Bankable Wind Resource Assessment

WEDAP
Regional Technical Assistance Program
Quantum Leap in Wind
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Agenda

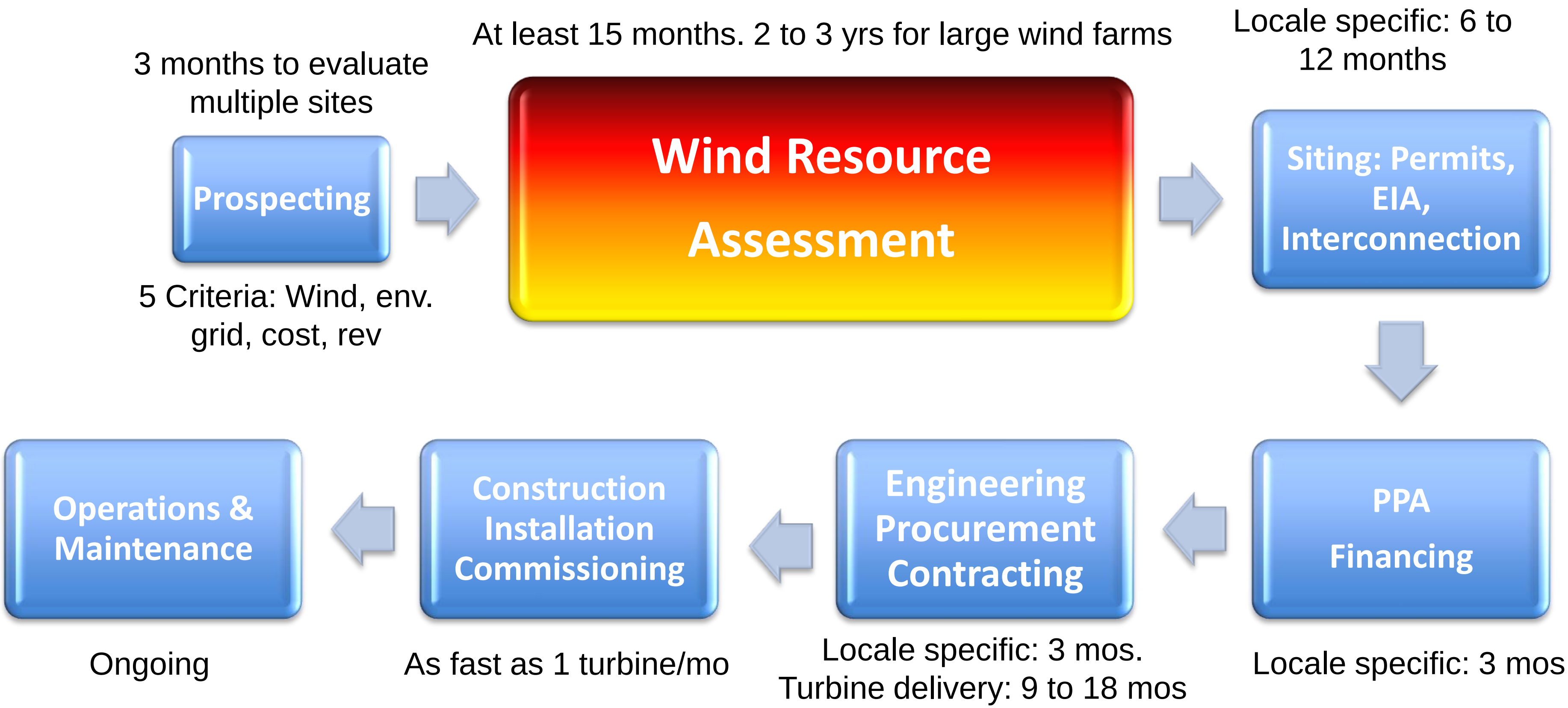
- What is wind resource assessment?
  - Measure wind speed: Do profits measure up?
  - Extrapolation: Do profits extrapolate?
  - Shape factor: Are profits shapely?
  - Shear: Will profits get sheared?
  - Turbulence: Are profits turbulent?
  - Roughness & terrain: Are profits in rough terrain?
- Losses: How much loss of profit?
- Uncertainty: How uncertain are profits?
- Example of Bankable WRA
- Common reasons for rejecting B-WRA
- Checklist
- Conclusions

Objectives

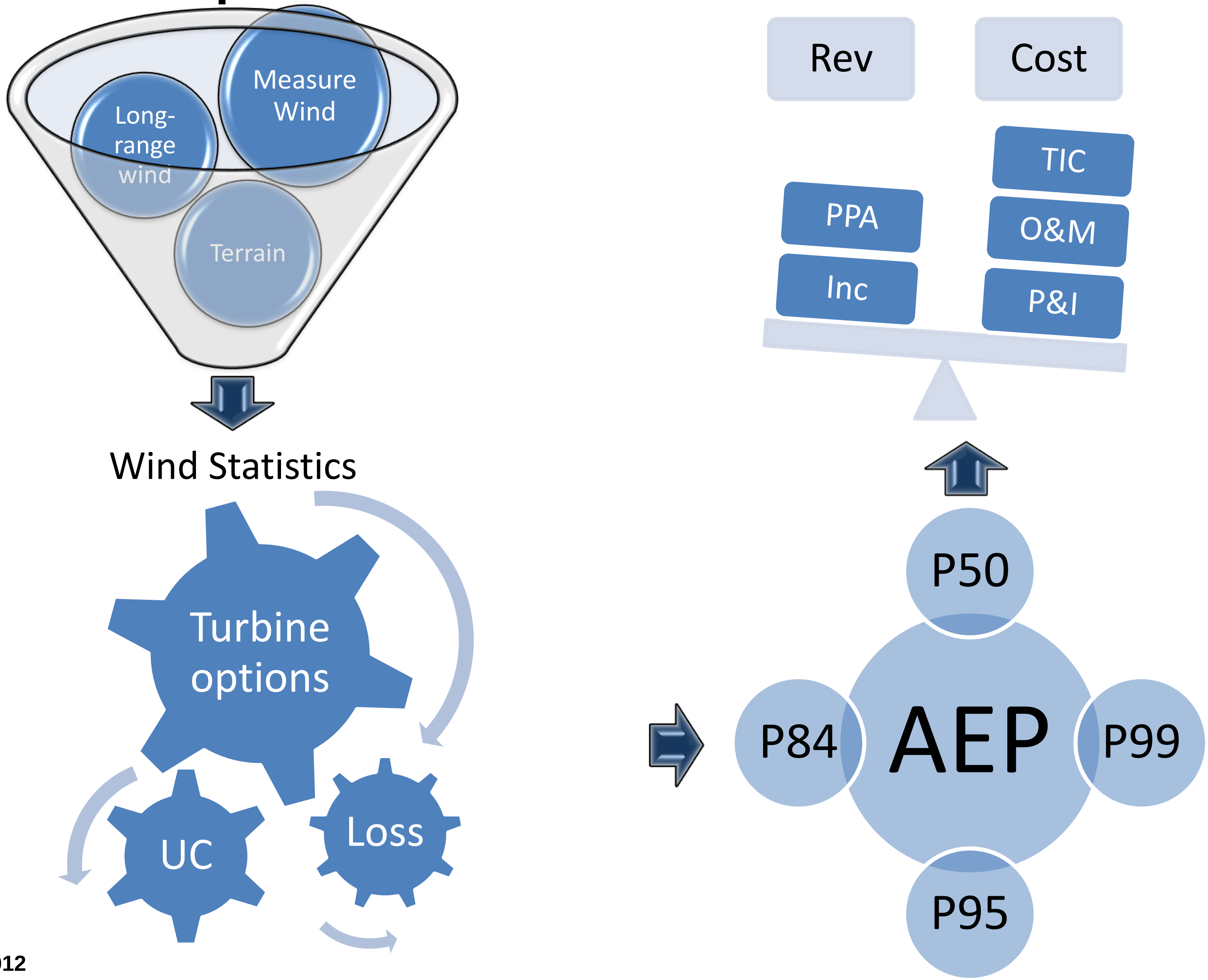
- Learning Objectives
  - Understand the role of wind resource assessment (WRA)
  - Understand the three levels of WRA
  - Understand factors that are influence wind energy production
  - Understand losses in energy production
  - Understand the uncertainty associated with WRA

