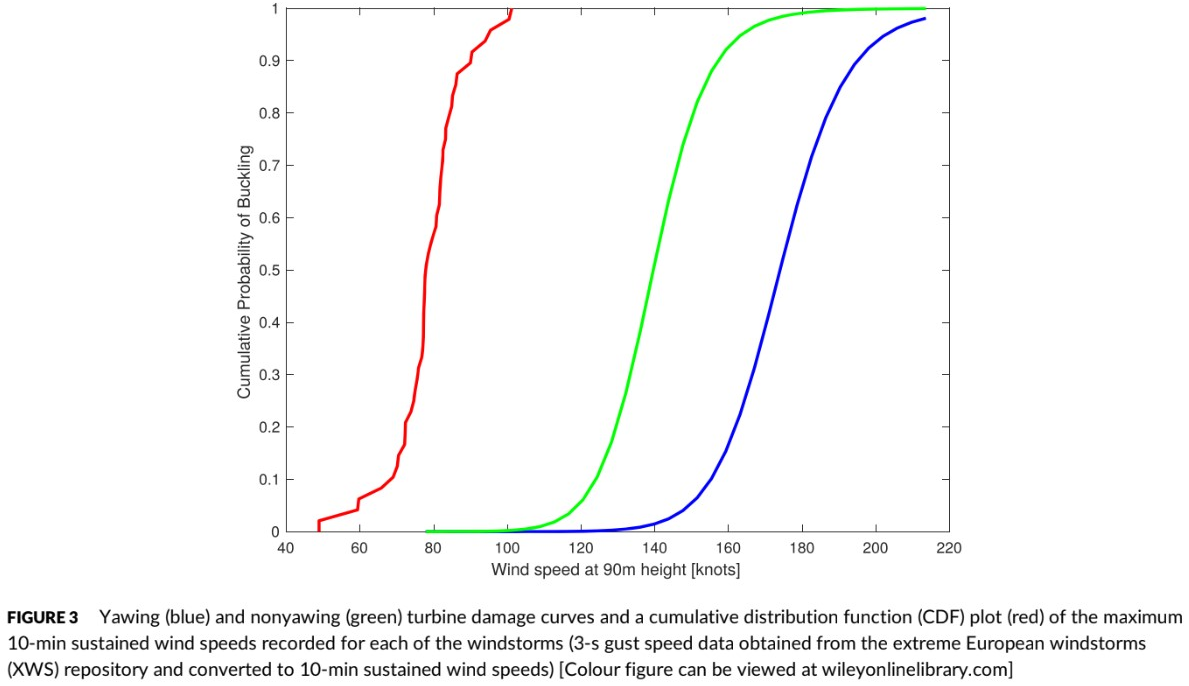


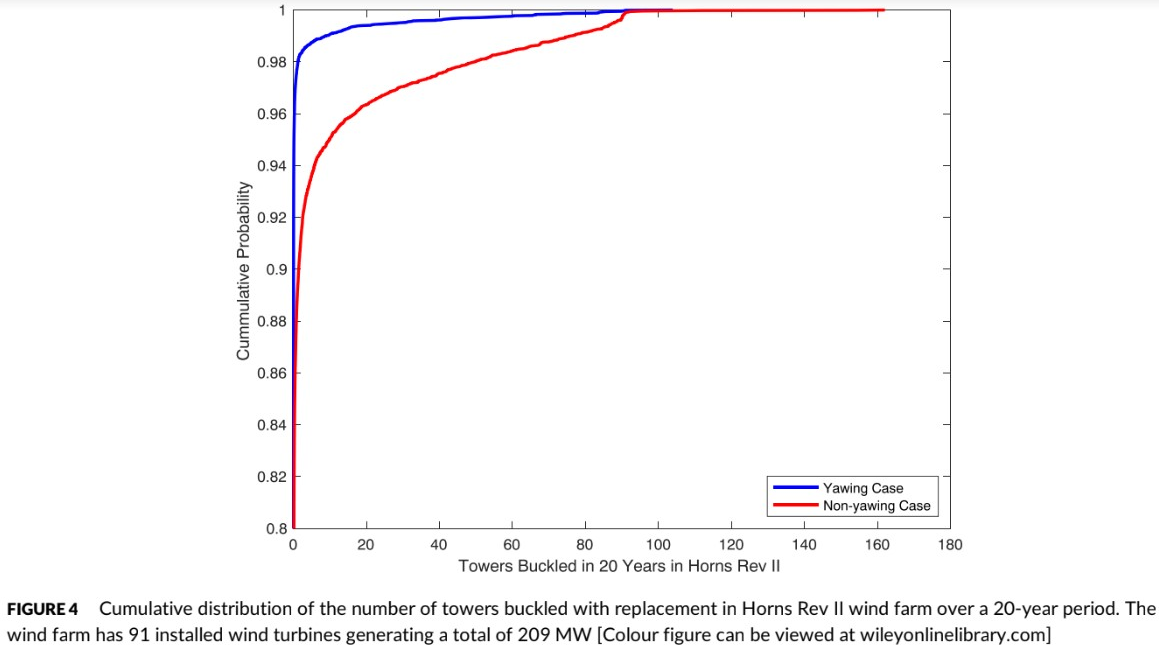
1. Using the log-logistic damage function (5), the probability of a single tower buckling as a result of each of the maximum hub height wind speeds (w) was computed. This was performed for both the yawing and nonyawing cases. The log-logistic parameters (α and β) used for the yawing and nonyawing cases are the same as those used in Rose et al.11 Table 2 shows log-logistic parameters for both yawing and nonyawing cases where the CDF is given by



