IEC 61400-15 Working Group

Progress Update #2 – Meeting 13

20 January 2018

San Diego, California - USA

Convener: Bob Sherwin, EAPC – USA

vtwindpower@gmail.com

Secretary: Jason Fields, NREL – USA

jason.fields@nrel.gov

Contents

List of Tables

List of Figures

1. Introduction

The IEC 61400-15 Working Group (WG) is developing an IEC standard for wind resource assessment, energy yield analysis and site suitability input estimation (the Standard). The working group is convened by Bob Sherwin (EAPC – USA), and the Secretary is Jason Fields (NREL – USA). The WG is comprised of 58 topic-area experts from 15 countries, including representatives from developers, turbine manufacturers, consultancies, labs, and academia. A list of WG members and Meeting 13 Attendees is available from the convener. This document presents a summary of the Standard's IEC TC-88 approved scope. It also provides an update on the status of the Standard development as of WG Meeting 13, held 16-19 January, 2018 in San Diego, California. This is not an official IEC document; it is a product solely of this working group. The aim of this document is to share the status of the Standard's development.

2. Scope of the Standard - IEC TC-88 Approved

The scope of the 61400-15 Standard is to define a framework for assessment and reporting of the wind resource, energy yield and site suitability input conditions for both onshore and offshore wind power plants. This includes:

1. Definition, measurement, and prediction of the long-term meteorological and wind flow characteristics at the site
2. Integration of the long-term meteorological and wind flow characteristics with wind turbine and balance of plant characteristics to predict net energy yield
3. Characterizing environmental extremes and other relevant plant design drivers
4. Assessing the uncertainty associated with each of these steps
5. 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.

The meteorological and wind flow characteristics addressed in this document relate to wind conditions, where parameters such as wind speed, wind direction, air density or air temperature are included to the extent that they affect the operation and structural integrity of a wind turbine (WTGS) and energy production analysis.

According to IEC 61400-1 and 61400-3 the site-specific conditions can be broken down into wind conditions, other environmental conditions, soil conditions, ocean/lake conditions and electrical conditions. All of these site conditions other than site-specific wind conditions and related documents are out of scope for this Standard.

3. Aim of the Standard

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

The basic and fundamental goal is to present consensus methodologies on site assessment and to create a set of standard reporting requirements which detail the measurement campaign, analysis processes, and considerations taken by the author of a wind resource characterization and energy yield assessment. The methodologies presented provide a framework to ensure a high-quality set of project data are collected and analyzed to support wind resource and site characterization. The standardized reporting process will provide a discrete list of criteria, which must be considered and reported on for all projects. These reporting procedures will provide transparency to report readers about the considerations taken during the analysis, and confidence that the analysis considered all of the key criteria and procedures identified by IEC 61400-15 for wind resource assessment.

At a minimum, the document will prescribe standard reporting elements and considerations during the analysis process, and recommend practices to reduce uncertainty for all elements of the assessment and campaign.

Two additional goals of the Standard, which should be explored by the committee:

- Develop a standard uncertainty calculation to be used for benchmarking
- Provide standardized inputs for turbine loads calculations

The document will not:

- Qualify or disqualify projects
- Qualify or disqualify consultants/Independent Engineers

4. Working Group Progress Update – Meeting 13

This section presents a summary of the WG's approach and progress as of 20 January 2018. Information here has consensus among the WG participants but is subject to review and revision. It is NOT officially approved or sanctioned by the IEC.

A report certified to the 61400-15 Standard will comply with a standard reporting format and uncertainty framework. The quality and accuracy of the underlying analysis and results will then be more easily evaluated and omissions clearly identified. A compliant report is expected to provide sufficient information for an independent assessor to evaluate the processes and results.

4.1. Working Group Structure and Approach

The WG has divided up the Standard development work into the initial topic-area packages:

- Site suitability inputs
- Uncertainties
- Reporting

Each of the uncertainty topic areas was assigned sub-groups to address the contributing parameters, and associated reporting requirements. Specifically, each sub-group is working to define:

- Descriptions
- Drivers

- A normal range of expected values
- A default model for calculating the uncertainty

An additional sub-group is developing methods to combine uncertainties.

Varying degrees of progress have been made within each of the sub-groups. The following sections describe the content that was sufficiently advanced for external review in each of the sub-groups.