"An accurate wind resource assessment is absolutely crucial to the success of the proposed project. Unless the promoter can present a high-quality wind resource assessment which satisfies lending institutions, the probability of securing debt financing is low."

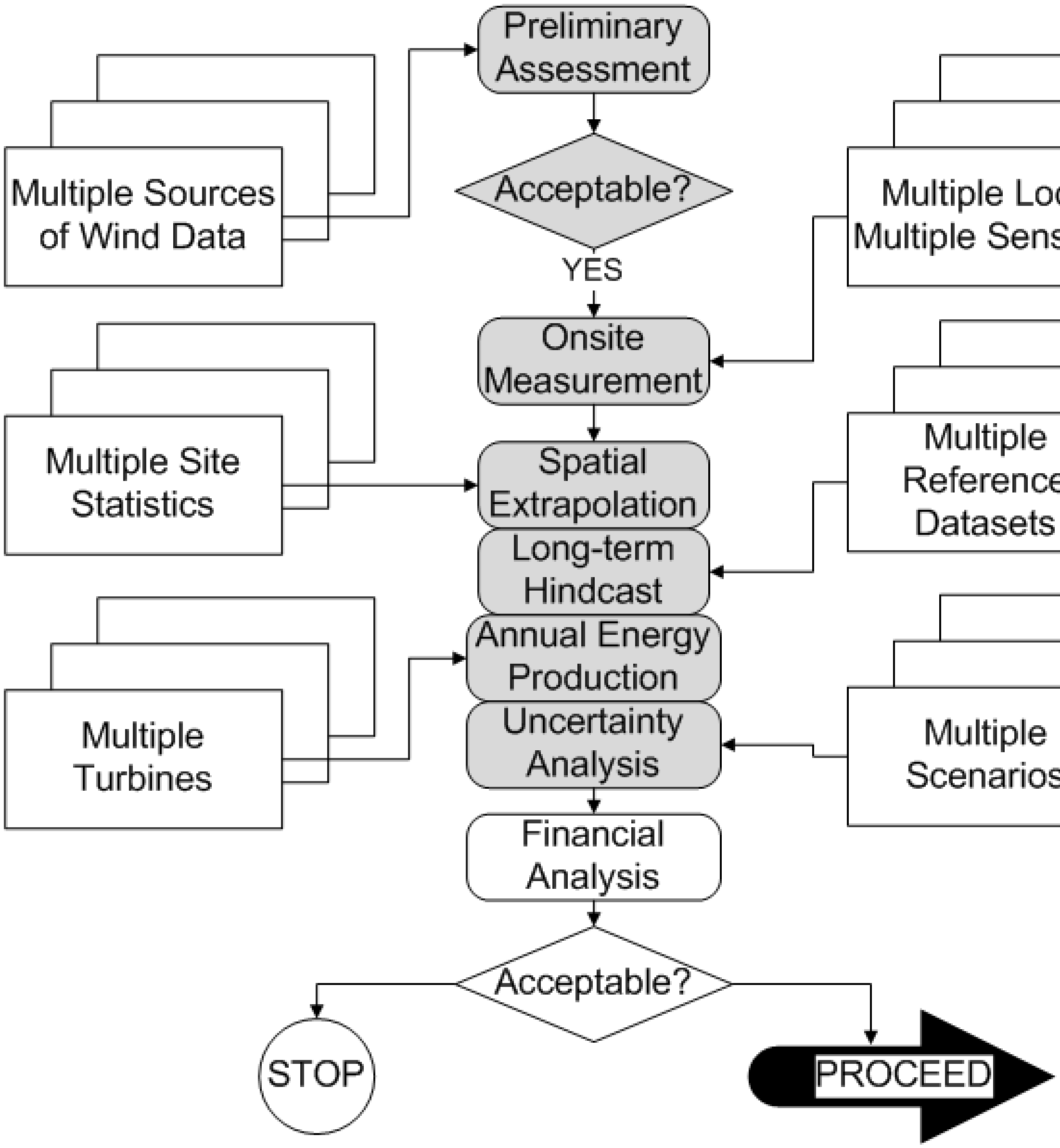
Role of WRA in Wind Project



Components of Level 3 WRA



Process of WRA



Source: P. Jain, Wind Energy Engineering, 2010

What is Wind Resource Assessment?

Wind Resource Assessment (WRA) is quantification of wind resources

Level 1

- Preliminary
- Publicly available wind data: Airport, NCAR, Weather stations, Wind resource maps
- Tools: RetScreen
- Energy estimate: +/- 50%

Level 2

- Preliminary
- Modeling of elevation contours & terrain
- 3-Tier, AWS Truepower
- Energy Estimate: +/- 30%

Level 3

- Based on onsite measurement
- Bankable under certain conditions
- WindPRO, WAsP, Wind Farmer
- Energy Estimate: +/- 10% to 15%

Why am I quantifying?

Why is WRA Accuracy Important?

Wind Speed Estimate δ	Energy estimate δ	Annual Income	IRR	NPV
14.0%	30.0%	$ 13.00	11.54%	$ 25.59
9.5%	20.0%	$ 12.00	10.32%	$ 16.50
4.9%	10.0%	$ 11.00	9.06%	$ 7.41
0.0%	0.0%	$ 10.00	7.75%	$ (1.68)
-5.1%	-10.0%	$ 9.00	6.39%	$ (10.77)
-10.6%	-20.0%	$ 8.00	4.96%	$ (19.87)
-16.3%	-30.0%	$ 7.00	3.44%	$ (28.96)

14% higher wind speed, which is 30% higher energy =>49% higher IRR
16% lower wind speed, which is 30% lower energy =>56% lower IRR

In above example: TIC=$100; Base case annual income=$10; Discount rate=8%

Level 1 WRA

- Wind resource is assessed from publicly available wind data or wind resource maps (from NREL)
- Source 1: Publicly available wind data
  - Airports
  - Weather stations
  - Meteorological tower
  - Reanalysis data (NCAR or ECMWF)
- Tools:
  - RetScreen: www.retscreen.net
  - Spreadsheet-based tools

Issues

- Quality of wind data is poor for wind projects
- Quality of instruments is unknown
- Often only partial data is available
- Shear is not available
- Turbulence is not available
- Not site specific data
- Statistical distribution of wind speed is not available

Output

- Average annual wind speed @ 80m= 6.91 m/s
- Average annual wind direction = 94.5 deg
- Average energy density @ 80m=available if distribution is assumed
- Average annual energy production= Approximate, e.g. 4.34GWh
  - With a 1.5MW GE XLE
  - Hub height=80m
  - Rotor dia=82.5m

Level 1 WRA, Contd.

