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TITLE:

Wind energy generation systems - Part 15-1: Site suitability input conditions for wind power plants

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WIND ENERGY GENERATION SYSTEMS –

Part 15-1: Site suitability input conditions for wind power plants

FOREWORD

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IEC 61400-15-1 has been prepared by IEC technical committee 88: Wind energy generation systems. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
88/XX/FDIS	88/XX/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

This part of IEC 61400 defines a framework for assessment and reporting of the turbine suitability conditions for both onshore and offshore power plants.

WIND ENERGY GENERATION SYSTEMS –

Part 15-1: Site suitability input conditions for wind power plants

1 Scope

The scope of this part of IEC 61400 is to define a framework for assessment and reporting of the wind turbine suitability conditions for both onshore and offshore wind power plants. This includes:

a) definition, measurement, and prediction of the long-term meteorological and wind flow characteristics at the site;
b) integration of the long-term meteorological and wind flow characteristics with wind turbine and balance-of-plant characteristics;
c) characterizing environmental extremes and other relevant plant design drivers;
d) addressing documentation and reporting requirements to help ensure the traceability of the assessment processes.

The framework will be defined such that applicable national norms are considered and industry best practices are utilized. This framework defines the minimum set of parameters. Additional parameters may be used if needed.

The meteorological and wind flow characteristics addressed in this document relate to wind conditions, where parameters such as wind speed, wind direction, turbulence intensity, wind shear, inflow angle,air density or air temperature are included to the extent that they affect the structural integrity of a wind turbine.

According to IEC 61400-1 and IEC 61400-3, site specific conditions are wind conditions, other environmental conditions, soil conditions, ocean/lake conditions and electrical conditions. All of these site-specific conditions other than site specific wind conditions and related atmospheric variables addressed herein are out of scope for this document.

This document is framed to complement and support the scope of related IEC 61400 series by defining environmental input conditions. It is not intended to supersede the design and suitability requirements presented in those documents. Specific analytical and modelling procedures as described in IEC 61400-1, IEC 61400-2, IEC 61400-3-1 and IEC TS 61400-3-2 are excluded from the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61400-1:2019, *Wind energy generation systems – Part 1: Design requirements*

IEC 61400-3-1:2019, *Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines*

IEC 61400-12-1:2022, *Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines*

ISO 2533:1975, *Standard Atmosphere*

ISO/IEC 21778:2017, *Information technology – The JSON data interchange syntax*

ISO/IEC 10646:2017, *Information technology – Universal Coded Character Set (UCS)*

ISO 3166, *Country codes*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

NOTE All the below parameters are expected to represent the climate conditions over the design lifetime of the wind turbine and apply at hub height.

3.1
inflow angle
angle between a horizontal plane and the wind velocity vector at hub height

Note 1 to entry: The inflow angle is positive if the wind velocity vector is pointing upwards. Referred to as flow inclination angle in IEC 61400-1:2019.

3.2
turbulence intensity
TI
ratio of the wind speed standard deviation to the mean wind speed determined from the same set of measured wind speed data and taken over a period of 10 min and based on at least 1 Hz sampling frequency

3.3
mean ambient turbulence intensity
average of a subset of the turbulence intensities

Note 1 to entry: The subset typically represents a bin within a wind speed and wind direction matrix.

3.4
standard deviation of turbulence intensity
standard deviation of a subset of the turbulence intensities

Note 1 to entry: The sub set typically represents a bin within a wind speed- wind direction matrix.

3.5
associated data source
primary data source used to derive wind conditions for a given turbine location

Note 1 to entry: This can include, but is not limited to, meteorological towers, remote sensing devices, production data or model data.

3.6
number of samples
number of data points which form the basis of the associated parameter value

3.7
mean wind shear
wind shear (or power law) exponent as defined in IEC 61400-1:2019 and estimated across the rotor swept area

3.8
average turbulence intensity at 15 m/s
mean ambient turbulence intensity over all wind directions in the 15 m/s wind speed bin

Note 1 to entry: Bin width is defined as 14,5 to 15,5 m/s.

3.9
annual mean ambient temperature
annual mean ambient temperature at the site

3.10
annual wind speed frequency distribution
annual distribution of occurrences as a function of wind direction and/or wind speeds

3.11
Weibull distribution
probability distribution function

3.12
coefficient of variation
standard deviation divided by the mean value

3.13
extreme ambient turbulence intensity
extreme ten minute value of the ambient turbulence intensity with a return period of 50 years as a function of wind speed

3.14
omni-directional
one value describing all direction sectors

3.15
roughness
texture of the surface topography that is irregular (not smooth) due to the soil surface and/or the presence of vegetation and obstacles such as built-up areas

3.16
site suitability/turbine suitability
given combination of site conditions and turbine properties impacting structural integrity

4 Symbols, units and abbreviated terms

4.1 Symbols and units

φ	annual mean inflow angle	[deg]
TI	mean ambient turbulence intensity as defined in 3.8	[-]
σ_{σ}	standard deviation of estimated wind speed standard deviation	[-]
α	mean wind shear (or power law) exponent	[-]
α_{eff}	effective wind shear exponent	[-]
d	displacement height	[m]
D	rotor diameter	[m]

z_{hub}	hub height	[m]
V_{50}	extreme wind speed (averaged over 10 min) with a recurrence interval of 50 years	[m/s]
V_{e50}	expected extreme wind speed (averaged over 3 s), with a recurrence time interval of 50 years.	[m/s]
ρ	air density	[kg/m^3]
V_{ave}	annual mean wind speed at hub height	[m/s]
C	scale parameter of the Weibull distribution function	[m/s]
k	shape parameter of the Weibull distribution function	[-]
C_{CT}	turbulence structure correction parameter	[-]
P	air pressure	[hPa]
T	air temperature	[K]
V_{xy}	horizontal component of wind speed	[m/s]
V_z	vertical component of wind speed	[m/s]
RH	relative humidity	[%]

4.2 Abbreviated terms

CFD Computational Fluid Dynamics

COV Coefficient of Variation

GEV Generalized Extreme Value Distribution

GPD Generalized Pareto Distribution

MCP Measure Correlate Predict

MIS Method of Independent Storms

NWP Normal Wind Profile Model

POT Peak-Over-Threshold

TI Turbulence Intensity

5 Methodologies to determine turbine suitability input parameters

5.1 General

A site suitability assessment consists of the analysis of the atmospheric and obstacle conditions that influence the fatigue and ultimate loads that a wind turbine will withstand throughout its lifetime.

Generally, data from an onsite measurement(s) is available as input to determine the wind turbine suitability parameters. Ideally, measurements are collected at locations that represent the full range of meteorological conditions expected at the wind turbine locations. However, since measurements at each wind turbine location are challenging to obtain, it is common practice to associate clusters of wind turbines to existing onsite measurements in combination with wind flow modelling. The following list includes the topographic characteristics that should be considered when determining turbine association.

- Distance between representative measuring device(s) or location and turbine.
- Differences in elevation (relative elevation between measurement station and turbine).
- Exposure (can be estimated as the difference between the elevation/slope at the measurement location and the average elevation/slope in the surrounding area).
- Surface roughness (land use and/or forestry).
- Relevant obstacles.

The purpose of this clause is to describe both the methodology[1] and best practices to calculate or estimate such conditions at the wind turbine locations. Note that additional parameters (such as oceanic) required to evaluate turbine suitability for offshore sites will not be addressed in this version of the standard.

Wind turbines are structures which incorporate static and dynamic loading. Therefore local measurements are generally used to assess the site conditions.

For all parameters which are not addressed in this document and for which there are no reliable data from measurements, the corresponding design values from IEC 61400-1:2019 may be used. Where different methods can be applied to derive parameters the chosen method shall be described, justified and reported as part of the Turbine Suitability Input reporting in Annex B.