1. From the probability of buckling a single turbine, the total number of turbines buckled on a wind farm with n turbines was computed. The total sum of damaged turbines over each 20-year period for a particular wind farm was then obtained. From the number of wind turbines damaged, consequent financial losses were computed using the cost per turbine for each of the wind farms. Aggregating the wind farms in the North Sea and considering the entire area as one portfolio, Figure 2 shows the CDF plots highlighting the probabilistic extent of financial loss over a 20-year period for both yawing and nonyawing cases in the North Sea.







***3.2 Insurer perspective***

Prior to providing cover against all forms of perils, insurers and reinsurers need to be able to quantify the associated risk. Key indicators of the underlying risk are the annual average loss (AAL) and probable maximum loss (PML). The AAL is the average loss of all simulated events, weighted by their probability of annual occurrence, and offers a means of comparing the risks associated with different perils. The PML is the maximum loss expected to incur on a policy, representing the worst-case scenario for an insurer. To obtain these values as a result of extreme windstorms, all the assets in the North Sea were considered as one combined portfolio, and the detailed simulation in Section 2 was performed for T = 1 year.

From the 10 000 1-year simulations generated, the AAL (€1.987m) and PML (€1.267bn) estimates were derived.

**WIND DATA**

Reference: GUIDELINES FOR CONVERTING BETWEEN VARIOUS WIND

AVERAGING PERIODS IN TROPICAL CYCLONE CONDITIONS

The WMO standard for estimating the mean wind is the 10-min average. This has the advantage of averaging over a period that is typically sufficiently long to incorporate most of the shorter period fluctuations in natural wind (turbulence) but is sufficiently short to be normally regarded as representing a period of near-constant background mean wind.

Although any period of time can be chosen for averaging the wind speed, shorter periods of

averaging will typically produce more erratic values than the 10-min average. For example, ten 1-min averages taken during a 10-min period will produce values that lie both above and below the 10-min mean value. Any single 1-min random sample is an equally valid (unbiased) estimate of the mean wind but it is likely to be higher or lower than the true mean wind. Hence, while one estimate of the mean wind is (statistically) as good as another, in practice, mean winds measured over shorter periods will possess greater variance and will therefore be ―less reliable‖. Alternatively, if there was no turbulence in the wind, then all averaging periods would yield the same true mean wind speed.

The practice of ―converting between wind speeds that are obtained from different wind averaging periods (e.g. 10-min, 1-min, 2-min, 3-min etc) is only applicable if the shorter averaging period wind is regarded as a ―gust, i.e. the highest average wind speed of that duration within some longer period of observation.

The ―maximum 1-min sustained‖ wind, as used in some WMO regions, refers to the highest 1-min average within a period of observation and is therefore also a gust relative to the estimated mean wind over that same period. Even a 10-min average wind can be a gust if it is the highest 10-min average observed within, say an hour, assuming that the mean wind is constant over that one hour period. It is important that all wind speed values be correctly identified as a mean or a gust. Hence, wind speed conversions to account for varying averaging periods are only applicable in the context of a maximum (gust) wind speed of a given duration observed within some longer interval.