Source 2: Online wind resource mapping applications or non-interactive color maps of wind resources

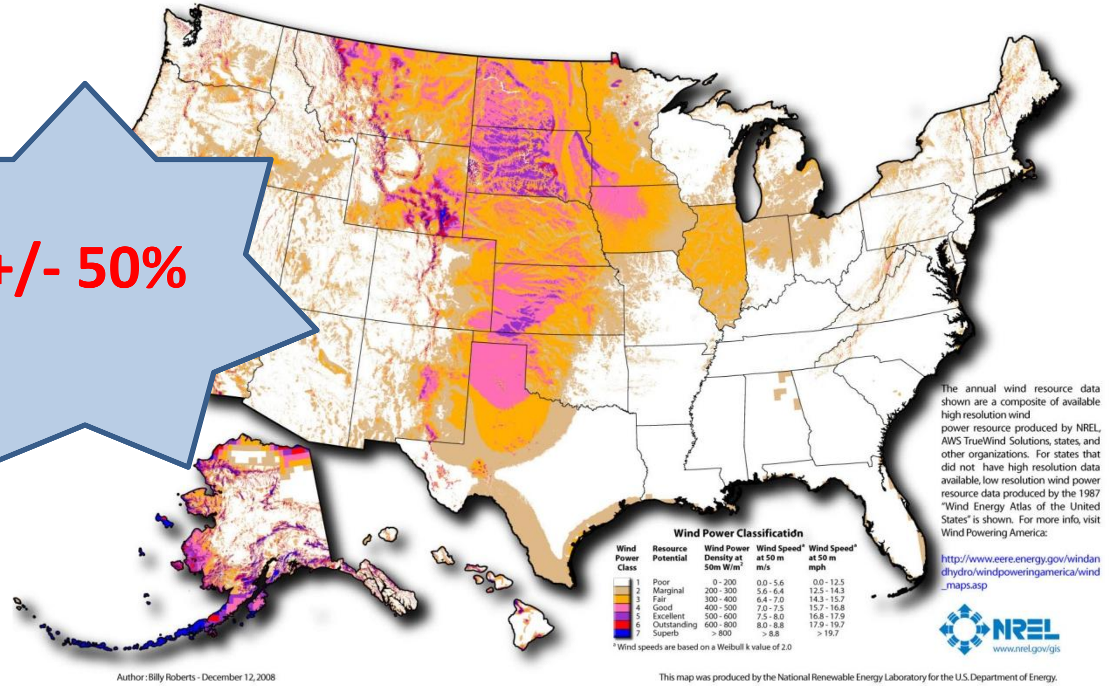
- www.3Tier.com/firstLook
- www.WindNavigator.com
- http://www.windatlas.dk.
- NREL
- SWERA

Issues:

- Quality of wind data & instrument is poor
- Not available: Shear, Turbulence, Statistical distribution
- Not site specific data

- Issues:
  - Geographical resolution is coarse:, e.g.5Km x 5Km grid
  - Computations are based on numerical models; data used by numerical models is suspect

- Output:



+/- 50%

Source of graphics: 3Tier & NREL

Level 2 WRA

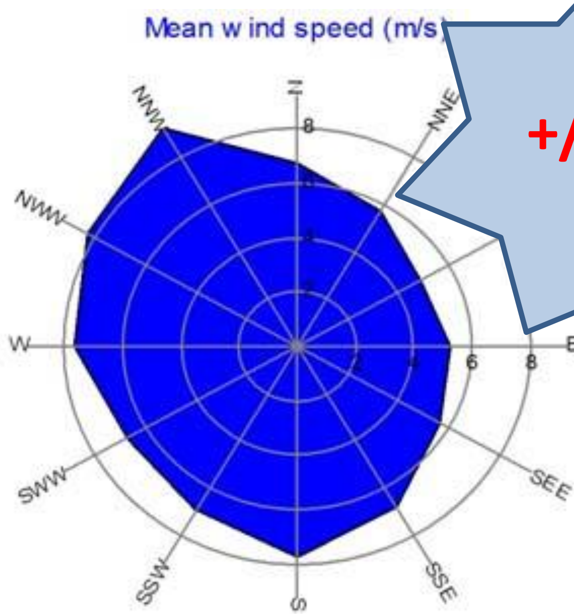
- Wind resource is assessed by creating a GIS model of site with elevation and terrain data, and downscaling of wind data
- Source of wind data is from publicly available sources
  - Airports
  - Weather stations
  - Meteorological tower
  - Reanalysis data (NCAR or ECMWF)
- Tools:
  - 3-Tier
  - AWS Truepower
  - Wind Logics

Issues

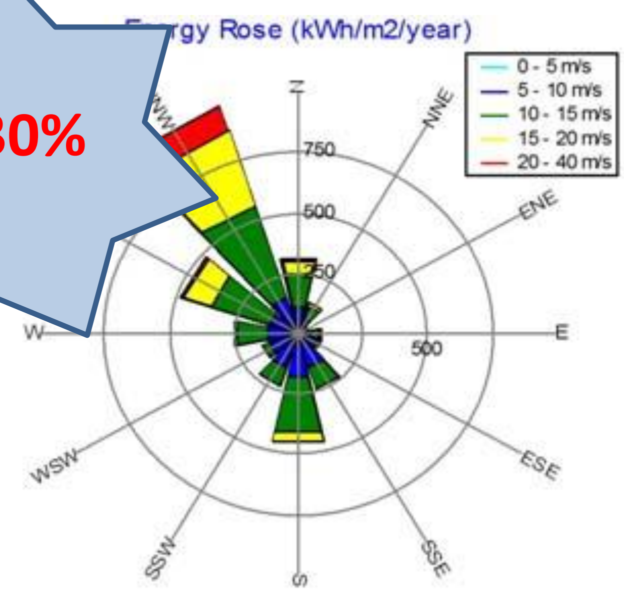
- Quality of wind data is poor
- Extrapolations are not valid:
  - Spatial
  - Height
  - Temporal

Output

- Average annual wind speed, direction, energy density
- Average AEP= 4.34GWh
  - With a 1.5MW GE XLE, hub=80m, rotor dia.=82.5m