Whenever a validated approach is called for in this clause, this means to traceably justify the model applicability according to the state-of-the-art science and technology. The information on the state-of-the-art flow models including their potential, limitations and important technical aspects of flow models are described in [1][2].

5.2 Assessment of wind speed

5.2.1 Wind speed distribution

5.2.1.1 General

The wind speed distribution is significant for wind turbine design because it determines the frequency of occurrence of individual load conditions for the normal design situations. The wind speed distribution shall be derived from onsite measurement(s) with the format of either wind speed frequency or Weibull distributions, both omni-directional and sector-wise based. If a Weibull distribution is used the goodness of fitting shall be checked since a Weibull function may not be valid to represent the wind speed distribution at some sites, e.g. where binomial wind distributions may fit better. The data shall be long-term representative and transferred to each wind turbine's location at corresponding hub heights.

5.2.1.2 Long-term adjustment

The wind speed distribution shall be representative of the operational lifetime of the wind turbine being evaluated in the site suitability assessment.

If the data is not representative, long-term adjustment shall be carried out by using either long-term adjustment factor(s), a Measure Correlate and Predict (MCP) method as defined in for example [2] or a more advanced method, examples of which can be found in [3].

5.2.1.3 Vertical extrapolation of wind speed[3]

The wind distribution shall be adjusted to proposed wind turbine hub height(s). Either power law, logarithmic law, flow simulation, or combinations of the methods shall be used [4].

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1 All methods have limitations when extrapolating wind conditions spatially. User needs to be aware that the uncertainty in extrapolated parameters may grow significantly with increasing distance from the measurement point. This is especially relevant at sites with complex terrain, complex surface roughness, and/or complex flow conditions, or when extrapolating onshore to offshore (or the reverse).

2 Numbers in square brackets refer to the bibliography.

3 Vertical and horizontal extrapolation may be done simultaneously by using a flow model.

5.2.1.4 Horizontal extrapolation of wind speed

The wind speed data shall be extrapolated to the turbine location by using a validated flow model (e.g. by use of speed up factors that account for the increase in the speed of the wind flow due to terrain topography).

5.2.2 Extreme wind speed with a recurrence interval of 50 years

5.2.2.1 General

Estimation of the extreme wind speed with a recurrence period of 50 years is necessary for characterization of wind turbine ultimate loads. Extreme wind speed estimates are accompanied by high uncertainty and any estimate of extreme wind speed should be considered in the context of its uncertainty. For converting between V_{50} and V_{e50}, 2.3.2 in [5] or guideline [6] can be used.

At sites that are prone to some atmospheric phenomena that cause extreme winds, such as severe thunderstorms, tropical cyclones, and strong downwind events, on-site measurements of any duration could be used, but may need to be adjusted and thus need to be used with caution. Regional or otherwise representative historical data of extreme wind events may be used for the estimation of extreme wind speed.

The methods listed in this section may be used. Considering the quality and consistency of all sources of data and methods, justification of the selected extreme wind speed value shall be given.

Alternatively, the local recognized standard or guideline which specifies the design wind speed with the recurrence period of 50 years may be used to derive the extreme wind speed.

5.2.2.2 Estimation of extreme wind speed using onsite data

5.2.2.2.1 General

The most common approach is to identify a series of extreme wind speed events so that a mathematical distribution function can be fitted to the measured extreme wind events. Care is needed to set appropriate thresholds, evaluate the quality of the distribution, and understand the representativeness of the dataset of the long-term climate. For detail refer to Annex C and Annex D.

Vertical and spatial extrapolations of extreme wind speeds may be based on the following approach.

5.2.2.2.2 Vertical extrapolation of extreme winds

Vertical extrapolation of extreme wind speeds observed during tropical cyclones or other unique storms may employ an event-specific shear value with adequate justification. For example, see [6] for a hurricane conditions offshore, based upon observed wind profiles[6].

Relevant shear values shall be used for vertical extrapolation of high wind speed events. Vertical extrapolation may be made using various methods. Shear values for vertical extrapolation should be derived from representative long-term measured data if available. This could consider the highest 0,1 % measured wind speeds, or instantaneous profiles at the time of independent peak storm events. Extrapolation beyond the heights of measurement should be conducted with caution. Other methods could be using wind shear power law exponent value of 0,11 as recommended in IEC 61400-1 or the use of flow models.

Offshore extreme wind might face higher wind shear due to marine phenomena (e.g., Gulf stream, upwelling).

5.2.2.2.3 Horizontal extrapolation of extreme winds

Horizontal extrapolation of extreme winds may be based on appropriate speed up factors that are representative of extreme wind speeds. Suggested methods are to extrapolate the extreme wind speed or to extrapolate the individual contributing extreme wind speed events before estimating the extreme wind speed at each wind turbine.

5.2.2.3 Estimation of extreme wind speed using global or mesoscale models

Global or mesoscale models may be used for the estimation of extreme wind speed distributions. A sufficient period of simulation shall be carried out to generate virtual measurement data. A sufficient period shall cover at least the lifetime required for the project. The methods for the selection of extreme wind events and extreme distribution fitting outlined in 5.2.2.2 also apply to the analysis of model data and are described in Annex C.

Model data should be validated and if necessary calibrated using representative measured data whenever possible, considering the methods outlined in Annex D. This is especially important if extreme wind estimates are intended for engineering design. In offshore regions, long duration model data can be critical to represent rare storm events, especially if these are of tropical origin. Short duration measured data are generally required to ensure the model is representative of the target location(Ideally, at least one year of on-site measurements shall be required to check the seasonal representativeness of global or mesoscale models)

Sophisticated methods applied to mesoscale model data on onshore wind projects are described in Annex E. Offshore wind projects, often using global rather than mesoscale models, usually adopt simpler methods. First, the effective averaging period of the model is established. This is typically longer than one hour for a global model. The extreme wind estimates from the model are then converted from this long averaging period to the required 10 minutes mean and 3 seconds gust using appropriate factors. Relevant factors may differ from those in Table 1 of 61400-3-1:2019.

Downscaling global models to mesoscale resolution is established best practice onshore and has proven benefits in nearshore regions. However, global models can be used effectively without downscaling at some offshore locations.

It is recommended to validate the simulation results by using onsite measurement data.

5.2.2.4 Estimation of extreme wind speed for tropical cyclone regions

In regions prone to tropical cyclones (e.g. cyclones, hurricanes and typhoons), the extreme wind speed shall be evaluated by appropriate methods, for example as given in IEC 61400-1:2019, Annex J. If the coefficient of variation of extreme wind distribution (IEC61400-1:2019, 7.4.7) may exceed 0,15, this value shall be evaluated. Uniform COV value may be used unless there is a significant difference in the meteorological conditions within the wind farm.

5.3 Assessment of turbulence intensity

5.3.1 Ambient turbulence intensity

5.3.1.1 General

If measurements have been collected onsite, the ambient turbulence intensity and the standard deviation of the turbulence intensity shall be calculated according to IEC 61400-1:2019, 3.58. De-trending of measurement data is not needed. If de-trending methods are used, only a linear de-trending should be applied. The baseline is assumed to be data measured at a point (cup/sonic anemometers), unless TI from a remote sensing device can be justified or adjusted using methods that are clearly defined to closely represent the point measurement.

5.3.1.2 Vertical extrapolation of TI

Whenever measurements are recorded at a different height than the hub height of the wind turbine and the TI from a height closest to the hub height (preferably lower) is not representative, the turbulence shall be extrapolated to hub height. The following methods may be considered:

- The wind speed standard deviation can be assumed constant while the wind speed is extrapolated to hub height. This method is only applicable to an upward extrapolation. Care should be taken when extrapolating wind speed to hub height since the rate of change of TI with height may be different from the rate of change of wind speed with height.
- Use validated flow models to predict the TI at appropriate heights. The model prediction shall be calibrated based on the available TI measurements.
- Extrapolation of standard deviation using similarity theory or observation fitting.

