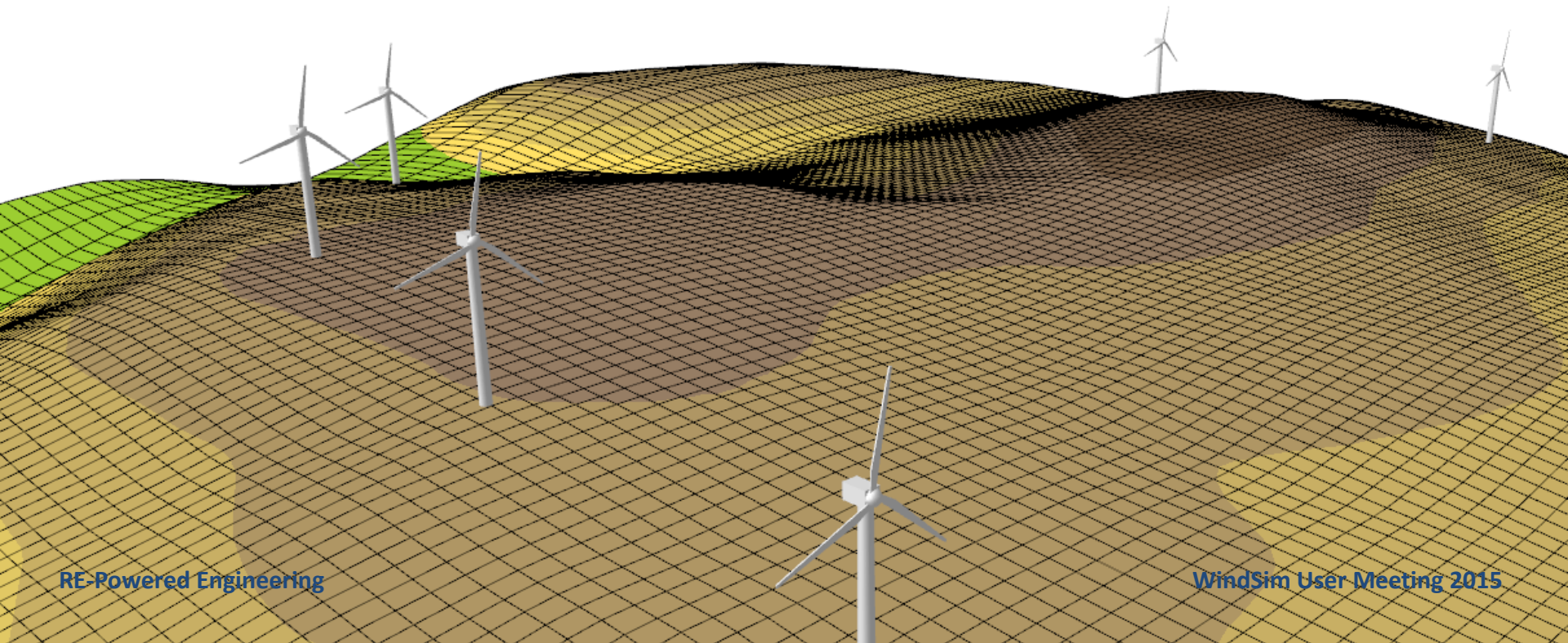


Uncertainty in Wind Energy Assessment

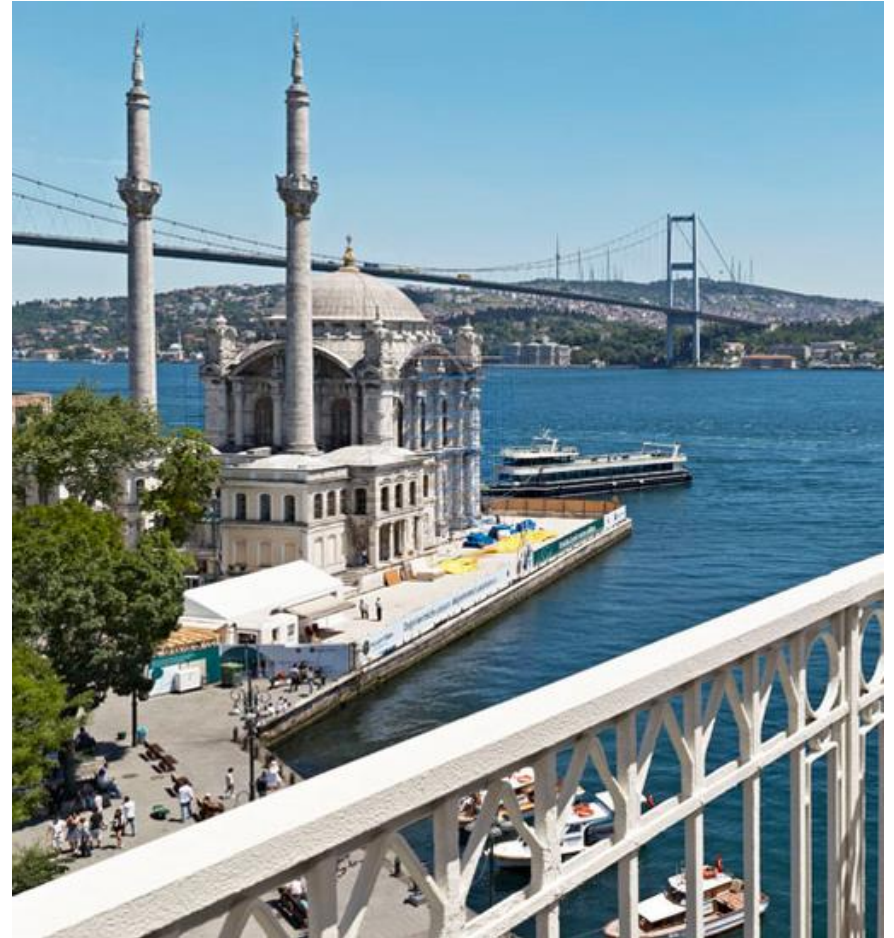
(Emphasis on Model Uncertainty)

Akgün Kalkan



Company

- Founded by two senior Aeronautical Engineers in 2010
- Located in İstanbul, Turkey
- A team of six dedicated engineers
- Software sales and independent consultancy projects
- Expertise in CFD and numerical methods
- Solution partners: WindSim, Vortex



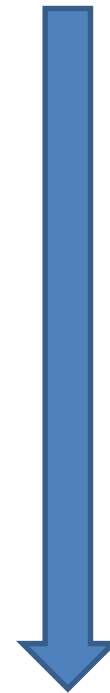
Wind Energy Investment



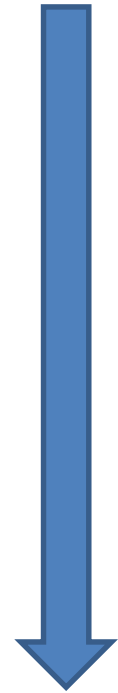
Project Finance

- The financial evaluation a wind energy project is very sensitive to wind resource.
- Accurately predicting the wind resource is critical to a realistic IRR.
- A very critical part of resource assessment is estimating and quantifying uncertainties.
- In wind projects uncertainty is expressed in terms of probability of exceedance values (P50, P75, P90), banks generally use P75 or P90 values.
- P50 means that there is a probability of %50 that energy yield will be more than P50. P75 means that there is %25 chance that P75 level of AEP will not be reached.