GUST FACTOR:

The ―gust factor is then a theoretical conversion between an estimate of the mean wind speed and the expected highest gust wind speed of a given duration within a stated observation period.

In order for a gust factor to be representative, certain conditions must be met, many of which may not be exactly satisfied during a specific weather event or at a specific location.

There are two specific assumptions that apply for the theoretical estimation of gust factors:

(a) Turbulent Flow with a Steady Mean Wind Speed: If the mean wind is not steady within the period of the observation, then the observed gust is likely to deviate from the expected gust obtained from the statistical theory.

(b) Constant Surface Features:wind gusts measured on hills and slopes are likely to

deviate from the theory.

Also, as gust factors are normally expected to increase towards the surface as a result of increasing mixing, the nominated factor is only applicable between the mean wind speed and the gust wind speed at the same height (e.g. +10 m) above the surface.

Symbols:

V600 is a 10-min averaged mean wind estimate;

V60 is a 1-min averaged mean wind estimate;

V3 is a 3-sec averaged mean wind estimate.

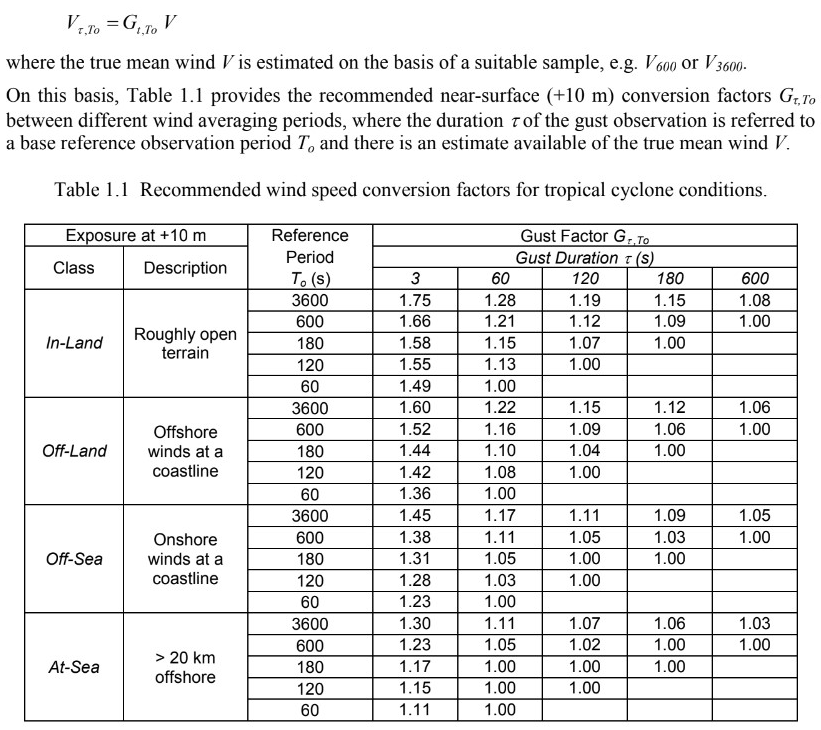
V60,600 is the highest 1-min mean (gust) within a 10-min observation period;

V3,60 is the highest 3-sec mean (gust) within a 1-min observation period.

the nominal land context is

strong winds, typically VTo > 17 m s-1

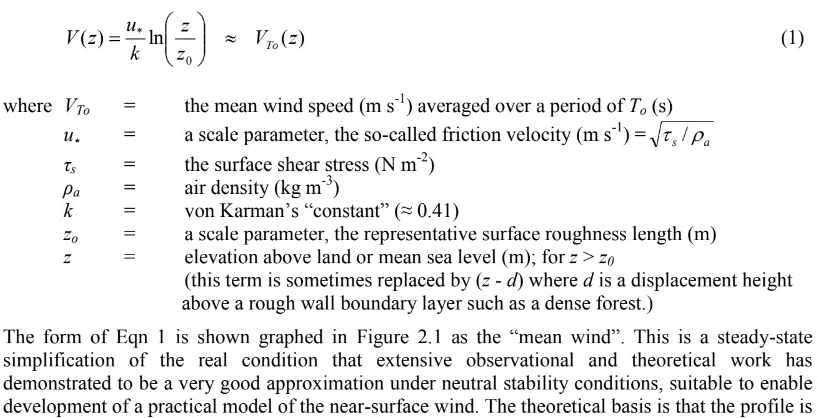
standard exposure with roughness length z0 = 0.03 m and height z= +10 m. However, there are instances where the available data do not exactly represent this situation – some for obviously practical reasons – and some is reported within specific wind speed bands.