+/- 30%



Graphics created in WindPRO

Level 3 WRA

- Wind resource assessment is based on onsite wind measurement and GIS model of site with elevation and terrain data
- Source of wind data is from
  - At least one year of onsite met-tower data at 3 heights
  - Long-term reference data
- Tools:
  - WindPRO
  - WAsP
  - WindFarmer

Output

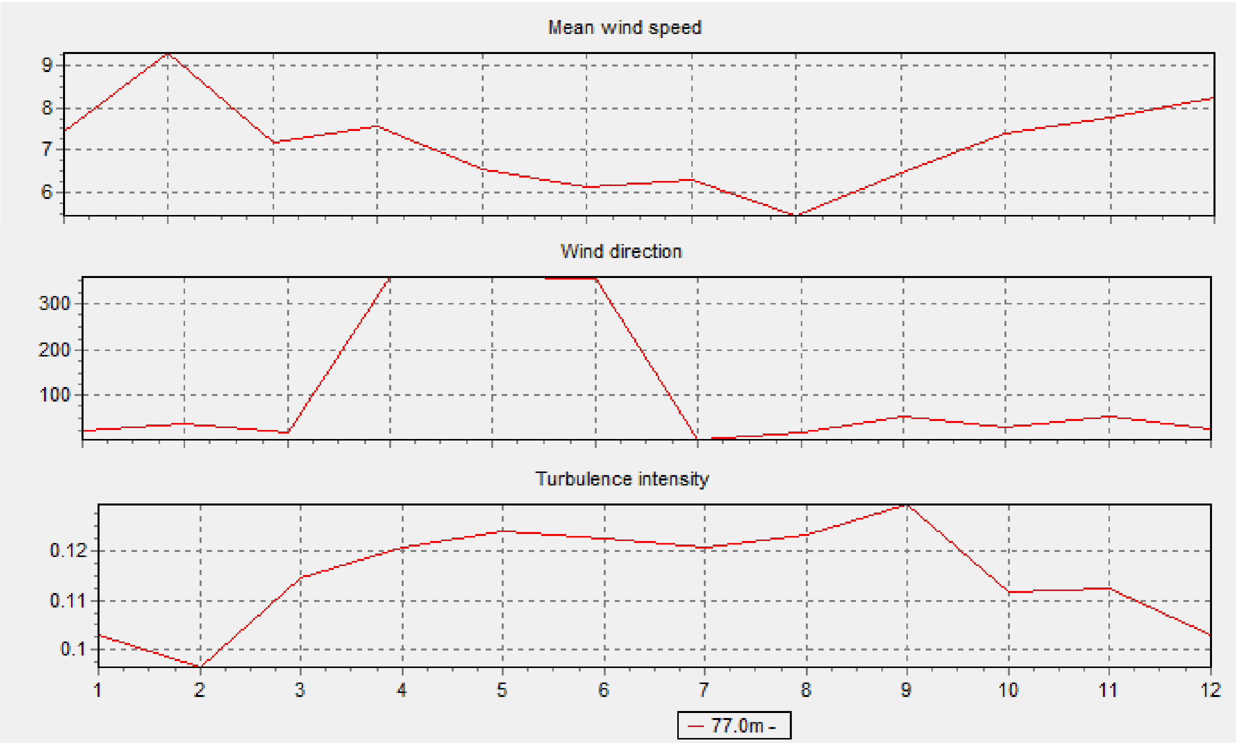
- Average annual wind speed, direction, energy density
- Wind shear based on measured wind speed at multiple heights
- Diurnal and monthly variation
- Turbulence
- Spatial extrapolation
- Temporal extrapolation

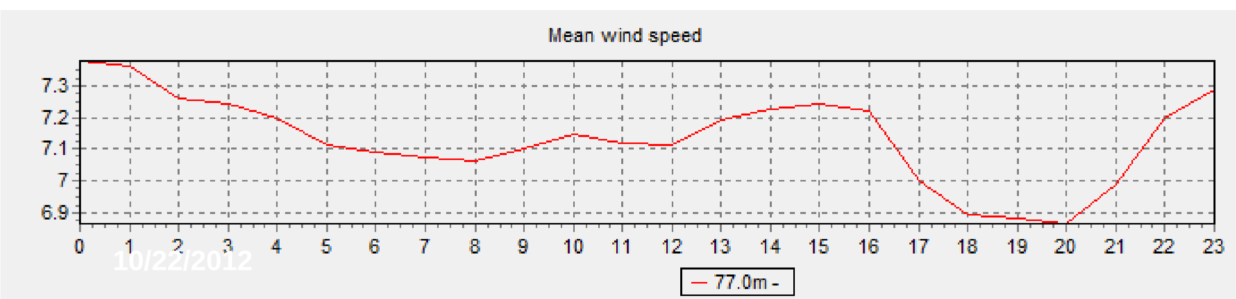
Output

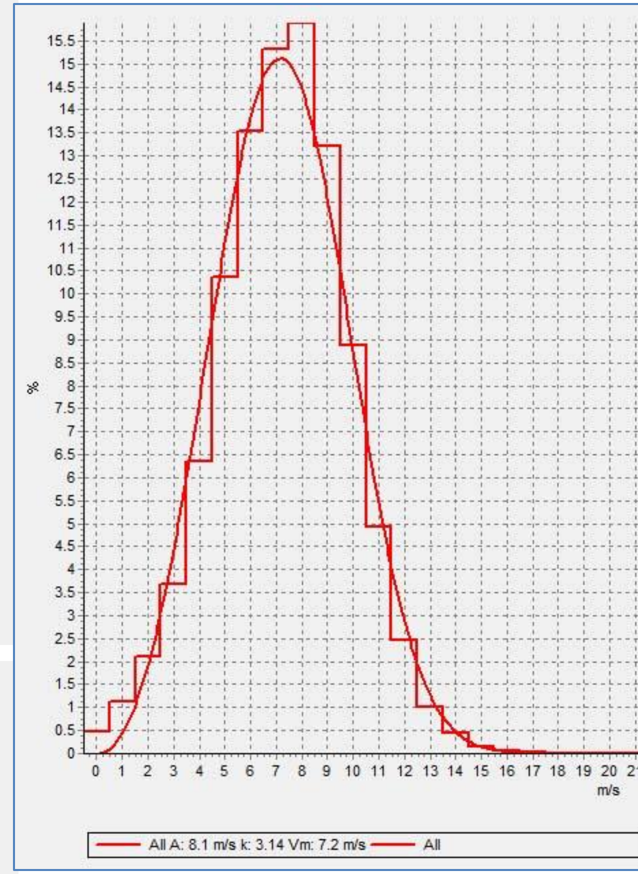
- Average AEP= 4.34GWh
  - With a 1.5MW GE XLE, hub=80m, rotor dia.=82.5m
- Capacity factor
- Wind farm layout*
- Wake losses*