4.2. Energy Yield

The WG has identified approaches to energy assessment based upon each of (or a combination of) the following:

1. Wind measurements
2. Production data
3. Virtual data (mesoscale model)

The WG has developed loss and uncertainty frameworks to cover assessment approaches 1 and 2. Assessment approach 3 or more complex hybrid analyses planned to be addressed by the group.

Table 1 below shows the loss register framework. Table 2 shows the high-level uncertainty categories associated with a wind measurement based analysis, with Tables 2.1 to 2.6 showing the sub-level categorization. Tables 2.1 through 2.6 have been updated based upon WG progress, where relevant.

Production data from wind turbines in operation (reference wind turbines) may serve as “site specific wind and energy information” and can be applied to verify the estimated wind and/or energy potential for the prospective site. In such a case site-specific wind measurements may not be necessary. The uncertainty framework of this approach is below in Table 3, with Tables 3.1 to 3.6 showing the sub-level categorization.

The ongoing work of the group is to establish methodologies to quantify and combine the uncertainties for both wind based and production-based uncertainties, and to define the reporting requirements against each analysis. For cases where both production data and wind measurements are available the uncertainty formulation would involve some combination of wind based and production based frameworks, and this has yet to be defined.

The following sub-sections present a summary of the advancements within each of the sub-groups addressing measurement-based energy yield analyses.

4.2.1. Historical Data/Project Lifetime Variability

The historical data and project lifetime variability sub-group progress has been focused in two areas. The first area involved the development of expanded definitions of the sub-level categories (detailed in Table 2-1) to ensure that all appropriate methodologies are captured within the framework. The components to each of the sub-levels have been examined in terms of the uncertainty contribution and the main driving components have identified. The second area involves conducting a literature review of published documents relating to the quantification of uncertainty for the appropriate methodologies. It is noted that as the underlying correlation methodology used in the historical wind resource category is not unique to the Wind Industry, the literature review is at this stage wide ranging.

4.2.2. Site Measurement

A draft measurement uncertainty framework has been developed based upon existing IEC standards (e.g., 61400-12-1, ed. 2), and augmented based upon expected uncertainty drivers present as part of the Wind Resource Assessment and Energy Yield processes. The intent of this section is to define the uncertainty associated with validated time series of measurement parameters per monitoring level (i.e. measurement height above the surface) at each measurement station. The framework is being defined to accommodate diverse measurement station types, including masts, fixed remote sensing, and floating remote sensing systems. Guidance on the estimation and calculation of the uncertainty contributors is underway. The narrative section is in the drafting process and planned to include, but not necessarily be limited to, the following:

- A description of the uncertainty contributors and calculation processes, including limitations and assumptions;
- Normative and informative equations for each contributor, including guidance on the combination of measurement uncertainties;
- Flow-chart guidance on calculating the uncertainties;
- Representative ranges of values.

All of the uncertainty contributors outlined in Table 2.3 are being addressed in a slightly revised framework which is currently under development.

4.2.3. Spatial Extrapolation

Spatial extrapolation uncertainty has been categorized into three main sub-levels. No analytical common approach exists for determining the horizontal extrapolation uncertainty that covers all components of the uncertainty for the different site characteristics. Consequently, the driving factors have been identified for each of the three sub-categories (see table 2.5) and guidance is being developed to allow the reader to assess a site against these criteria, and to pragmatically quantify the uncertainty for each sub-category.

The method will be calibrated against project datasets to verify that the results are consistent with current industry standards. The narrative section to accompany the method is also in the drafting process and is expected to include a description of the evaluation process to assist the reader in the selection of appropriate uncertainty values.

4.2.4. Vertical Extrapolation

The vertical extrapolation group has focused on summarizing existing methods of vertical extrapolation and validating uncertainty models for those methods. The group has completed a draft of the language to be included in the standard as well as developed a mathematical uncertainty model. Testing of the uncertainty methods and integration into the standards document are the anticipated next steps for the group.

4.2.5. Operational Data

The “Operational Data” Group has formulated an approach to use production data from operational wind turbines as “site specific wind and energy information” which can be applied to verify the estimated wind and/or energy potential for the prospective site. In such a case site specific wind measurements may not be necessary. The production data have to meet certain requirements in terms of duration, distance and height which are similar to those for on-site wind measurements.