AEP



RISK

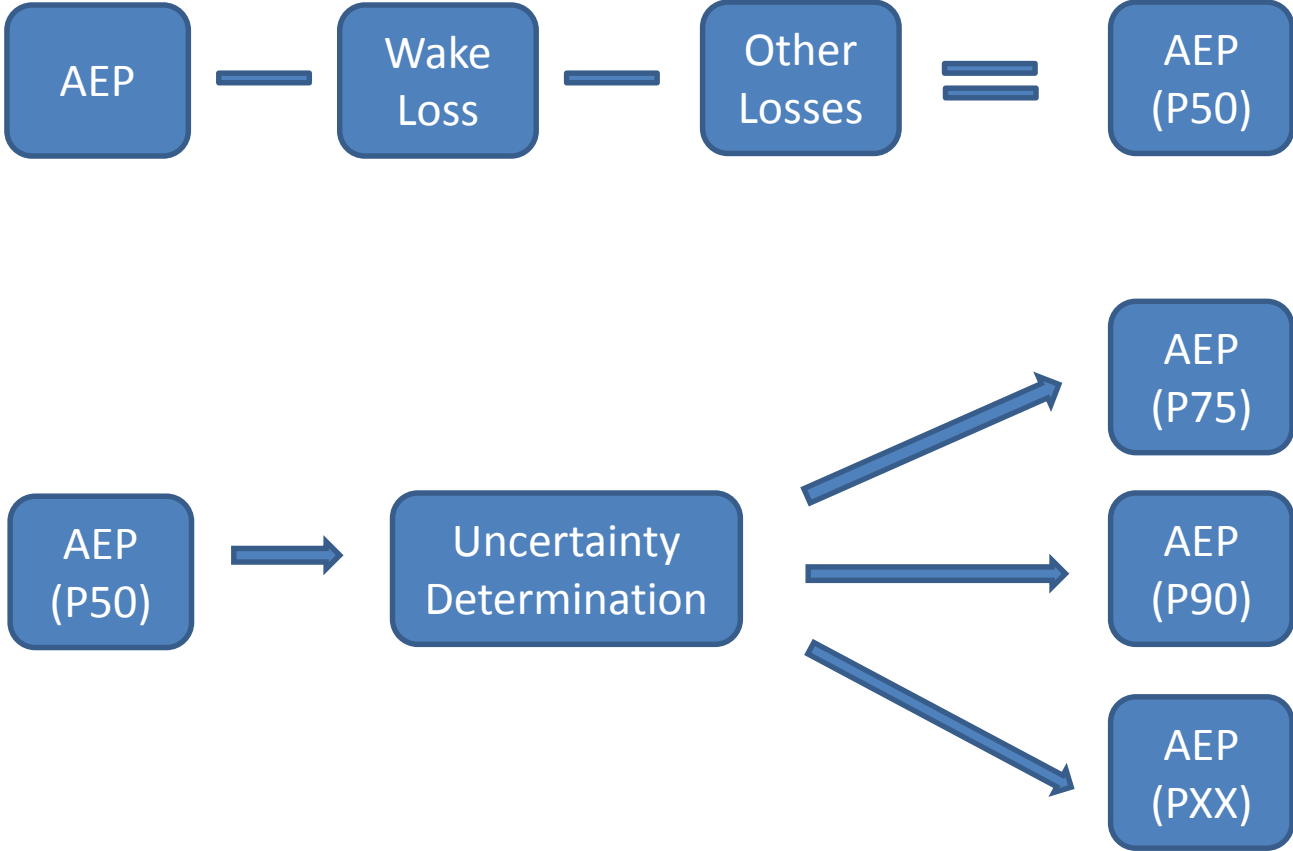


P50

P75

P90

Uncertainty



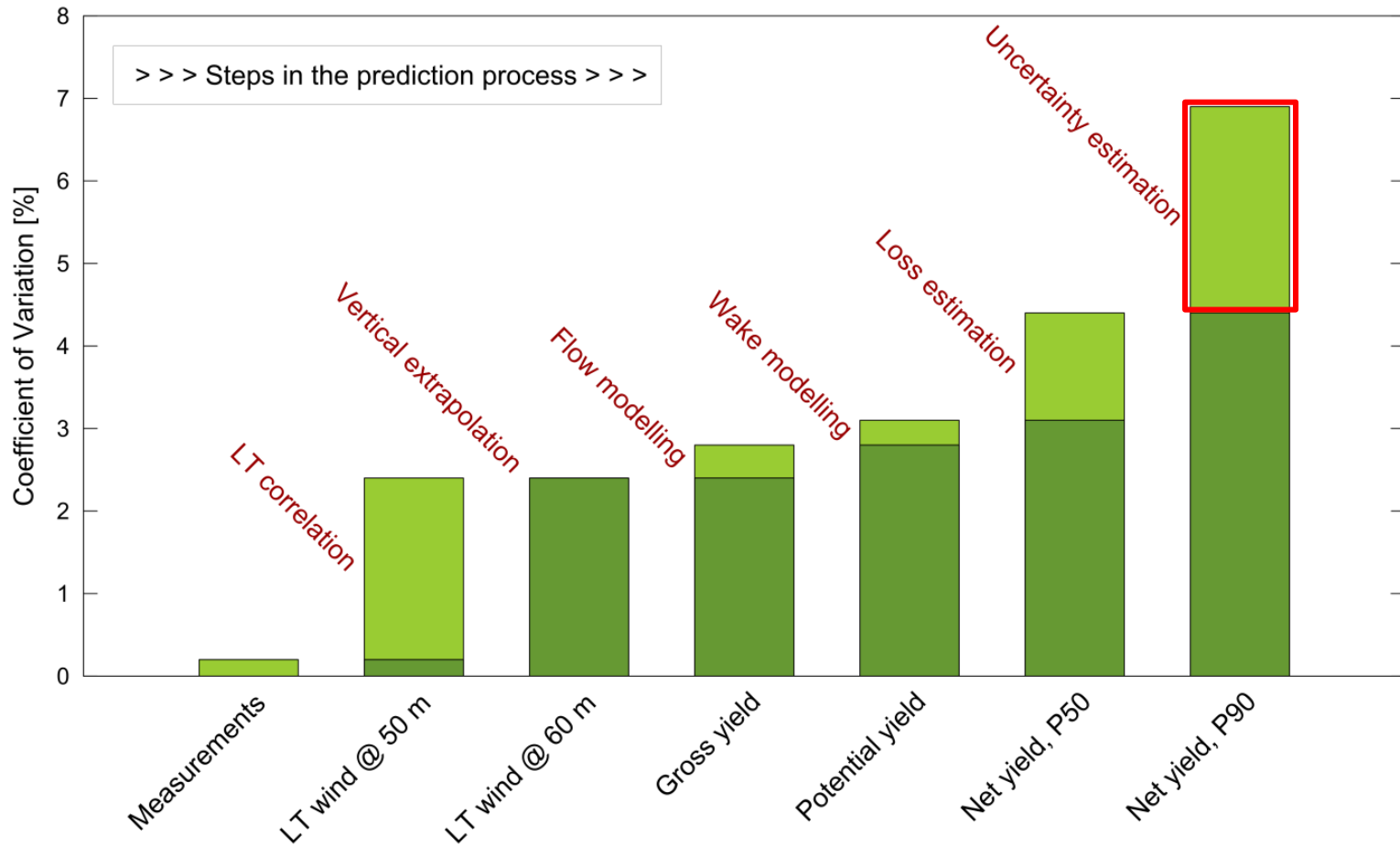
Uncertainty

- However it is not easy to figure out the uncertainty of a project. Most of the parameters are estimated, some of them are calculated.