+/- 15%

Level 3 WRA: Diurnal & Monthly profile, Weibull



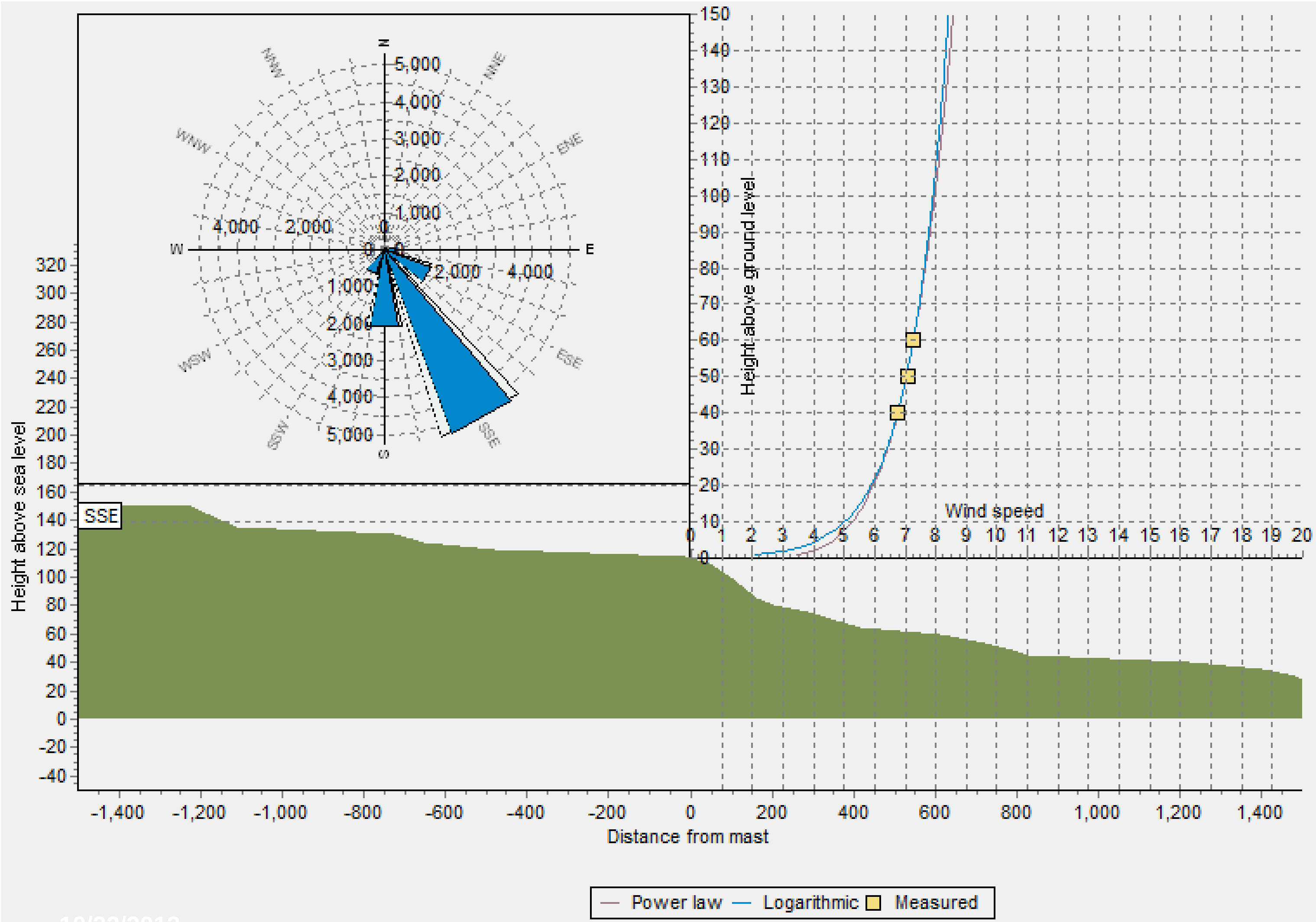




- **Daily and monthly profile of WS, WD and TI**
- **Statistical distribution of wind speed**

Graphics created in WindPRO

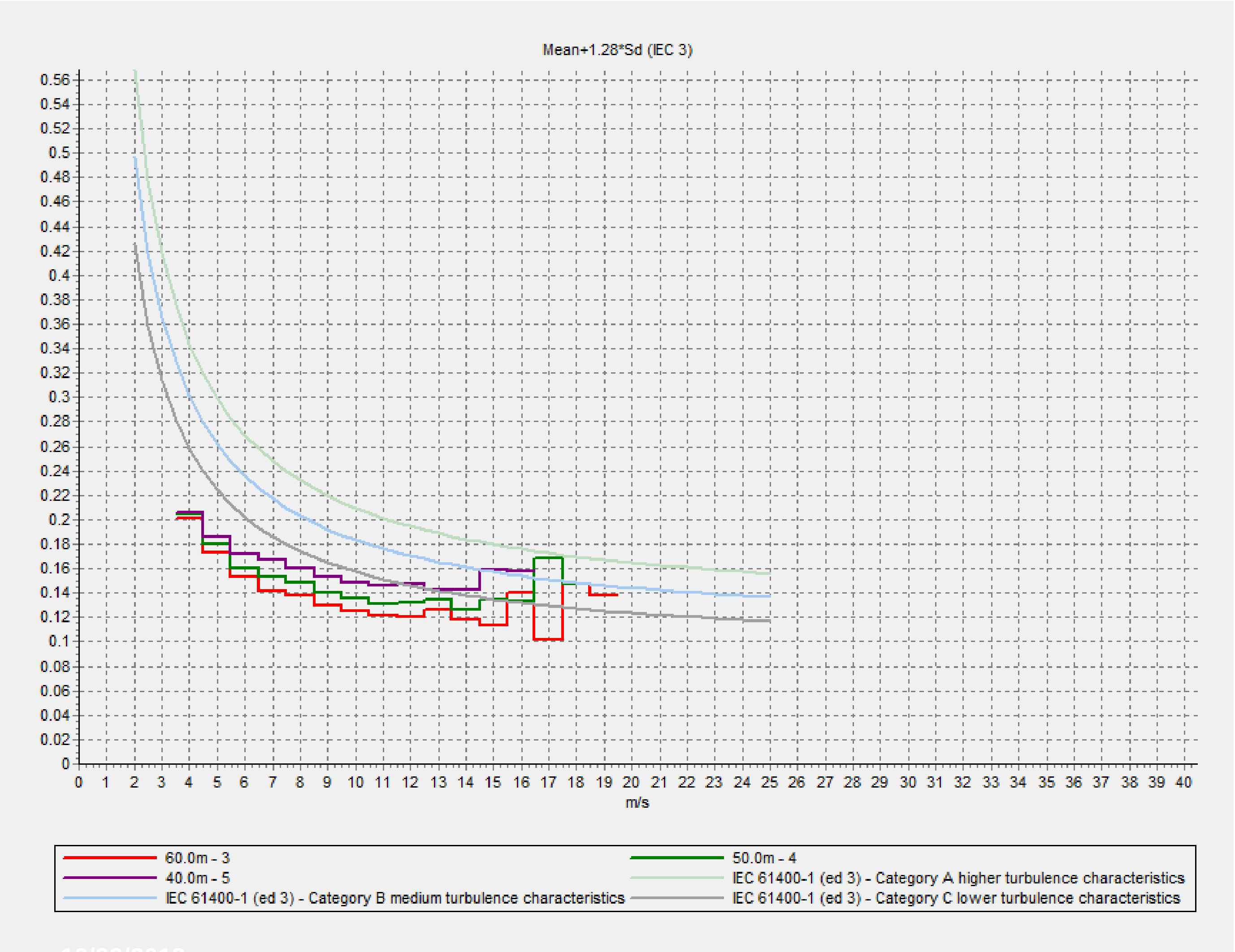
Level 3 WRA: Shear Profile



- Principal energy is from SSE direction.
- Wind speed profile indicates shear
- Elevation indicates contour along SSE direction