The uncertainty framework is similar to that for wind measurements with respect to the Historical wind resource, Project evaluation period variability, vertical and horizontal extrapolation and plant performance. The measurement uncertainty is replaced by “Production Data Uncertainty”. The latter is subdivided into the categories Data, Operation Mode, Turbine Performance, Data Analysis, and Representativeness for planned WTG.

4.2.6. Virtual Data

Products named virtual met mast (VMM) data are numerical weather prediction and/or climate model simulation outputs. Given the spectrum of methods used to generate VMM data within the industry and the wide range of usages of VMM data, it is important to establish the best practices for atmospheric modeling to allow non-experts to easily gauge the scientific and technical rigor and validity of VMM data. The aim should be to provide as much methodological transparency as possible, which will ultimately elevate awareness and confidence in VMM products.

In that spirit the VMM data working group is tasked to provide:

- A documentation standard or minimum level of documentation required for VMM data,
- Uncertainty calculation methodologies for the different VMM data use cases.

The VMM data working group developed a documentation standard for VMM data and drafted a decision tree for the uncertainty assessment of VMM data depending on the kind of adjustment data source, where adjustment means calibration of the VMM data using on-site data (type A adjustment), satellite measurements (B) or wind farm production data (C). When VMM data is used in absence of on-site measurements (D), validation studies need to be presented that are representative for the specific application: The VMM data working group drafted a validation framework that aims to ensure VMM data is validated against a set of representative observations.

4.2.7. Plant Performance

The plant performance uncertainty working group addresses all the uncertainties of the plant losses (as laid out in Table 1 of this document) and its subcomponents. For that purpose, the plant performance working group developed a spreadsheet that incorporates transparent decision trees to come up with benchmark uncertainties for low, medium and high uncertainty cases, e.g. for wake loss uncertainties this assessment involves the quantity and quality of representative validation studies for the wake model in question. The working group, as per committee consensus, is scheduled to finalize the work on the spreadsheet ahead of the next IEC meeting, so it can share and seek committee consensus of the outcome.

4.2.8. Combining Uncertainty

The Combining Uncertainties working group has developed a spreadsheet model that incorporates the “Guide to the expression of uncertainty in measurement” (GUM) standard method of combining uncertainties. The model includes the option to allow for cross-correlations of uncertainties between measurement masts in multiple mast projects as well as allowing for any correlations of uncertainty components associated with the same mast. Work to determine the relevance and impact of the various potential cross-correlations is ongoing. The outputs (uncertainty values) from each of the uncertainty component working groups will serve as the inputs to the combination model.

Consensus within the committee as a whole has been achieved regarding the method of combination. The writing of documentation on methodology, guidance and instructions for use are in progress. An example case will also be developed to illustrate the use of the combination model.

Once all of the uncertainty inputs are finalized by all of the working groups, the model will be released to various industry beta testers for evaluate and feedback.

4.2.9. Reporting

The reporting group addresses the overall structure of uncertainty and results reporting. The reporting itself will be modular, to allow for variations in procedural order and methodology. The structure will be closely tied to the uncertainties outlined above. Each section must clearly define the following: inputs, process, metrics, section outputs and uncertainty.

4.3. Site Suitability

Wind turbines are subject to environmental and electrical conditions including the influence of nearby turbines, which affect their loading, durability and operation. This work focuses on 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, and the cold climate conditions. Effort has been focused on how to report these input parameters and their associated uncertainties to allow the manufactures to undertake site suitability calculations.

The suitability sub-group's efforts thus far have focused on two areas. The first area of focus is to provide a harmonized framework for sharing summarized site conditions between different parties - primarily consultants, turbine manufacturers, and developers. This framework, structured in a Digital Exchange Format (DEF), would replace the existing summarized data formats currently used by different organizations. The intent is to create a consensus standard reporting format for site conditions to communicate the input parameters necessary for site suitability review and/or mechanical load assessment.

This exchange format deals with project information, turbine layout, average and extreme wind conditions, turbulence intensity and its standard deviation, temperature, shear, inflow angle, terrain complexity, and related parameters. The format has been designed to be comprehensive in nature and aims to replace individual manufacturers' site suitability forms, allowing a developer or third party to complete the form once and issue the data to multiple manufactures. A graphical representation of the DEF's intended function is presented in Figure 1. The DEF does not exclude the use or consideration of the underlying wind and site data for suitability inputs, which will be at the discretion of the turbine OEM or developer.