- There is no standard yet, but there is one coming, probably in 2018 (IEC 61400-15, *Assessment of Wind Resource, Energy Yield and Site Suitability Input Conditions for Wind Power Plants*)
- There are some existing methods but not complete: IEC 61400-1, IEC 61400-12 and IEC 61400-26.
- Lack of a standard leads to subjectivity, the results depend on the expertise and approach of the consultant.



CREYAP I Results

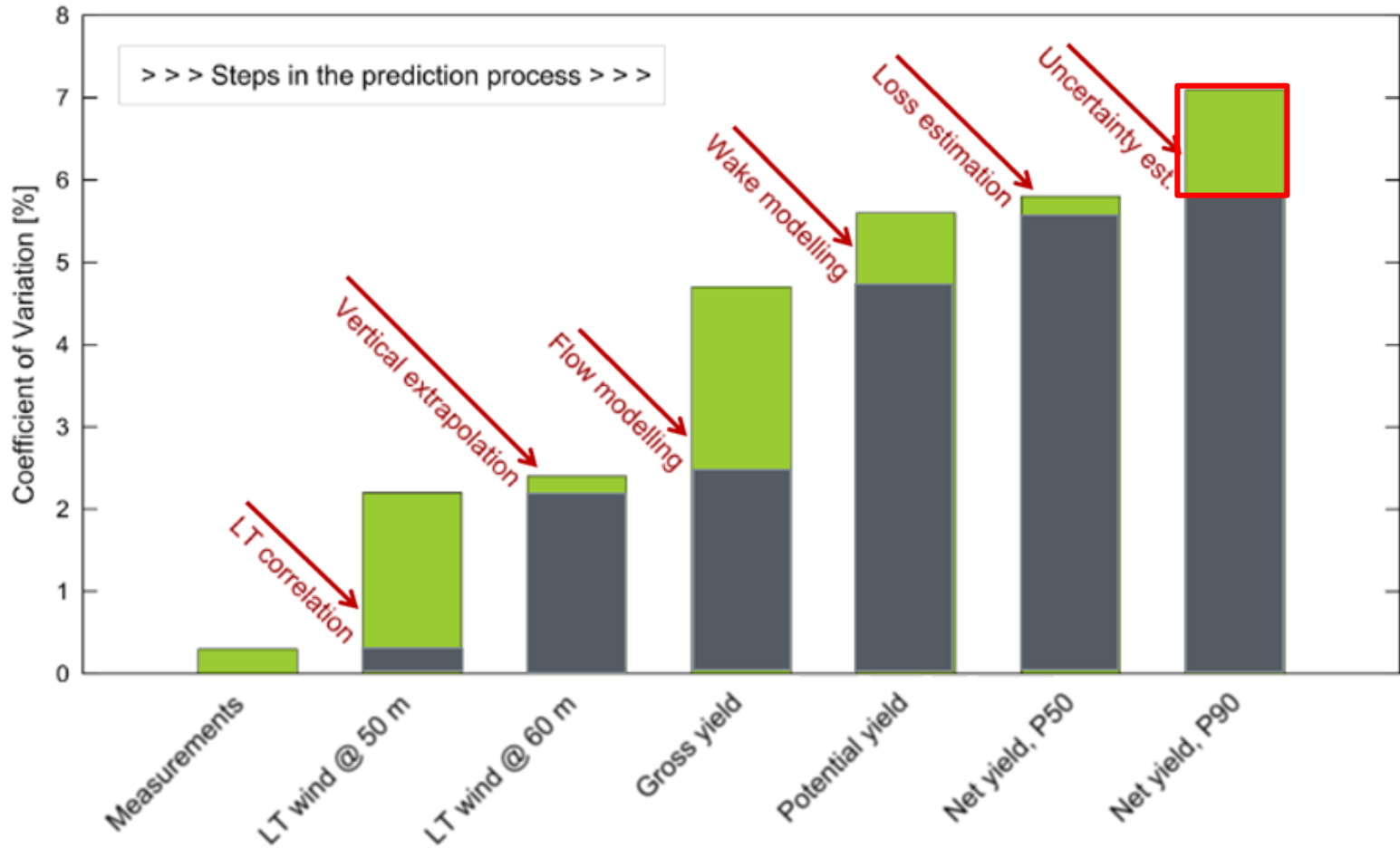
CREYAP I: 37 participants, 28 MW, Scotland