Graphics created in WindPRO

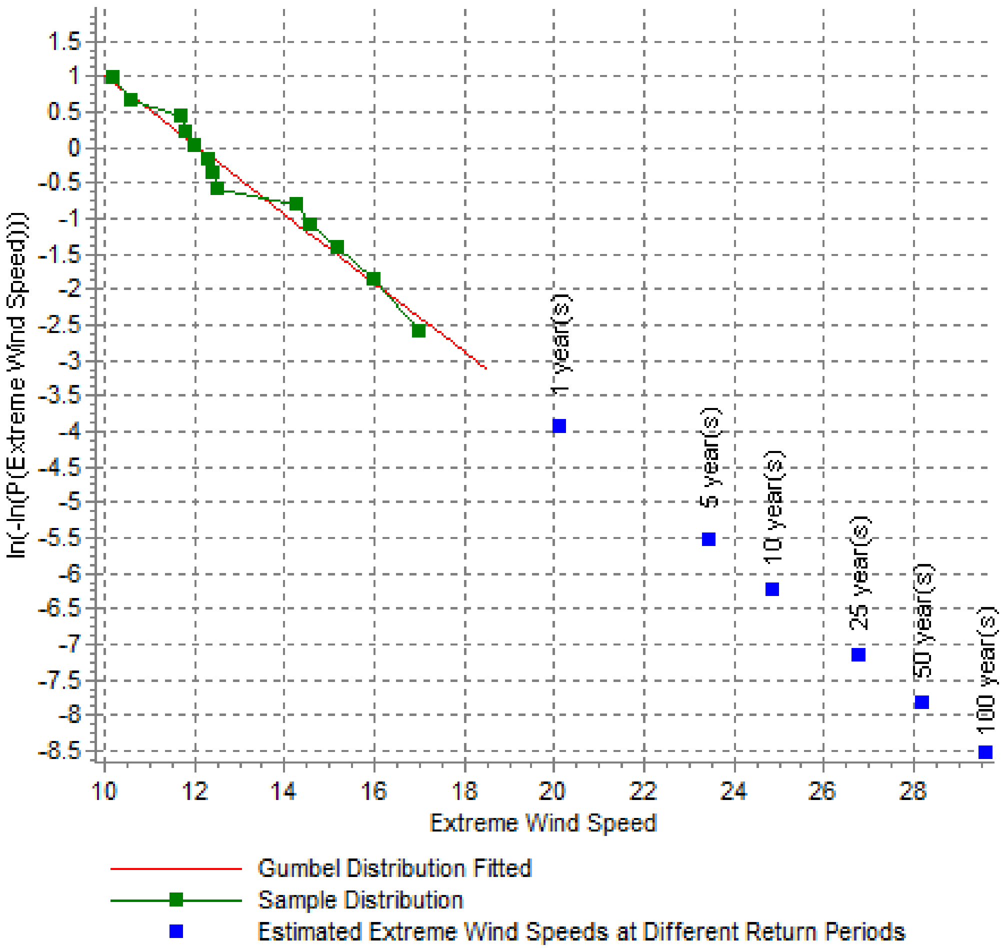
Level 3 WRA: Turbulence



- Turbulence Intensity Vs Wind Speed.
- Plot of IEC Turbine category: TI Vs WS

Graphics created in WindPRO

3 WRA: Extreme Wind Speed



- 50 year extreme wind speed based on 10min wind speed data is 28 m/s
- IEC Turbine category is determined based on extreme wind speed

Graphics created in WindPRO

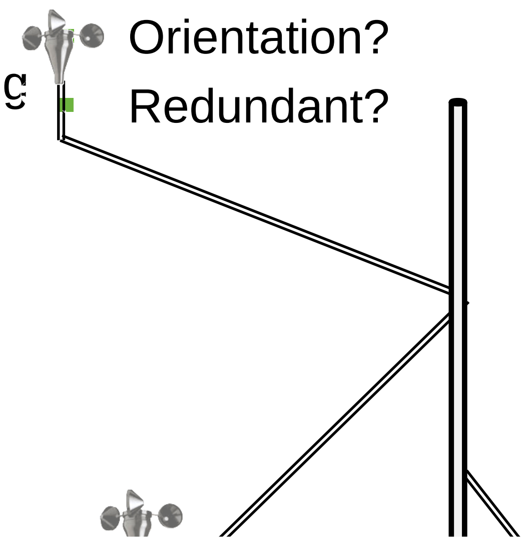
Questions?

Measure wind speed: Do my profits measure up?

- Wind speed is one of the key determinants to a viable project
- It is expensive
- It takes at least one year, in most cases longer
- High degree of care must be exercised in planning and executing wind measurement
- Gold standard: Hub height measurement

Location, Configuration

- Where? Best wind spot, worst wind spot or median
- How tall? As close to hub height as possible
- Boom length? 9 times diameter
- Orientation?
- Redundant?



Instruments

- Individually calibrated
- 1 to 2% error in measurement
- Good record keeping

Data Processing

- Keep the raw data as – is with timestamp
- Document the rules of processing data
- Detecting faulty readings; removing bad data
- **Auditable process**

Is data trustworthy?

Extrapolation: Will my profits be extrapolated?

Three extrapolations

- Temporal: One to 3 year measurement. What is projected wind speed for 20 yrs—life of wind project?
- Spatial: During wind farm one met-tower per 6 to 10 turbines. What is wind speed at proposed turbine locations?
- Vertical: Typical heights are 60, 40 and 30m. What is wind speed at hub height—85m to 100m?