5.3.1.3 Horizontal extrapolation of TI

The TI from the reference measurement point(s) shall be extrapolated to each wind turbine location. The method shall be validated against data for the flow complexity of the site under consideration. Complexity does not only cover orography, but also other impacts such as roughness, forest or thermal stratification. The following methods may be considered:

- Use empirical formulas based on surface roughness to obtain correction factors between measurement device location and wind turbine location. This method can only be used for non-complex or low complexity categories according to IEC 61400-1:2019, 11.2. Care should be taken when using this method when the roughness at the sites is very heterogeneous or when obstacles or forests are expected to influence TI at the wind turbine position.
- Use validated flow models to predict the TI at turbine locations and calibrate the model prediction based on TI measurements.
- Use TI weighted average of surrounding measurement devices (e.g. inverse distance).

The standard deviation of turbulence intensity at the turbine locations may be assumed to be the same as the most representative measurement device. Other methods may be applied.

5.3.1.4 Alternative approaches for estimation of TI

If no measurements are available onsite then consider evaluation of the turbulence using one of the following methods.

- Empirical formulas based on surface roughness. This method should not be applied for sites which belong to the high complexity category according to IEC 61400-1:2019, 11.2. Care should be taken when using this method for medium complexity sites, when the roughness at the sites is very heterogeneous or when obstacles or forests are expected to influence TI at the wind turbine position.
- Use flow models that have been validated to predict turbulence in sites with similar conditions of the site of interest, in terms of terrain complexity and roughness characteristics.

Other methods may be used if they are properly justified and validated in site conditions similar to the site of interest, in terms of terrain complexity and roughness characteristics.

5.3.1.5 Incomplete TI bin data treatment

If sufficient data are not available in a given wind speed bin, the turbulence distribution shall be extrapolated for incomplete bins appropriately. An incomplete bin may be defined as having fewer data points than is required to represent the mean and standard deviation of TI with an acceptable level of error based on sample size, variance of the sample, distribution function and a probability of exceedance limit.

The following methods may be considered:

- Extrapolation of wind speed standard deviation using a linear function similar to those of the NTM in IEC 61400-1:2019, 6.3.2.3.
- Use the nearest complete bin TI value in same wind direction to fill incomplete bins. When a missing bin is equidistant from 2 complete bins consider averaging if both complete bins are representative.
- To avoid discarding data bins with fewer data points, data bins can be combined and the average TI value applied to bins used for combination.
- For TI extrapolation for offshore sites see IEC 61400-3-1:2019 section [6.4.3.3].

Other applicable methods may be used. Methods listed above are also valid for the Representative TI as defined in IEC 61400-1:2019.

5.3.2 Extreme ambient turbulence intensity

The extreme ambient turbulence intensity shall be calculated from onsite measurement data. Extrapolation and filling the gap methods described in 5.3.1.2, 5.3.1.3 and 5.3.1.5 may also be applied to the estimation of extreme ambient turbulence intensity.

IEC 61400-1:2019 proposes two methods [4] to calculate the ambient turbulence intensity distribution to a 50 year return period, but other methods may be used if they are properly justified.

5.3.3 Turbulence structure correction parameter

The turbulence structure correction parameter calculation is defined in IEC 61400-1:2019, 11.2.

5.4 Inflow angle

An inflow angle for each wind direction sector (i) based on measured and/or simulated values from a validated flow model shall be calculated by using the following equation:

$$\varphi_i = \tan^{-1}\left(\frac{v_z}{v_{xy}}\right) \tag{1}$$

If no site measurements or simulations are available, the inflow angle may be estimated based on terrain slope according to IEC 61400-1:2019, 11.9.2.

To calculate the omni-directional inflow angle either a frequency or energy-weighted mean shall be performed.

4 IEC 61400-1:2019, 11.3.2, footnote 32.

5.5 Wind shear

5.5.1 General

Average wind shear exponent values (power law), at the measurement location shall be calculated using one of the following methods. Other wind shear models such as log law may be used if they are properly justified.

- For each ten-minute value of the wind speed, the wind shear exponent shall be calculated using the power law as defined for the normal wind profile model (NWP). All ten-minute shear values, for wind speeds above 3 m/s, shall be grouped by wind direction sectors as defined in Annex A and the arithmetic mean[5] for each sector shall be derived.
- The concurrent wind speed values at all desired heights shall be temporally averaged at each height. When using non-integer year(s) of wind shear data it is key to ensure data applied is seasonally unbiased. The wind shear exponent shall be calculated using the NWP. This same procedure shall be performed by wind direction sectors.

The grouping of wind shear exponent by wind direction sector shall be performed according to the wind speed and wind direction data from the measurement level most representative of hub height.

To calculate the omni-directional average wind shear exponent either a frequency or energy-weighted mean shall be performed for as many complete annual periods as are available for such calculations.

The measurement heights used for calculation shall be chosen to best represent the wind shear exponent from bottom tip to tip height. If the measurement heights are not representative for the shear across the rotor area, consider using a power law wind profile or other applicable wind profiles that describe the rotor swept area.

If a displacement height d is appropriate (obstacles, forestry, etc.), when vertically extrapolating wind speed measurements, then an effective wind shear exponent calculation must be incorporated. An example using measured wind speed V at two heights z is shown here:

$$\alpha_{\text{eff}} = \frac{\ln\left(\frac{V_1}{V_2}\right)}{\ln\left(\frac{z_1 - d}{z_2 - d}\right)} \tag{2}$$

It is generally recommended to provide additional information which can be raw wind data or more refined statistics (e.g. 12 × 24 matrix) to identify cases where the wind direction sectors may not be sufficient and additional representation is required. The wind turbine manufacturer may request raw wind data for detailed analysis. Examples of shear values with high variability or extreme (low or high) shear values have been reported for certain areas in connection with highly stratified flow, complex terrain or severe roughness changes.

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[5] The arithmetic mean of all ten minute values provides a frequency weighted shear value. This serves as an approximation for an energy-weighted average shear value as required by IEC 61400-1:2019. Alternatively an energy-weighted mean shear may be calculated.

If wind conditions occur that are not amenable to analysis in terms of a power law wind profile, or other wind models are used in the assessment of the suitability of the project site, they should be described. This description will include their diurnal, seasonal, and directional prevalence, and the heights and wind speeds at which they occur. Reasons why these conditions may occur include, but are not limited to, low level jets, intermediate boundary layers, atmospheric stratification and stability effects, and the influence of topography. They may represent intermediate load scenarios that cannot be described as either production or ultimate load cases, being more frequent than extreme and more severe than fatigue scenarios, and so do not fall within the scope of established load evaluation procedures. Nevertheless their occurrence may have implications for the strategies that should be adopted to ensure successful operation of the wind project and so these conditions should be noted to inform those strategies and support confidence in that outcome.

If no measurements are available onsite then consider evaluation of the shear using an appropriate flow model or representative nearby data. Alternatively if the site is non-complex or falls into the low complexity category according to IEC 61400-1:2019, the wind shear exponent may be calculated based on roughness data and on the long-term distribution of the surface sensible heat flux according to [7].

Calculation of wind shear during extreme wind speed events is addressed in 5.2.2.2.2.

5.5.2 Spatial extrapolation of wind shear

The most representative shear measurement(s) or a combination of available shear measurements can be used if measurement position and turbine site are associated according to the characteristics described in 5.1. Alternatively, if the shear measurements are not representative for the specific wind turbine positions, validated flow models can be used to predict the wind shear at appropriate heights. The model prediction shall be calibrated based on the available measurements.