Mortensen, N. G., Ejsing Jørgensen, H., Anderson, M., & Hutton, K-A. (2012), *Comparison of resource and energy yield assessment procedures*, Proceedings of EWEA 2012

CREYAP II Results

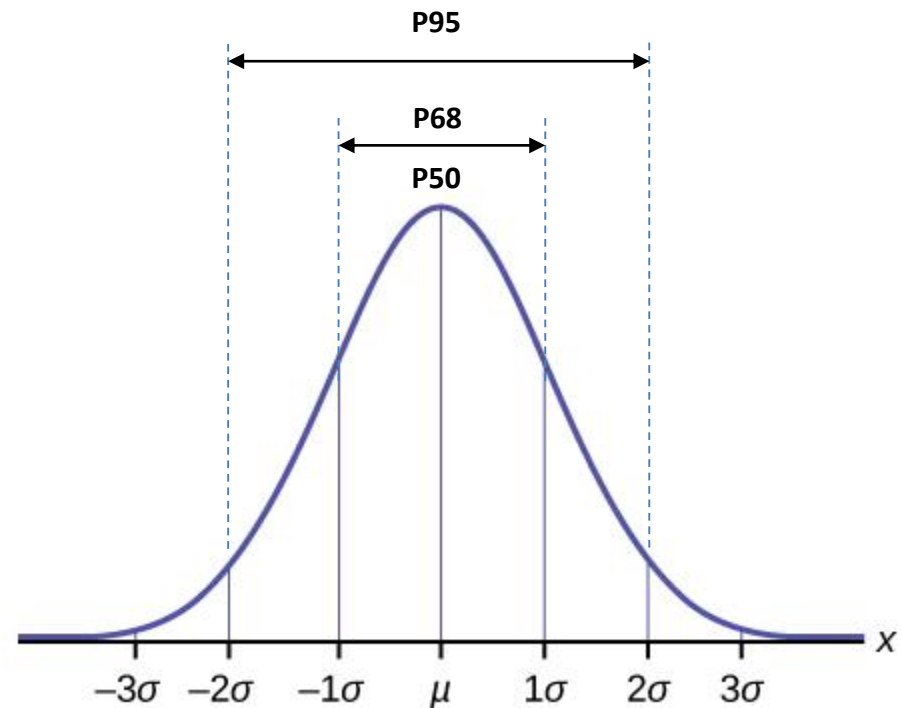
CREYAP II: 56 participants, 28.6 MW, Scotland



Mortensen, N. G., & Ejning Jørgensen, H. (2013). *Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II*. EWEA Technology Workshop: Resource Assessment, Dublin, Ireland, 26/06/13

Definition of Uncertainty

- Uncertainty (σ) can be defined as std. deviation about the mean, doubt in calculated AEP.
- The uncertainty of individual assessment processes must be combined to define a total uncertainty for the project.
- In classical approach it is assumed that uncertainty is normally distributed.
- P50 value is the mean of the distribution.