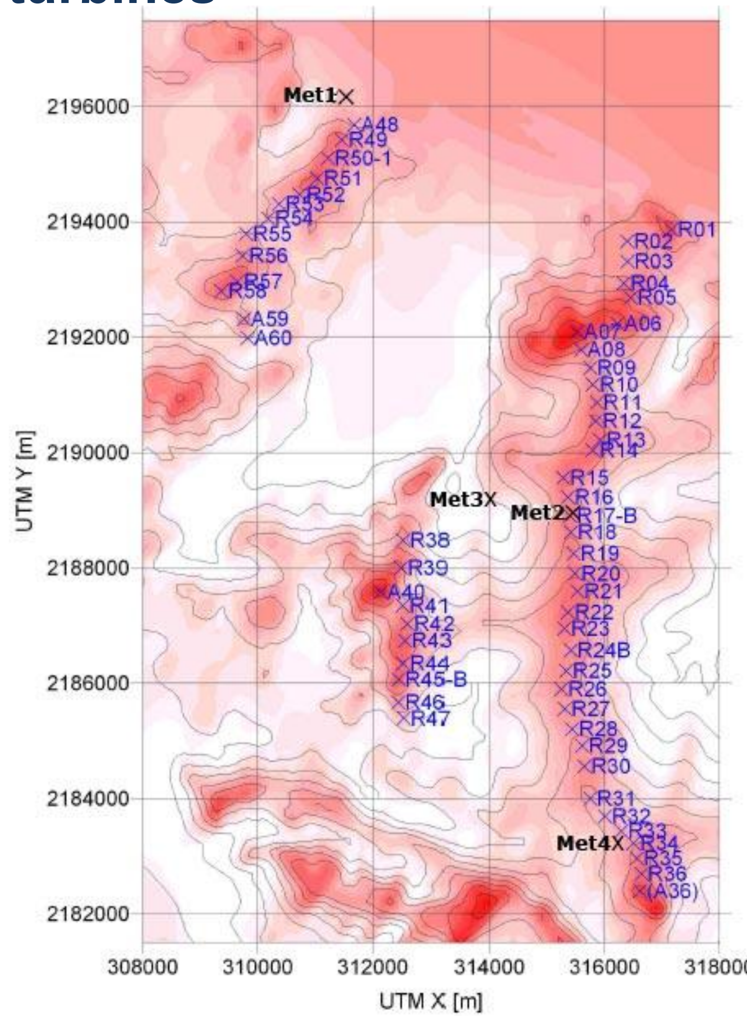
Temporal Extrapolation

- Comparison of measurement and long range reference, Chart of year-to-year variation
- Measure-Correlate-Predict (MCP) method is used.
- If correlation is good, then prediction is done
- Process is also called Hind-casting vs Forecasting

Spatial Extrapolation

- For resource assessment of wind farm one met-tower per 6 to 10 turbines are used.
- Rough terrain requires more met-towers
- What is wind speed at proposed turbine locations?
- Spatial extrapolation is done by deriving Regional Wind Climate (RWC)
- RWC strips out the affect of terrain, roughness and obstacles from measured data
- RWC is then localized by reapplying site specific terrain, roughness and obstacles

Layout of met-towers and turbines



Example: Vertical Extrapolation

Case 1: Wind measurement for one year yields

- Annual average wind speed at 30m = 6.9 m/s
- Average temperature 30C
- High winds during day time

Case 2: Wind measurement for one year yields

- Annual average wind speed at 30m = 6.5 m/s
- Average temperature 18C
- High winds during night time

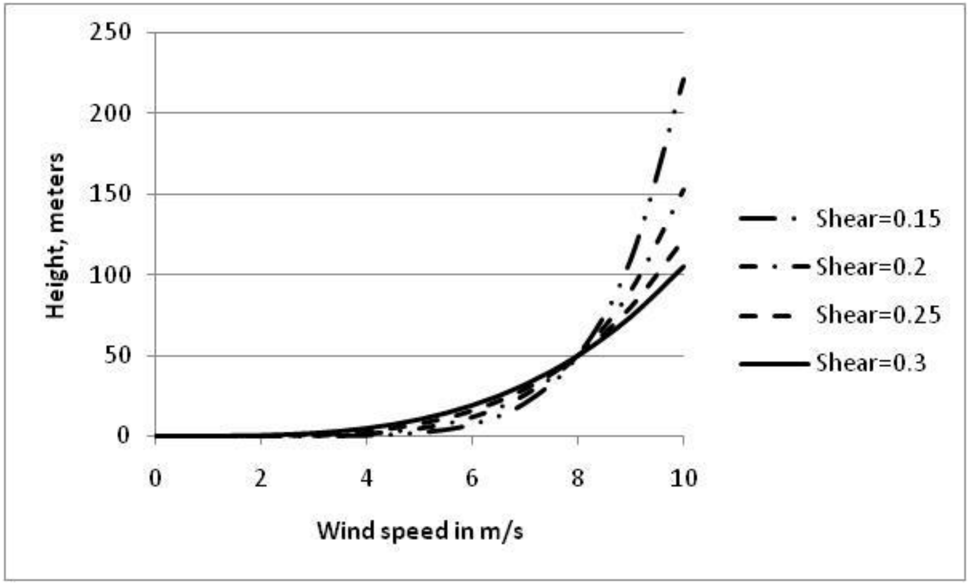
If hub height is 85m, which location is preferable?

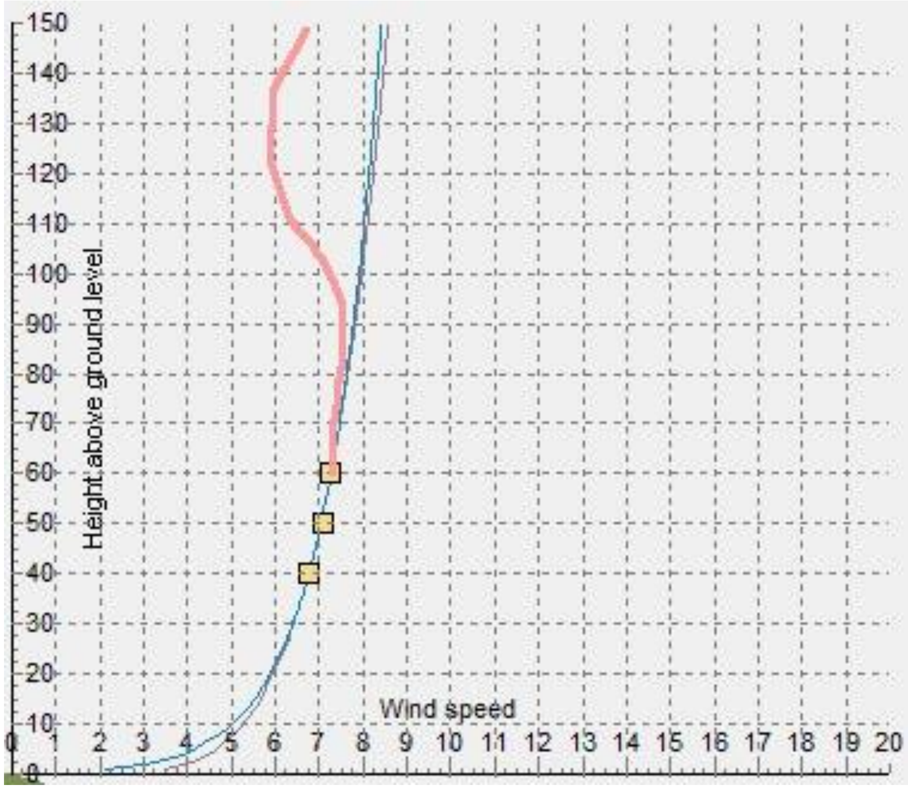
- Using standard shear factor of 0.15, speed at hub height is:
  - 8 m/s in case 1
  - 7.6 m/s in case 2
- Shear in case 1 is low due to thermal mixing/convection
- Shear in case 2 is high
- Results in item 1 are incorrect
- With shear of 0.125 in case 1 and 0.25 in case 2, speeds are 7.86 and 8.44 m/s

Shear: Will my profits get sheared?