5.6 Temperature

Whenever temperature measurements are recorded the air temperature sensor shall be mounted within 10 m of hub height to represent the air temperature at the wind turbine rotor centreline. If installed below it is required that the temperature is extrapolated, as per IEC 61400-12-1:2017, 7.4. Alternatively, the temperature can be extrapolated to the desired height considering the following methods:

- If the temperature gradient is measured on-site, use that gradient to extrapolate to the hub height.(Consider differences between ground elevation for the measurement device and turbine positions).
- Use the tropospheric International Standard Atmosphere temperature gradient, defined in ISO 2533:1975 as −0,65 ºC/100m. The temperature values should be representative for the climate of the site. Caution shall be taken when atmospheric stability is non-standard as this can cause over- or underestimation of extrapolated temperatures.

Temperature gradients derived from well-configured mesoscale models may also be used in environments where the ISO temperature gradient does not apply year-round. For example, offshore in regions with seasonal variation between air and water temperatures.

The temperature values shall be representative of the operational lifetime of the wind turbine being evaluated in the site suitability assessment. A long-term adjustment should be performed if necessary. General guidance on methodology can be found in references [2] and [8].

The following climate representative value shall be derived:

– Yearly mean ambient temperature (hourly mean value) [°C] and extreme temperature ranges as the minimum and maximum ambient temperature to be expected in hourly average [°C] (recurrence period 1 year) shall be assessed including frequency distributions of temperature.If an icing climate with relevant rotor icing is to be expected, icing condition may be assessed according to Annex L of IEC 61400-1:2019.

5.7 Air density

Air density can be calculated using the method described in IEC 61400-12-1:2017, 9.1.5.

$$\rho = \frac{1}{T}\left(\frac{P}{R_0} - \phi P_w\left(\frac{1}{R_0} - \frac{1}{R_w}\right)\right) \tag{3}$$

ρ	Air Density [kg/m^3]
T	Air temperature at hub height [K]
P	Air pressure at hub height [Pa]
R_0	Specific gas constant for dry air [J/(kgK)] = 287,058
ϕ	Relative humidity (range 0 % to 100 %)
R_w	Specific gas constant for water vapour [J/(kgK)] = 461,495
P_w	Vapour pressure [Pa]

Vapour pressure P_w depends on mean air temperature.

$$P_w = 0{,}0000205 \times \exp(0{,}063184\,6 \times T)$$

Alternatively, air density can be calculated based on the ideal gas law:

$$\rho = \frac{1}{R} \times \frac{P}{T} \text{ with} \frac{1}{R} = 0{,}003\,484 \left[\frac{K \times s^2}{m^2}\right] \tag{4}$$

If air pressure measurements are not available, pressure can be calculated assuming a temperature gradient of −0,65 °C/100 m, a sea level pressure of 1 013,25 hPa at standard atmosphere and site air temperature at the appropriate height above sea level, using the methods described in ISO 2533.

Air density shall be representative of the operational lifetime of the wind turbine being evaluated in the site suitability assessment. A long-term adjustment should be performed if necessary. General guidance on methodology can be found in references [2] and [8]. In case of large site elevation differences, air density per wind turbine shall be calculated. If no on-site measurements are available, consider using long-term reference data.[6]

[6] The coherence of the air density variations and extreme wind conditions may suggest analyzing extreme air density values.

5.8 Site conditions modelling close to significant structures and obstacles

Relevant site conditions close to significant structures, obstacles and/or forest (growth/felling) as defined under IEC 61400-1:2019, 11.3.2, are recommended to be assessed either with measurements or with a validated flow model.

Annex A
(normative)

Requirements to fill out Site Suitability Input Conditions Form

This annex provides information on the data that are to be input into the Site Suitability Input Conditions Form in digital exchange format. This annex provides information on the data that are to be input into the Site Suitability Input Conditions Form in digital exchange format. Requirements for the digital exchange format are given in Annex F.

Below are some general considerations:

- Sectors: The first centred on 0º (true north) and clockwise (maximum 30º sector width)
- Wind speed bins: Contiguous bins covering the wind speed range from 0 m/s to 40 m/s. The wind speed range shall be divided into wind bins centredcentred on the integer value by either:
  – 1 m/s bin width: for the bin centredcentred at 1 m/s, the bin will start at 0,5 m/s and end at 1,5 m/s. Note the first bin will be from 0 m/s to 0.5 m/s.
  – 2 m/s bin width: for the bin centred at 2 m/s, the bin will start at 1m/s and end at 3 m/s. Note the first bin will be from 0 m/s to 1 m/s.
- Temperature bins: Centred on the integer value with 1ºC bin width.
- All parameters required in the Site Suitability Input Conditions Form shall be provided both at the available measurement device locations and at wind turbine locations.
- All parameters required in the Site Suitability Input Conditions Form shall be provided at hub height unless they refer to the measurement devices or are differently defined (or the most representative value if hub height does not apply i.e. wind shear across the rotor).

A.1 Turbine layout summary

Some of the parameters below need input from the person completing the form while others are filled automatically when the different sheets are completed.

- Project Name: Input the name of the project for every single wind turbine object of study as well as for neighbouring wind turbines that need to be considered.
- Wind turbine ID: Define unique wind turbine ID for each of the wind turbines on site and neighbouring wind turbines if applicable.
- Easting or Longitude: This is the longitude or eastward coordinate in UTM WGS84 including zone if applicable as defined under the "project information" sheet.
- Northing or Latitude: This is the latitude or northward coordinate in UTM WGS84 including zone if applicable as defined under the "project information" sheet.
- Ground Elevation relative to Mean Sea Level (m): Define height relative to mean sea level of the wind turbine base.
- Wind turbine Manufacturer: Define for each wind turbine on site and neighbouring wind turbines if applicable.
- Wind turbine model: Define for each wind turbine on site and neighbouring wind turbines if applicable. Neighbouring wind turbine/power plantshall be considered when they cause mean wind speed reduction on the new wind power plant.
- Wind turbine Rated Power (MW): Define for each wind turbine on site and neighbouring wind turbines if applicable
- Operational mode: Define for each wind turbine on site if operational configuration or control setting like cold/warm climate package, low noise aero add-ons, power boost etc.

- Rotor Diameter(m): Define for each wind turbine on site and neighbouring wind turbines if applicable.
- Hub Height (m): Define for each wind turbine on site and neighbouring wind turbines if applicable the hub height above ground level or above turbine base. For offshore specify Mean Sea Level (MSL) elevation for bottom fix turbines.
- Associated data source (meteorological tower, remote sensing device): Define which measurement type has been considered more representative for each of the wind turbines and therefore used to define the climatic conditions at each location.
- V_{50}: Set the value of the extreme 10-minute wind speed (50 year recurrence) for wind turbines on site.
- Ve_{50}: Set the value of the extreme 3-second wind speed (50 year recurrence) for wind turbine on site. This value is optional.
- COV: The coefficient of variation is only needed for sites prone to tropical cyclones.
- Air Density (kg/m^3): Annual average air density.
- Annual Average Wind Speed at Hub Height (m/s).
- Scale Parameter of Weibull Function (m/s) [C]: from sheet 'WS Weibull'.
- Shape Parameter of Weibull Function [k]: from sheet 'WS Weibull'.
- Turbulence Structure Correction Parameter[CCT]: from sheet 'CCT'.
- Annual Mean Wind Shear: from sheet 'Shear'.
- Annual Average Turbulence Intensity at 15 m/s [TI_{15}]: from sheet 'Ambient Mean TI'.
- Standard Deviation of Turbulence Intensity at 15 m/s [σI]: from sheet 'SD TI'.
- Inflow Angle (degrees): from sheet 'Inflow Angle'.