$$P50 = \mu$$

$$P75 = \mu - 0.67\sigma$$

$$P90 = \mu - 1.28\sigma$$

$$P95 = \mu - 1.96\sigma$$

Definition of Uncertainty

- If the individual uncertainty components are independent, the total uncertainty can be calculated using the relationship below:

$$\sigma^2 = \sum_{i=1}^N c_i^2 \sigma_i^2$$

σ - combined uncertainty

c_i - sensitivity

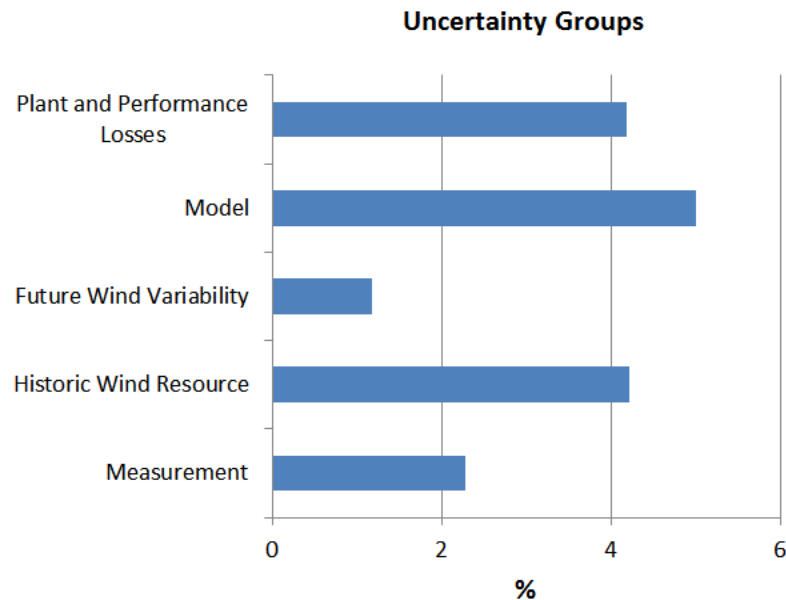
σ_i - individual uncertainty component

N - number of uncertainty components

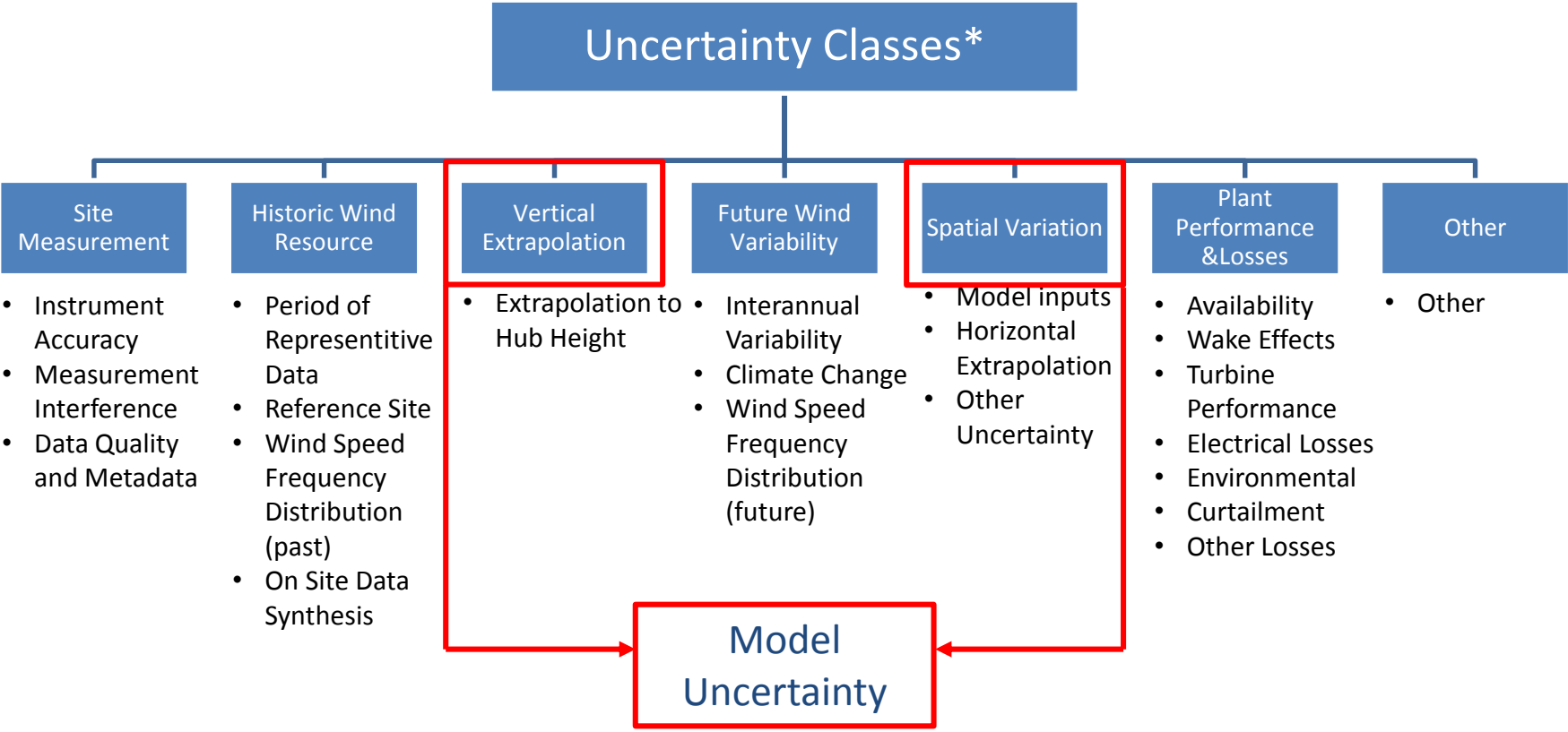
- Total uncertainty is more sensitive to changes in larger values.
- Individual uncertainty components has their specific way of estimation or calculation related to their nature.