The second area of focus is to provide narrative guidance and definition on site conditions inputs which are loosely or not defined in 61400-1. For example, there will be guidance for estimating the 50-year extreme wind speeds, extrapolating shear and turbulence intensity from mast locations and heights to turbine positions and heights, among other things.

Informative methods for calculating all suitability input parameters, and associated uncertainties, will be provided. Where there is consensus, the methods will be standardized.

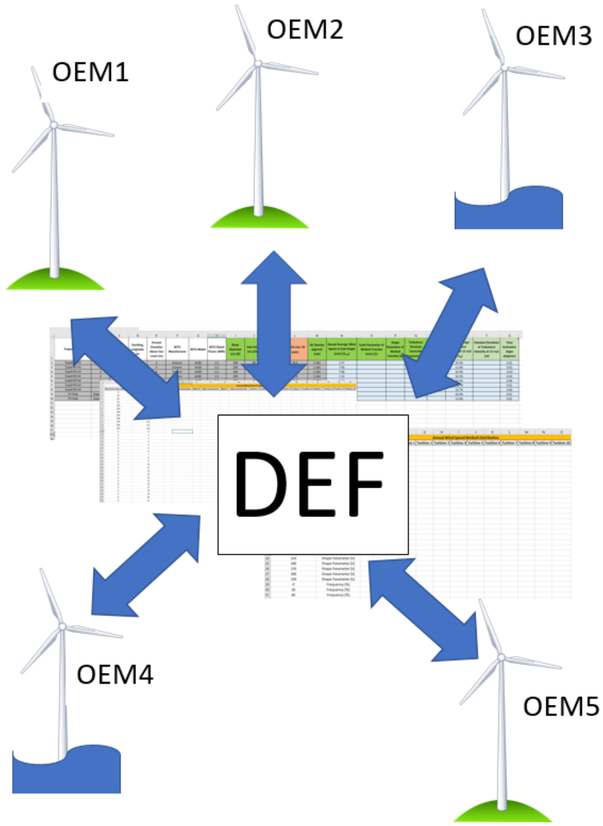

Figure 1: Site Suitability Input Digital Exchange Format (DEF) Sharing Concept

4.4. Offshore

Offshore atmospheric conditions, including those described in 61400-3, will be considered in each topic area and recommended variations will be presented where necessary.

5. Working Group Next Steps

The WG will continue developing uncertainty calculation methods for each of the categories described above. The near term focus will be ensuring consistency amongst the uncertainty subcomponents as well as focusing on usability and validation of the recommended methods. Reporting requirements for energy yield and suitability input analyses will also be developed further.

The next meeting for the WG is planned for the week of 23-27 April, 2018 in Tokyo, Japan. Presentations and/or discussions of WG progress are anticipated to be held as part of the AWEA WRA working group webinars, AWEA Wind Resource & Project Energy Assessment Conference, as well as other venues as requested.

Table 1: Loss Framework

Wake Effect	
Internal Wake Effects	Wake effects internal to the wind plant
External Wake Effects	Wake effects generated externally to the wind plant
Future Wake Effects	Wake effects that will impact future energy projections based upon either confirmed or predicted new project development or decommissioning
Availability	
Turbine Availability	Turbine availability (energy-based), considering: Warranted availability, non-contractual availability, Restart after grid outage, Site Access, Downtime (or speed) to energy ratio, First Year / Plant start-up Availability
Balance of Plant Availability	Availability of substation and collection system, Other non-turbine availability, Warranted Availability, Site Access, First Year / Plant start-up
Grid Availability	Grid being outside Grid connection agreement operational parameters, actual grid downtime, delays in restart after grid outages.
Electrical	
Electrical Efficiency	Electrical losses between low or medium voltage side of the transformer of WTG(S) and the energy measurement point
Facility Parasitic Consumption	Turbine extreme weather packages, Other turbine and/or plant parasitic electrical losses (while operating or not operating)
Turbine Performance	
Sub-Optimal Performance	Performance deviations from the optimal wind plant performance due to software, instrumentation, and control setting issues
Generic Power Curve Adjustment	Expected deviation between advertised power curve and actual power performance in standard conditions ("inner range"[1])
Site-specific Power Curve Adjustment	Accommodating for inclined flow, TI, density, shear, and other site / project-specific adjustments ("outer range"[1])
High Wind Hysteresis	Energy lost in hysteresis loop between high wind speed cut-out and recut-in.
Environmental	
Icing	Performance degradation and shut down due to icing
Degradation	Blade fouling, efficiency losses, and other environmentally-driven performance degradation
Environmental Loss	High/low Temperature shut down or de-rate, Lightning, hail, and other environmental shut downs
Exposure	Tree growth or logging, other building development, etc.
Curtailments / Operational Strategies	
Load Curtailment	Speed and/or direction curtailments to mitigate loads
Grid Curtailment	PPA / off-taker curtailments, grid limitations
Environmental / Permit Curtailment	Birds, Bats, marine mammals, flicker, noise (when not captured in the power curve), etc.
Operational Strategies	Any periodic up-rating, down-rating, optimization or shut-down not captured in the power curve or availability carve-outs