A.2 Measurement device summary

The following parameters need to be defined:

- Measurement Device ID: Define unique measurement device ID for each of the measurements.
- Easting: This is the eastward coordinate in UTM WGS84 including zone if applicable as defined under "project information" sheet.
- Northing: This is the northward coordinate in UTM WGS84 including zone if applicable as defined under "project information" sheet.
- Ground Elevation Above Sea Level (m): Define height above sea level of the wind turbine base. This only applies to onshore.
- Measurement height (m): Define height of measurement above ground level.

A.3 Expected annual wind speed frequency distribution (%)

Expected annual wind speed frequency for all measuring devices and wind turbines are defined in two different ways:

- frequency by sector;
- frequency by sector and wind speed bins.

Expected annual wind speed occurrences for all measuring devices is defined in two different ways:

- occurrences by sector;
- occurrences by sector distributed by wind speed bins.

A.4 Expected annual wind speed Weibull distribution (%)

The Wind Speed Weibull distribution is defined in IEC 61400-1:2019, 3.68 and should be representative of the long-term. This can be omitted if the Weibull function does not represent the wind speed distribution at the site and the wind speed frequency distribution has been included.

The overall and sector-wise distribution of the wind speed is defined by the scale (C) and shape (k) parameters.

$$P_W(V_0) = 1 - \exp\left[-(V_0 / C)^k\right] \quad \text{(A.1)}$$

$$\text{with} V_{\text{ave}} = \begin{Bmatrix} C\Gamma\left(1+\frac{1}{k}\right) \\ \frac{C\sqrt{\pi}}{2}, \text{ if } k = 2 \end{Bmatrix} \quad \text{(A.2)}$$

At least 12 sectors should be considered (maximum 30º of width), the first centred at 0º (north) and presented clockwise.

- All/Scale Parameter(m/s) [C]: Scale parameter of the Weibull distribution considering all wind speeds in all sectors
- 0/…/330 Scale Parameter(m/s) [C]: Scale parameter of the Weibull distribution considering all wind speeds in the sector of study
- All/Shape Parameter [k]: Shape parameter of the Weibull distribution considering all wind speeds in all sectors
- 0/…/330 Shape Parameter [k]: Shape parameter of the Weibull distribution considering all wind speeds in the sector of study
- 0/…/330 Frequency (%): Frequency of the Weibull distribution considering all wind speeds in the sector of study. For time series data set, the frequency under 'WS Weibull' should match the frequency information under 'WS Frequency"

A.5 Turbulence intensity (TI)

The turbulence intensity is defined in IEC 61400-1:2019, 3.58 based on periods of 10 min.

This information shall be included in the Site Suitability Input Conditions Form in the form of mean ambient turbulence intensity by both wind speed bin and by wind direction sector.

The table contains mean TI values for each wind speed bin for all wind directions, and for each wind direction sector. All provided in wind speed bins.

This information shall be provided both at the available measurement device locations and at least omni-directional data at wind turbine locations.

The turbulence structure correction parameter shall be calculated according to IEC 61400-1:2019, 11.2.

A.6 Standard deviation of turbulence intensity

This information shall be included in the Site Suitability Input Conditions Form in the form of Standard Deviation of Turbulence Intensity by both wind speed bin and by wind direction sector.

This information shall be provided at the available measurement device locations and at least omni-directional data at wind turbine locations.

A.7 Extreme ambient turbulence intensity

The turbulence intensity is defined in IEC 61400-1:2019, 11.3.2, footnote 32 based on periods of 10 min and shall be provided at the measurement(s) point and wind turbine location(s).

The table contains omni-directional extreme ambient turbulence Intensity values for each wind speed bin.

A.8 Sector-wiseInflow angle

The Inflow angle is calculated based on 5.4.

Provide omni-directional, sector-wise and absolute maximum inflow angles.

A.9 Wind shear

The wind shear during power production is defined in IEC 61400-1:2019, 3.67, Equation 2 (power law).

Omni-directional and sector-wise wind shear is presented in the Site Suitability Input Conditions Form.

A.10 Temperature

Based on temperature data (10 min or hourly data), both from onsite measurements, local long term meteorological stations and/or meso scale model, frequency distributions of temperature are required.

The information to be included in the Site Suitability Input Conditions Form will be the frequency for each temperature bin, for temperature ranges from ≤ −40 °C to ≥ +50 °C.

Annex B
(normative)

Turbine suitability input reporting

B.1 General

This annex describes the climatic conditions as required by IEC 61400-1 for the assessment of wind turbine site suitability. This includes the relevant wind parameters, the parameters that describe the topographical complexity of the terrain and the cold climate conditions. The purpose of this annex is to provide guidance on how to report these parameters.

The following reporting structure and the Site Suitability Input Conditions Form shall be completed.

B.2 Reporting structure

B.2.1 General

All of the following chapters shall be included to fulfil IEC 61400-15-1 reporting requirements, or cross-referenced to if the corresponding information is available in existing report(s). Such existing report(s) shall be included as an annex or listed within the bibliography.

B.2.2 General information

This chapter shall include the following points:

- Company name
- Name of the person who completed the External Environmental Conditions Form and this report
- Version number of Site Suitability Input Conditions Form and cause for different version
- Number, type and manufacturer of intended turbines (optional)
- Site Suitability Input Conditions Form filename
- Date

B.2.3 Introduction

The following text shall be included as a standardized introduction to the report:

The objective of this report is to describe the measurements, methodology, and analysis techniques that were used to derive the climatic conditions present at a specific wind project site according to IEC 61400-15-1 for the purposes of wind turbine structural integrity and site suitability analysis in accordance with IEC 61400-1:2019, 11.2 Topographical complexity, 11.3 Wind conditions, 11.9, 11.10, and 14.8 Assessment of cold climate conditions. Other parts of Clause 11 do not need to be addressed.

B.2.4 Summary of site characteristics

This chapter shall include an overview of the project and notable site characteristics, including:

- Description of the project site and topography
- Description of the wind climate, including the primary atmospheric conditions that drive the wind resource. Describe if other site conditions are relevant for the study such as hurricanes or tropical storms, katabatic/anabatic winds, earthquake area, low/high temperatures
- Extreme topography of the project area that can potentially affect the wind regime, taking appropriate orographic obstacles in consideration
- Large variations of land use or ground conditions

B.2.5 Project description

B.2.5.1 General

The project description shall include the following sections with its following points:

B.2.5.2 Wind power plant overview

- Location of the wind power plant including maps of the region and country.

B.2.5.3 Wind power plant layout and measurement location(s)

- Detailed map of the wind power plant. (Aerial, graph, etc.) which includes wind turbine(s), measurement location(s) and all relevant (existing and consented) wind turbine(s)
- Identification of the coordinate system, datum and zone.
- Include minimum turbine distances expressed in rotor diameters of the neighbouring turbine or in meters

B.2.5.4 Orography

- Elevation maps including the wind turbine(s) and all measurement location(s) (small- and large-scale)

B.2.5.5 Roughness, vegetation and obstacles

- Detailed map(s) which includes an aerial view of the wind power plant highlighting roughness, vegetation and obstacles including the wind turbine(s) and all measurement location(s)
- The characteristics of the vegetation and expected change over time

B.2.6 Wind input data

B.2.6.1 General

The wind data used shall be reported including following sections and points.