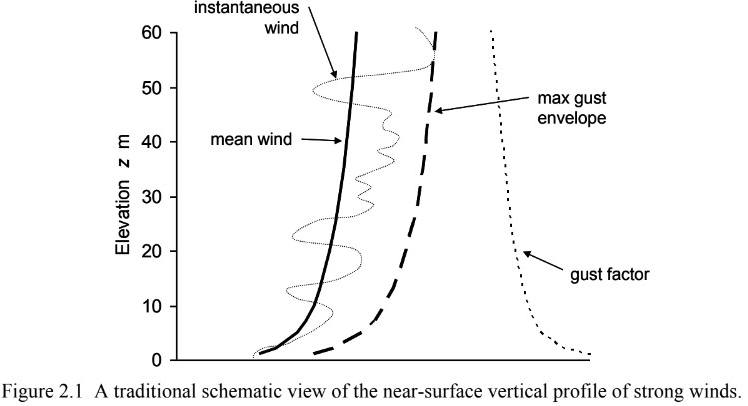


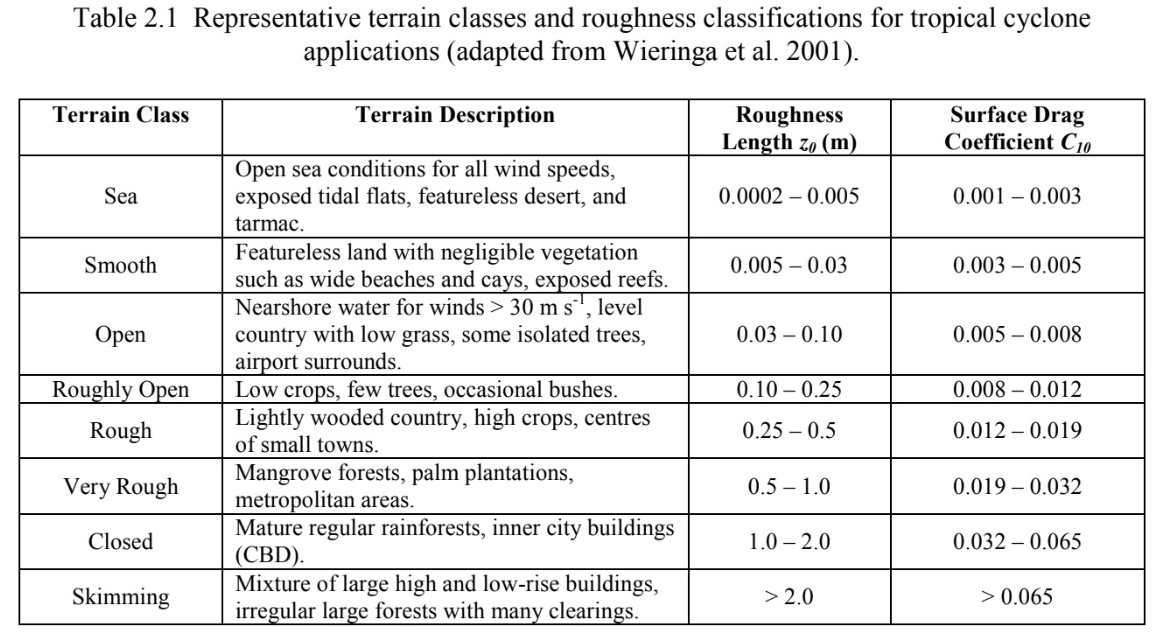
**MEAN WIND SPEED**

While the term ―wind speed‖ in common or colloquial use can occasionally be misused, it is

generally accepted to be the mean or average wind, with reasonably widespread public recognition of, and respect for, the co-existence of the temporarily higher ―gust‖ and lower ―lull winds.



****

****