[1] As defined by Power Curve Working group http://www.pcwg.org

Table 2: Uncertainty Framework – Wind Measurement Based Energy Yield

Primary Uncertainty Categories
Historical Wind Resource
Project Evaluation Period Variability
Measurement Uncertainty
Vertical Extrapolation
Horizontal Extrapolation
Plant Performance

Table 2.1: Measurement Based Uncertainty Categories - Historical Wind Resource

Historical Wind Resource	
Sub-level	**Notes/definition:**
Long-term Period:	**What is the statistical representativeness of the chosen historical and/or site data period**? I.e. the Inter-annual variability (coefficient of variation) of the historical reference data period in years.
Reference Data:	**How accurate/reliable is the chosen reference data source**? I.e. historical data consistency (e.g. is/are there possible underlying trend(s) in the data);
Long term adjustment:	**What is the uncertainty associated with the prediction process?** Statistical/empirical uncertainty in establishing a correlation or carrying out a prediction, which may be conditioned upon the correlation method and span/quantity of concurrent data period.
Wind Speed and Direction Distribution:	**Mean wind speed aside, how representative is the measured/predicted distribution and wind/energy rose shape of the long-term?** This makes most sense as an energy uncertainty term.
On-site Data Synthesis:	Uncertainty associated with gap-filling missing data periods. Usually done using directional correlations/MCP and, hence, long-term and reference data categories may apply.

Table 2.2: Measurement Based Uncertainty Categories - Project Evaluation Period Variability

Project Evaluation Period Variability	
Sub-level	**Notes/definition:**
Modelled Operational Period:	The statistical uncertainty associated with how closely the wind resource over the modelled operational period (i.e. 1-year, 10-year, etc.) may match the long-term site average.
Climate Change:	Changes in the future period of performance associated with long term climatic changes and global temperature increase which may differ from the historical long-term site average.
Plant Performance:	The statistical uncertainty associated with how closely the plant performance over the modelled operational period (i.e. 1-year, 10-year, etc.) may match the long-term site average.

Table 2.3: Measurement Based Uncertainty Categories - Measurement Uncertainties

Measurement Uncertainty	
Sub-level	**Notes/definition:**
Direct Measurement Uncertainties – those directly affecting the Measurement Uncertainty Category	
Wind Speed Measurement:	Including effects for Wind Speed Sensor Characteristics (Cup / sonic), Wind Speed Sensor Mounting / Deployment (Cup / sonic), Wind Speed Sensor Data Handling and Processing Characteristics (e.g. tower shadow, icing, degradation, etc.), System Motion, Consistency and Exposure, Data Acquisition, and Data Handling. Additionally, the reduction in uncertainty due to Sensor Combination is considered
Data Integrity and Documentation:	Documentation, Verification, and Traceability of the data
Indirect Measurement Uncertainties – those contributing to other uncertainty categories	
Wind Direction Measurement / Rose:	Sensor type/quality, Operational characteristics, Mounting Effects, Alignment, Acquisition, Long-term representativeness
Further atmospheric parameters:	Air Temperature, Pressure, Relative Humidity, and other atmospheric parameters

Table 2.4: Measurement Based Uncertainty Categories - Vertical Extrapolation

Vertical Extrapolation	
Sub-level	**Notes/definition:**
Model Inputs:	Terrain Surface Characterization, Wind data measurement height(s), wind statistic(s)/shear, measurement uncertainty
Model Components:	Representativeness per height/terrain, profile fit,