B.2.6.2 Measurement campaign (meteorological tower and remote sensing)

- Information about measurement campaign including name and location of measurement devices
- Measurement heights
- Information about measurement equipment, sensors, calibration sheets (where applicable) and maintenance reports with references or as annex
- Recorded statistics, averaging time interval (e.g. 10 min) and duration of measurement campaign
- Measurement installation report reference or as annex
- Data logger configuration (where applicable)

B.2.6.3 Quality check and filtering

- Description of data filtering process
- Data availability after data filtering
- Other actions (such as replace and refill of data gaps)

B.2.6.4 Presentation of measured data

- Availability for primary selected signals optionally include other signals
- Wind speed frequency histogram and if relevant Weibull distribution
- Wind speed frequency and energy-rose
- Vertical wind profile
- Plot of turbulence intensity as a function of wind speed
- Other plots or information if relevant (temperature, diurnal wind speed etc.)
- Description of dataset proposed for further processing

B.2.6.5 Long-term reference data

- Location, measurement height, distance to wind power plant
- Data source and specifications (measurement equipment, model etc.)
- Signals, period and averaging
- Reliability and consistency over time of long-term reference data (e.g. by comparisons between different data sources)

B.2.7 Long-term adjusted wind data

The reporting of the long-term adjusted wind data shall include the following points:

- Comparison of conditions between measured and long-term reference data (e.g. wind rose, wind speed scatter plot, correlation factor(s))
- Justification of long-term adjustment method used
- Results of long-term adjustment analysis

B.2.8 Flow modelling

B.2.8.1 General

The flow modelling shall be reported including the following sections and points:

B.2.8.2 Modelling inputs

- Sources of the elevation and roughness data used with information about the resolution of the data and if applicable about the methods to derive or process the data
- Description of the wind flow model applied including following model settings:
  - domain size (overall and region of interest)
  - minimum horizontal and vertical grid resolution
  - model name and version number
  - turbulence model or settings for linear model
  - if relevant, atmospheric stability approach and forest model

B.2.8.3 Flow model validation and quality control

- Justification of applicability of model

B.2.8.4 Quality check

- For sites with more than 1 meteorological measurement station provide horizontal cross prediction or equivalent analysis showing the wind flow models ability to predict main wind flow parameters within the site area.
- In case measurements are not present in turbine hub height a vertical extrapolation analysis should also be shown.
- For CFD model approach: check convergence

B.2.9 Site suitability parameters

The external environmental conditions shall be provided specific to turbine locations and at turbine hub height including:

- Descriptions of the calculation methods and data source
- Summary table from the Site Suitability Input Conditions Form including:
  - Annual wind speed distribution and annual mean wind speed
  - Air density and temperature
  - Extreme wind speed (V_{50}) optionally (Ve_{50})
  - Turbulence Intensity (Include a note in case turbulence data has been de-trended)
  - Assessment of the topographical complexity
  - Extreme turbulence intensity
  - Wind shear exponent
  - Inflow angle

B.2.10 References

B.2.10.1 General

References shall be reported including following sections and points:

B.2.10.2 Standards and guidelines

- Relevant references

B.2.10.3 Detailed list of input data

- List of data that have been used for the analysis presented in the current report

Annex C
(informative)

Estimation of extreme wind speed distribution

C.1 General

There are different methodologies to estimate extreme wind speeds if measurements have been collected onsite. The most common approach attempts to accumulate a series of high wind observations so that a distribution can be fitted to the events in an attempt to predict a 50 year return wind speed.

C.2 Selection of high wind events

Multiple approaches are available to evaluate a 50 year return wind speed using measured, onsite data. Each approach involves selection of high wind events observed during the data record using slight differences in the selection method while aiming to select events that are independent and identically distributed.

- The Block Maxima method divides the onsite observations into blocks of fixed length and extracts the highest wind speed event from each block. Because of the need to define blocks large enough to ensure uncorrelated events, on site measurements need to span several years to create a statistically representative sample.
- The Peaks-over-Threshold (POT) [9] puts more weight on sub-sampling more storms from the wind data time series than the Block Maxima method by considering wind events that exceed a sufficiently high threshold. Selection of an appropriate threshold is important to ensure the storm sample has both a suitable size and complies with the identical distribution criterion of extreme value statistics. The independence requirement of extreme value statistics means it is essential that the POT method includes an independence criterion. [10]
- Method of Independent Storms (MIS) [10] is the same as POT method when the independence criterion of a minimum duration (typically a few days) between valid high wind speed events to ensure peaks are sufficiently separated in time.

The Method of Independent Storms provides a more stable framework over the Block Maxima and Peaks-over-threshold methods, and is therefore the recommended approach to estimate extreme wind speeds when measured on site data is available. Beyond purely statistical considerations, all methods presented here are prone to the "meteorological" uncertainty imposed by inter-annual variations in storminess which necessitates a long-term adjustment as described in Annex D.

C.3 Extreme value distribution fitting

There are multiple Extreme Value Distributions that can be fitted to high wind speed events to extrapolate to a return period of 50 years, e.g. GEV (Generalized Extreme Value Distribution), Gumbel (special case of the GEV) or GPD (Generalized Pareto Distribution). The Gumbel method is the most widely used method in the industry. Only independent high wind speed events should be considered in the Gumbel fitting process.

Annex D
(informative)

Extreme winds long-term adjustment

The length of measurement needed for estimation of extreme wind speed distribution varies depending on methodology, where as short as four years may be used for MIS and ten years or more may be required for other methodologies. Long term adjustment is recommended whenever the length of measurements is shorter than needed for the relevant model. Two methods to consider are the Bayesian approach [11] and the Technical University of Denmark (DTU) spectra correction method [12]. These methods utilize long-term mesoscale reference data.

Alternatively, if nearby long-term measurement data is available, the MCP method mentioned in IEC 61400-1:2019, Annex F may be used.

Annex E
(informative)

Temporal and spatial resolution correction for mesoscale model

E.1 General

The wind speed calculated by using a mesoscale atmospheric model is usually based on low resolution in both time and space. This implies that the output of mesoscale model cannot directly be used to estimate extreme wind speeds. This annex provides a method that is widely used in mesoscale modelling to correct the effect of the limited temporal and spatial resolution.

E.2 Temporal resolution

The mesoscale model's finite grid spacing limits the size of the eddies that can be resolved by the model, and thereby limits the effective temporal resolution of the simulation. For example, a simulation with a 5 km grid spacing resolves a temporal scale of around 30 min. This implies that the mesoscale model underestimates the variability of winds averaged over an interval shorter than 30 min, and therefore will underestimate extreme values of 10-minute averaged wind speeds. Several methods are proposed to correct this effect.

One approach is to multiply a correction factor between two different temporal resolutions. The factors for different temporal resolution for non-tropical cyclone case were extensively studied by Larsen and Mann [13] and empirical formulae are proposed [13].

Another approach is to use the statistical relation between the wind speeds with different temporal resolutions, and to apply a Monte-Carlo Simulation to generate synthetic time series of 10 min average wind speed. Yamaguchi et al, [14] describes the statistical relation between two different averaging times for tropical cyclone and non-tropical cyclone cases. It was also shown that for non-tropical cyclone cases, the extreme wind speed of synthetic time series is identical to the value obtained by the first method by using the factor described [13] for non-tropical cyclone case [14].

Note that regardless of the method used, the uncertainty of the derived extreme wind speed estimates is inversely related to the length of the model simulation, just as it is when deriving extreme winds from long-term measured records. A minimum of 10 years should be used.

E.3 Spatial resolution

Mesoscale models are limited by their finite grid to resolve fine-scale terrain features, and are thereby limited in their ability to resolve the associated fine-scale terrain-induced flows which includes the effect of the terrain with the resolution of mesoscale model grid size. One approach to downscale the wind flows to higher resolution than the model's grid spacing is called Idealizing and Realizing [15]. In this method, first by using the flow model simulation with the same resolution of orography and roughness as mesoscale model is carried out and idealized wind flow over flat terrain is estimated inversely from the mesoscale simulation results. Then, flow simulation with fine resolution of orography and roughness is carried out to estimate real wind speed. Mesoscale model wind speeds can also be downscaled in the time domain based on the method proposed by Misu and Ishihara [16].