Uncertainty Classes

- Generally, uncertainty coming from the numerical model is the highest, this shows that proper and accurate numerical modeling of the site is very important in terms financial risk.



Uncertainty Classes



*Framework for the Categorization of Losses and Uncertainty for Wind Energy Assessments, DNV Kema

Model Uncertainty

Before going to model uncertainty, we have to make sure that we have a high quality model:

- Model covers sufficient area around site boundaries, to take into account terrain effects and prevent wall effects
- High resolution cells in both in vertical and horizontal (10-15 meters) directions
- Detailed and accurate roughness modelling following a site visit
- Convergence is reached in all sectors, especially in main wind sectors
- Wake is calculated in 20 or 30 subsectors

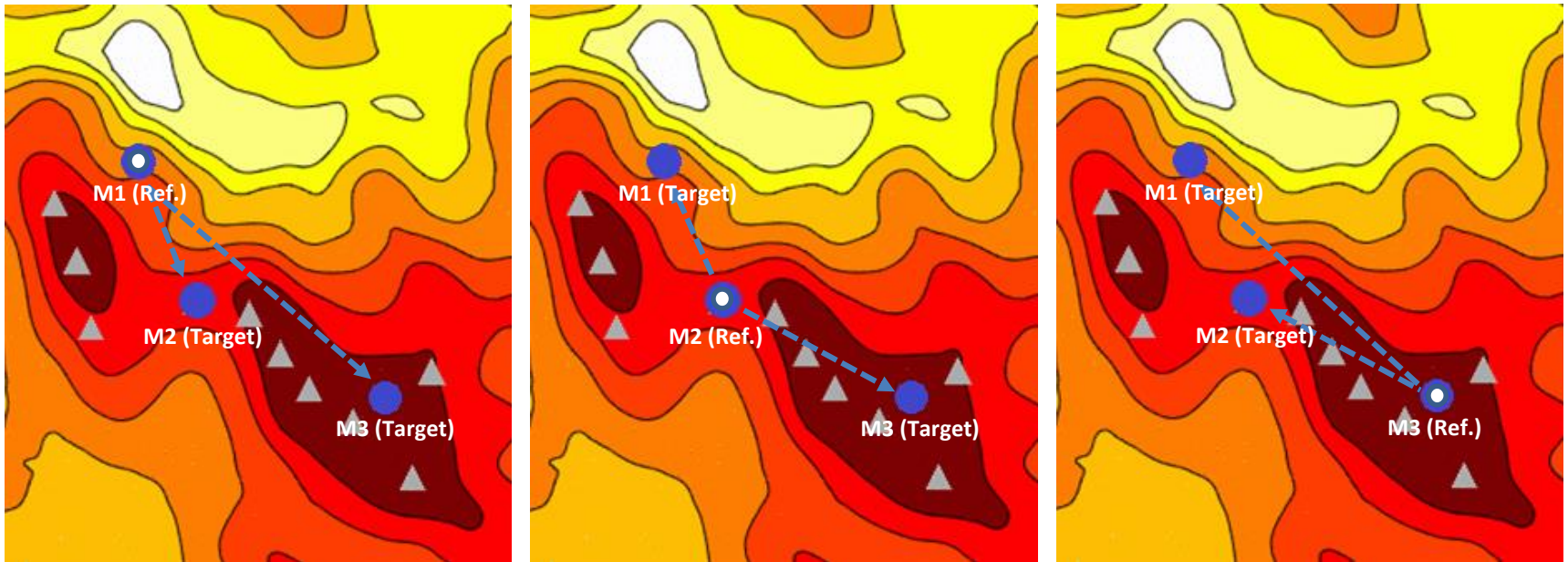
Model Uncertainty

Simple to complex approaches:

- If only one mast exists estimation of the model uncertainty can be done taking into account terrain complexity (WS 7.0 has a new tool), roughness and location of the mast. A single value (4%-8%) for all turbines.
- Alternatively, uncertainty can be calculated per turbine, taking into account horizontal distance to the mast (1%/km) and vertical distance between mast height and hub height (1%/10m).
- If there is more than one mast, the site can be divided into two different regions or alternatively results can be weighted related to the distance to the masts.

Model Uncertainty (Cross Checking)

If more than one mast exist, a cross-checking study can be done between the masts to determine the modeling error.



Cross-checking combinations with three masts

Model Uncertainty (Cross Checking)

- After cross checking is completed you will have a list of errors related to combinations between masts and sensors by sector.
- Errors between sensors in different heights can give clues about vertical extrapolation uncertainty, check roughness if the values are high.
- For reliable results, use data in exact same time frame and without LT correlation.
- Errors related to main wind sector has more impact.

A list of error percentages:

M1 V1 vs M1 V2

M1 V1 vs M1 V3

.

.

M1 V1 vs M2 V1

M1 V1 vs M2 V2

M1 V1 vs M2 V3

.

.

.

Model Uncertainty (Cross Checking)

Ideally:

- There must be statistically enough (>5) masts to calculate the uncertainty
- Masts should be distributed well among the turbines in representative locations.
- Masts should have reliable data in the same time frame.
- If these conditions are met (rarely the case) then model uncertainty can be calculated by the simple relationship below.

$$\sigma_m = \delta_a / N^{0.5}$$

σ_m – model uncertainty

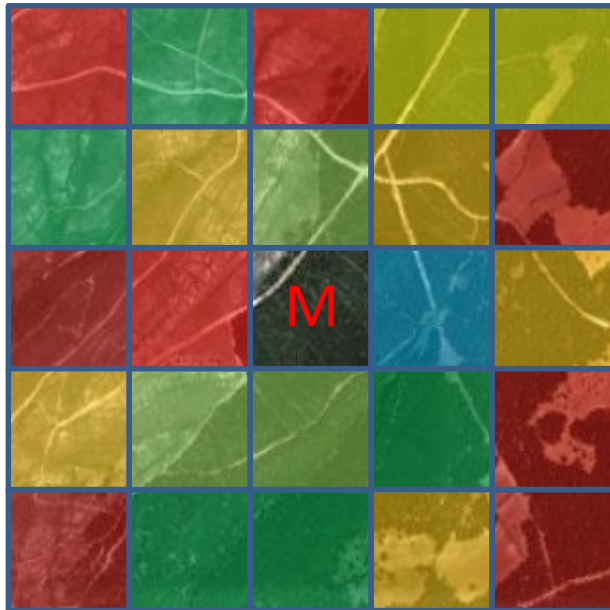
δ_a – SD of all errors

N – number of masts

Uncertainty Mapping

- Another approach can be to create an *Uncertainty Map* based on similarity of the parameters effecting wind resource.
- The similarity should be originated from the point where the mast is located, then every adjacent cell should be compared with each other in terms of defined parameters.
- The parameters can be listed as:
 - Distance to mast
 - Roughness
 - Forest
 - Terrain complexity
 - Altitude
 - Turbulence level
 - Sea or lake effects

Uncertainty Mapping



- For all the parameters, first check the cells adjacent to the one where the mast is located.
- Compare all the parameters to the parameters in the cell containing the mast.
- After the comparison, assign or calculate a level of uncertainty based on the difference.
- Move to the next row and column of cells and repeat the procedure.

Questions to Answer

- Which additional parameters?
- How do they effect uncertainty?
- Which of these parameters have larger impact on uncertainty ?
- How do they interact with each other ?

Contact



Corporate Name : İnovatif Teknoloji Mühendislik Enerji San. Tic. Ltd. Şti
Address : Kayışdağı Cad. No:3 Flora Suite & Office Kat:20/2002 Kozyatağı/İstanbul
Tel : +90 216 5773401
Fax : +90 216 5773024
E-mail : inores@inores.com