Table 2.5: Measurement Based Uncertainty Categories - Horizontal Extrapolation

Horizontal Extrapolation	
Sub-level	**Notes/definition and drivers:**
Model Inputs:	Fidelity and appropriateness given sensitivity of model to - terrain data, roughness, forestry info, atmospheric conditions. Drivers are • Accuracy of the measurement and prediction coordinates • Accuracy, resolution and extent of elevation data • Completeness, accuracy and extent of roughness/ground cover/obstacle data including forestry information • Completeness and accuracy of input data to describe the atmospheric conditions required for the modelling, where not considered elsewhere

<table>
<tr><th colspan="2">Horizontal Extrapolation</th></tr>
<tr><td>Model Stress:</td><td>Representativeness of initiation points relative to turbine locations in terms of complicating factors, e.g. Forestry, Stability, steep slopes, distance, elevation, veer. Intensity of and sensitivity to complicating factors

Drivers are
Distance (from prediction point and initiation point)
and the variation between initiation points and prediction points (and their surroundings) in terms of:
Elevation
Slopes
Forestry
Stability
Roughness
Proximity to coastline
Wind speed
Turbulence
Shear
Veer
Flow angle
and other.</td></tr>
<tr><td>Model Appropriateness:</td><td>Physical scientific plausibility of model to capture complicating factors. Validation of implementation of model - published validation of specific implementation and relevance to complicating factors present on site. On-site model verification: site-to-site (un-tuned, blind) – consider quality of any shear verification also.

Drivers are
Limitations of the model physics to capture complicating factors as expected on the site, e.g. flow separation, atmospheric stability, katabatic/anabatic and thermally driven flow
Suitability of model geometry (resolution and domain size)
Demonstrated accuracy to apply the specific implementation of the model under similar conditions and stresses
Accuracy of on-site model verification between measurement points, results of assessment of consistency and sensitivity of model results over the predicted area</td></tr>
</table>

Table 2.6: Measurement Based Uncertainty Categories – Plant Performance

Plant Performance	
Sub-level	**Notes/definition:**
Wake Effect:	Uncertainties to cover all components and subcomponents of loss factors outlined in Table 1
Availability:	
Electrical:	
Turbine Performance:	
Environmental:	
Curtailments / Operational Strategies:	

Table 3: Uncertainty Framework – Production Data Based Energy Yield

Primary Uncertainty Categories
Historical Wind Resource
Project Evaluation Period Variability
Production Data
Vertical Extrapolation
Horizontal Extrapolation
Plant Performance

Table 3.1: Production Data Based Uncertainty Categories - Historical Wind Resource

Historical Wind Resource	
Sub-level	**Notes/definition:**
See Table 2.1, Production Indexes also available.	

Table 3.2: Production Data Based Uncertainty Categories - Project Evaluation Period Variability

Project Evaluation Period Variability	
Sub-level	**Notes/definition:**
See table 2.2	

Table 3.3: Production Data Based Uncertainty Categories – Production Data Uncertainties

Production Data Uncertainty	
Sub-level	**Notes/definition:**
Data:	Reliability of data source (Availability of Operational Reports, Availability of SCADA documentation), Data quality such as Data definition, integrity, temporal resolution, data recovery, turbine availability, length of data period and Point of measurement (WTG/grid connection point), Class of Uncertainty of the power metering equipment
Operation mode:	Reliability of information, Detail of information (restrictions, change in operation mode), Wake effects (Availability of information on external turbines).
Turbine performance:	Influence of site specific wind conditions, site-specific power curve, Spread of standard factory components on operating reference turbines
Data analysis:	Availability correction, Detection and handling of erroneous data
Representativeness for planned WTG:	Distance and elevation difference between reference turbine(s) and planned turbine(s), Surface characteristics, WTG type, Hub height, reference turbine layout and/or exposure

Table 3.4: Production Data Based Uncertainty Categories - Vertical Extrapolation

Vertical Extrapolation	
Sub-level	**Notes/definition:**
Model Inputs:	Terrain Surface Characterization, reference turbines hub height(s), wind statistic(s)/shear, production data uncertainty.
Model Components:	Representativeness per height/terrain, profile fit,
Model Stressor:	Large extrapolation distance, complex terrain (reference turbine hub height relative to terrain complexity)

Table 3.5: Production Data Based Uncertainty Categories - Horizontal Extrapolation

Horizontal Extrapolation	
Sub-level	**Notes/definition:**
See Table 2.5	

Table 3.6: Production Data Based Uncertainty Categories – Plant Performance

Plant Performance	
Sub-level	**Notes/definition:**
See Table 2.6	