The general notice on flow simulation over complex terrain for wind energy application is mentioned in IEC TR 61400-12-4 [1].

Annex F
(normative)

Data exchange format for site suitability input conditions

F.1 General

This annex specifies the digital format version 1.0 for site suitability data exchange. The format shall be based on json file format (ISO/IEC 21778) and shall follow the specification in this document. The Universal Coded Character Set (ISO/IEC 10646) and UTF-8 encoding without BOM (Byte order mark) shall be used. The reference files which follow this specification can be found in [17].

F.2 Top level keys

Ten top level keys shown in Table F.1 shall be used. The value of each key is an object, which contains the information described in Table F.1. Each top level key except for "Meta Data" corresponds to one sheet of the reference spreadsheet [17]. The detailed descriptions of the corresponding objects are given in Clause F.3.

Table F.1 – The contents of the top level keys

Top Level Keys	Contents of the objects
DEF version	Version number. Note that the data type for this key is not an object but a string. (Specifically, the version specified in IEC61400-15-1:2023 is "1.0").
Meta Data	Summary of the meta data such as wind climate discretization information, number and IDs of wind turbine and measurement devices, coordinate system
Project Information	General project information.
Turbine layout Summary	Summary of the turbine layout and estimated wind climate at the position of turbine.
Measurement Device Summary	Summary of the measurement devices.
WS Frequency	Sector-wise and omni directional discretized frequency distribution of wind speed at each turbine positions and measurement device positions.
WS Weibull	Wind rose and sector-wise Weibull parameters.
Ambient Mean TI	sector-wise and omnidirectional ambient mean turbulence intensity as functions of wind speed
SD TI	sector-wise and omnidirectional standard deviation of turbulence intensity as functions of wind speed
Extreme Ambient TI	omnidirectional extreme ambient turbulence intensity
Temperature	temperature at measurement device point
Shear	directional and omnidirectional wind shear exponent
Inflow Angle	directional and omnidirectional vertical inflow angle
CcT	turbulence structure correction parameter CcT

F.3 Description of each object

The keys in the object "Meta data" are listed in Table F.2. Table F.2 also shows the type and the description of corresponding values.

Table F.2 – The keys in the object "Meta data"

keys	value type	description
Number of wind direction sectors	int	Number of wind direction sectors. This shall be 12 or 16 according to the local requirement.
Wind speed bin width	int	Wind speed bin width. This value shall be 1 or 2. If this value is 1, the bin width is 1 m/s centred at each integer number of wind speed in [m/s], except for the lowest wind speed bin which is defined between 0 m/s and 0,5 m/s. If this number is 2, the bin width is 2 m/s centred at each even number of wind speed in [m/s], except for the lowest wind speed bin which is defined between 0 m/s and 1 m/s. In both cases, the center wind speed of the highest wind speed bin is 40 m/s. (see Figure F.1) Thus, the total number of the wind speed bin is 41 when this value is 1, and 21 when this value is 2.
Number of measurement devices	int	The number of measurement devices included in this data exchange file.
Measurement device IDs	array of string	The IDs of the measurement devices. The number of the elements of the array is equal to "Number of measurement devices" defined in this section. This IDs are used throughout this file.
Number of wind turbines	int	The number of wind turbines included in this data exchange file.
Wind turbine IDs	array of string	The IDs of the wind turbines. The number of the elements of the array is equal to "Number of wind turbines" defined in this section. This IDs are used throughout this file.

Wind speed bin width shall be 1 or 2, see Figure F.1.

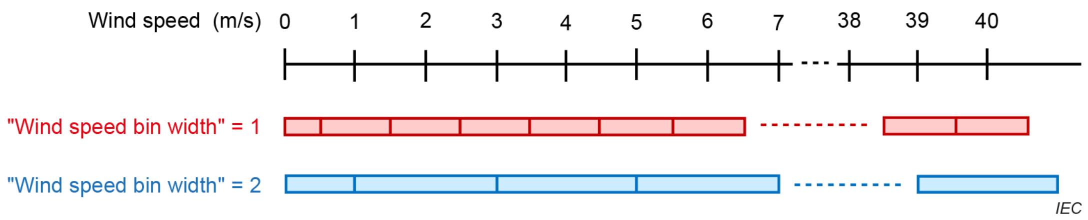

Figure F.1 – The definition of the wind speed bins

The keys in the object "Project Information" are listed in Table F.3. Table F.3 also shows the type and the description of corresponding values.

Table F.3 – The keys in the object "Project Information"

Keys	value type	description
Project name	string	The project name
Project owner	string	The owner of the project
Project number	string	The project number (optional)
Name	string	Name of person & organization completing form
Date	string	Date when form was completed. The format of the date shall be (YYYY-MM-DD).
Revision number	int	the revision number in an integer number
Reason for revision	string	The reason for the revision
Country & state	string	The country and state where the project is to be built. It is recommended to use ISO 3166.
Turbine Coordinates Datum	string	The coordinate datum used in this file. (e.g., WGS84)

Keys	value type	description
Turbine Coordinates Projection	string	If projected coordinate system (e.g., UTM) is used, the projection method shall be specified here. In addition, the detail of the projection (e.g., the zone of the UTM) shall also be specified here. If projected coordinate system is not used (i.e., longitude and latitude are used as the coordinate, this field shall be "lon-lat".
Accompanying report file name	string	The name of the accompanying report file name (if any).
Accompanying report revision number	string	The revision number of the accompanying report (if any).

The keys in the object "Turbine layout summary" are the IDs of wind turbines and the values for them are the objects the keys of which are listed in Table F.4.

Table F.4 – The keys in the objects of wind turbine IDs in the object "Turbine layout summary"

Keys	value type	unit	description
Project name	string	-	The project name
Easting, Latitude, etc	double	m or degree	easting in [m] or longitude in [deg] of the position of the wind turbine. This shall be in [m] when projected coordinate system is used and shall be in [deg] when longitude and latitude are used as the coordinate system.
Northing, Longitude, etc	double	m or degree	northing in [m] or latitude in [deg] of the position of the wind turbine. This shall be in [m] when projected coordinate system is used and shall be in [deg] when longitude and latitude are used as the coordinate system.
elevation	float	m	The elevation of the ground at the position of the wind turbine above sea level
Wind Turbine Manufacturer	string	-	The name of the manufacturer of the wind turbine.
model	string	-	The wind turbine model name
rated power	float	MW	Rated power of the turbine
rotor diameter	float	m	The diameter of the rotor
hub height	float	m	The hub height above ground level.
data source	string	-	The IDs of the measurement device (see Table F.5) from which the wind climate is derived.
Ve50	float	m/s	The extreme 3 s gust wind speed with the recurrence period of 50 years.
V50	float	m/s	The extreme 10 min averaged wind speed with the recurrence period of 50 years
COV	float	-	The coefficient of variation (COV) of the extreme wind speed. This is only relevant when COV of the extreme wind speed may exceed 15 %.
Air density	float	kg/m^3	Annual average air density
Annual Average Wind speed	float	m/s	Annual average wind speed
Weibull scale parameter	float	m/s	The omnidirectional Weibull scale parameter
Weibull shape parameter	float	-	The omnidirectional Weibull shape parameter
CCT	float	-	The turbulence structure correction parameter
Annual mean wind shear	float	-	The omnidirectional annual mean wind shear.
TI15	float	%	Annual average turbulence intensity at 15 m/s wind speed.
sigma I	float	%	The standard deviation of the turbulence intensity at 15 m/s wind speed, in [%]
Inflow angle	float	degree	The inclination of the wind velocity vector from

The keys in the object "Measurement device summary" are the IDs of measurement devices and the values for them are the objects the keys of which are listed in Table F.5.

Table F.5 – The keys in the objects of measurement device IDs in the object "Measurement device summary"

Keys	value type	unit	description
Easting, Latitude, etc	double	m or degree	easting in [m] or longitude in [deg] of the position of the measurement device.
Northing, Longitude, etc	double	m or degree	northing in [m] or latitude in [deg] of the position of the measurement device.
Ground elevation	float	m	elevation of the ground at the position of the measurement device above mean sea level (MSL)
Measurement device height	float	m	height above ground level where measurement device is located

The keys in the object "WS frequency" are the IDs of wind turbines and the measurement devices. The values for them are the objects the keys of which are listed in Table F.6. The key "WS Number of samples" is required only when the object is one of the IDs of the measurement devices.

Table F.6 – The keys in the objects of IDs of measurement device and wind turbine in the object "WS frequency"

Keys	value type	unit	description
WS frequency	2D array of float (array of array of float)	%	Discretized frequency distribution of wind speed for each wind speed bin and wind direction sector, presented as 2D array (array of array). The element number of the inner array is the number of wind speed bins (either 41 or 21 depending on "Wind speed bin width", see Table F.2). The element number of the outer array is equal to "Number of wind direction sectors". The frequency shall be presented by using percent (i.e., the sum of the all the elements shall be 100.).
WS number of samples	2D array of int (array of array of int)	-	The number of data samples included in each bin of wind speed and wind direction. The format of the array is the same as "WS frequency". This is only required for measurement devices.

The keys in the object "WS Weibull" are the IDs of wind turbines and the measurement devices. The values for them are the objects the keys of which are listed in Table F.7.

Table F.7 – The keys in the objects of IDs of measurement device and wind turbine in the object "WS Weibull"

Keys	value type	unit	description
WS Weibull scale parameter all directions	float	m/s	The omnidirectional scale parameter C of the Weibull distribution
WS Weibull shape parameter all directions	float	-	The omnidirectional shape parameter k of the Weibull distribution.
WS Weibull scale parameter	array of float	m/s	The scale parameter C of the Weibull distribution. The number of the element of the array is equal to "Number of wind direction sectors" (see Table F.2).
WS Weibull shape parameter	array of float	-	The shape parameter k of the Weibull distribution. The number of the element of the array is equal to "Number of wind direction sectors" (see Table F.2).
WS Weibull frequency	array of float	%	The frequency of occurrence of wind direction (wind rose). The number of the element of the array is equal to "Number of wind direction sectors" (see Table F.2). The sum of the values in all the elements shall be 100.

The keys in the object "Ambient mean TI" are the IDs of wind turbines and the measurement devices. The values of them are objects the keys of which are listed in Table F.8.

Table F.8 – The keys in the objects of IDs of measurement device and wind turbine in the object "Ambient mean TI"

Keys	value type	unit	description
Ambient mean TI all directions	array of float	%	The ambient mean turbulence intensity as function of wind speed for all wind directions. The element number of the array is the number of wind speed bins (either 41 or 21 depending on "Wind speed bin width", see Table F.2).
Ambient mean TI	2D array of float (array of array of float)	%	The ambient mean turbulence intensity as function of wind speed and wind direction, presented as 2D array (array of array). The element number of the inner array is the number of wind speed bins (either 41 or 21 depending on "Wind speed bin width", see Table F.2). The element number of the outer array is equal to "Number of wind direction sectors".

The keys in the object "SD TI" are the IDs of wind turbines and the measurement devices. The value of them is an object the keys of which are listed in Table F.9.

Table F.9 – The keys in the objects of IDs of measurement device and wind turbine in the object "SD TI"

Keys	value type	unit	description
SD TI all directions	array of float	%	The standard deviation of the turbulence intensity as function of wind speed for all wind directions. The element number of the array is the number of wind speed bins (either 41 or 21 depending on "Wind speed bin width", see Table F.2).
SD TI	2D array of float (array of array of float)	%	The standard deviation of the turbulence intensity as function of wind speed and wind direction, presented as 2D array (array of array). The element number of the inner array is the number of wind speed bins (either 41 or 21 depending on "Wind speed bin width", see Table F.2). The element number of the outer array is equal to "Number of wind direction sectors".

The keys in the object "Extreme ambient TI" are the IDs of wind turbines and the measurement devices. The value of them is an object with only one key "Extreme ambient TI" the detail of which is shown in Table F.10.

Table F.10 – The key in the objects of IDs of measurement device and wind turbine in the object "Extreme ambient TI"

Keys	value type	unit	description
Extreme ambient TI	array of float	%	Extreme ambient turbulence intensity as function of wind speed for all wind directions. The element number of the array is the number of wind speed bins (either 41 or 21 depending on "Wind speed bin width", see Table F.2).

The keys in the object "Temperature" are the IDs of the wind turbines and measurement devices. The value of them is an object the keys of which are listed in Table F.11.

Table F.11 – The keys in the objects of IDs of measurement device and wind turbine in the object "Temperature"

Keys	value type	unit	description
Yearly mean ambient Temperature	float	degree Celsius	Measured yearly mean ambient temperature at the measurement device.
Days per year with at least 1 h below −20°	float	day	Number of days per year with at least one hour below negative 20 degrees Celsius.
Temperature frequency	array of float	%	Discretized frequency distribution of temperature at the measurement site. The temperature bin is centred at each integer temperature in degree Celcius. The lowest temperature bin is centred at negative forty degree which include all the data below negative forty degree. The highest temperature bin is centred at positive fifty degree which include all the data above fifty degree. Thus, the number of the bin is 91 in total, meaning the number of the element of this array is also 91.
Temperature data occurrencies	array of int	-	Similar to "Temperature frequency" but shown as the number of 10 min value rather than the frequency. The bin setting is the same as "Temperature frequency".

The keys in the object "Shear" are the IDs of the wind turbines and the measurement devices. The value of them is an object the keys of which are listed in Table F.12.

Table F.12 – The keys in the objects of IDs of measurement device and wind turbine in the object "Shear"

Keys	value type	unit	description
Shear all directions	float	-	The shear exponent α calculated from all the wind directions.
Directional shear	array of float	-	The shear exponent α as a function of wind direction. The number of the element of the array is equal to "Number of wind direction sectors" (see Table F.2).

The keys in the object "Inflow angle" are the IDs of the wind turbines and the measurement devices. The value of them is an object the keys of which are listed in Table F.13.

Table F.13 – The keys in the objects of IDs of measurement device and wind turbine in the object "Inflow angle"

Keys	value type	unit	description
Inflow angle all directions	float	degree	The vertical inflow angle calculated from all wind direction data.
Inflow angle max	float	degree	The maximum vertical inflow angle.
Directional inflow angle	array of float	degree	The vertical inflow angle as a function of wind direction. The number of the element of the array is equal to "Number of wind direction sectors" (see Table F.2).

The keys in the object "CcT" are the IDs of the wind turbines and the measurement devices. The value of them is an object the keys of which are listed in Table F.14.

Table F.14 – The keys in the objects of IDs of measurement device and wind turbine in the object "CcT"

Keys	value type	unit	description
Sigma 3/Sigma 1	float	-	The ratio of the standard deviation of the vertical component of wind velocity (σ_3) to the standard deviation of the longitudinal component of wind velocity (σ_1).
Sigma 2/Sigma 1	float	-	The ratio of the standard deviation of the lateral component of wind velocity (σ_2) to the standard deviation of the longitudinal component of wind velocity (σ_1).
CcT	float	-	The turbulence structure correction parameter CcT.

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Reference repository

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