Wind Shear defines vertical extrapolation

- Measured height to hub height
- Energy is derived from entire swept area. E.g. 135m to 35m AGL.
- Large diurnal variation in shear
- Large seasonal variation in shear
- Models for computing shear are approximate





Shear model predicts monotonic curve, but profile may be complex, as indicated by the red line

Source: P. Jain, Wind Energy Engineering, 2010. Graphics created in WindPRO

Example: Wind Class/Energy Density

Wind measurement for one year yields:

- Annual average wind speed at 50m = 7.9m/s
- What is the wind class in this area?
- What is the power density?
- NREL Wind class table

		50 m	
Wind Class	**Wind Class Name**	**Power density, W/m²**	**Average wind speed, m/s**
1	Poor	0 – 200	0 – 5.6
2	Marginal	200 – 300	5.6 – 6.4
3	Fair	300 – 400	6.4 – 7.0
4	Good	400 – 500	7.0 – 7.5
5	Excellent	500 – 600	7.5 – 8.0
6	Outstanding	600 – 800	8.0 – 8.8
7	Superb	800–2,000	8.8 – 11.9

- Wind Class: Class 5 wind regime
- Power density: ~ 580 W/m^2
- Above numbers are incorrect, it assumes a Rayleigh distribution of wind speed
- Correct class = 4
- Correct power density = 424 W/m^2
- Power density is 27% lower, and therefore energy production will be 27% lower

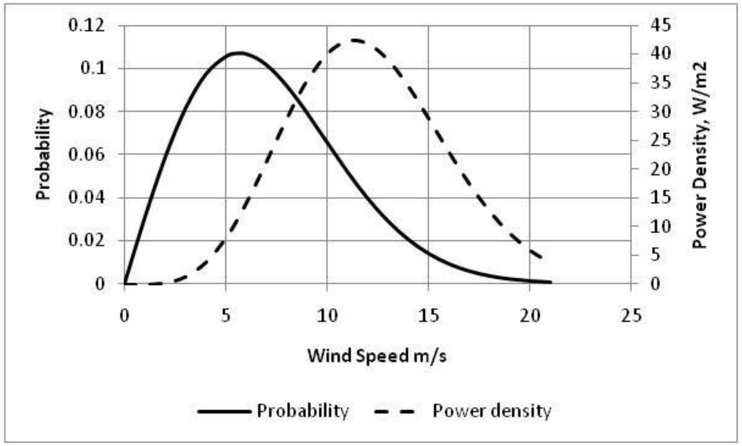
Source: P. Jain, Wind Energy Engineering, 2010

Shape factor: Are my profits shapely?

Statistical Distribution of Wind Speed

- Cubic relationship to energy makes the shape of wind speed distribution important
- If no statistics is available k=2 is assumed
- K=3, yields 10% less energy
- K=1 yields 10% more energy
- Norm is to compute Weibull distribution parameters in all 12 sectors

Average Wind speed, m/s	Incorrect Power Density, W/m²	Correct Power density, W/m²
3	17	32
4	39	75
5	77	146
5.6	108	206
6	132	253
6.5	168	321
7	210	401
7.5	258	494
8	314	599
8.5	376	719
9	447	853
10	613	1170
11	815	1557



Caribbean example

- Inland versus near the shore projects
- k=2 versus k=3; skewed distribution versus Gaussian distribution
- Energy production will be significantly lower
- Note: Highest energy production occurs at much higher wind speed compared to median or average

Source: P. Jain, Wind Energy Engineering, 2010

Turbulence: Are my profits turbulent?

Turbulence is a measure of variation in wind speed

- TI is defined as ratio of standard deviation of wind speed (10-min) and the average wind speed (10-min)
- According to IEC turbine classification scheme, higher turbulence requires different class of machine
- Higher TI leads to larger forces and fatigue loads
- Wake causes turbulence to significantly increase

RESULT

- Lower tower heights
- Smaller rotor diameters
- Lower energy production
- In wind farm with multiple rows of turbines, losses may be higher due to Wind Sector Management

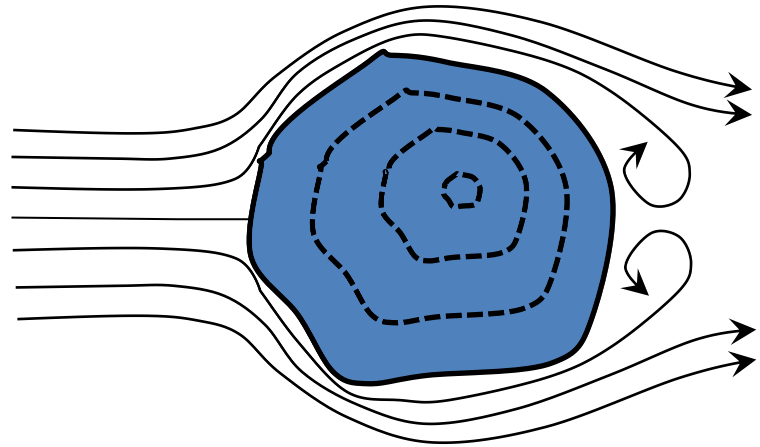
IEC turbine class, I_{ref} is TI at 15 m/s

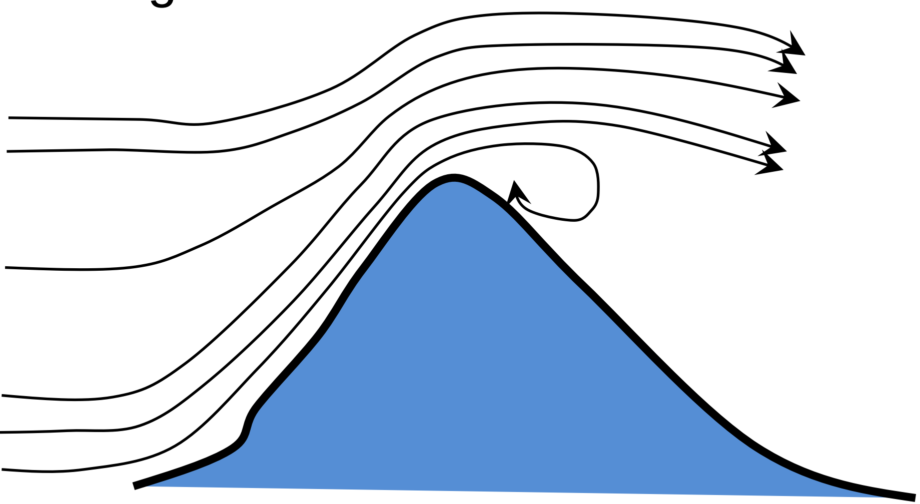
WTG Class		I	II	III
	V_{ref} (m/s)	50	42.5	37.5
A	I_{ref}		0.16	
B	I_{ref}		0.14	
C	I_{ref}		0.12	

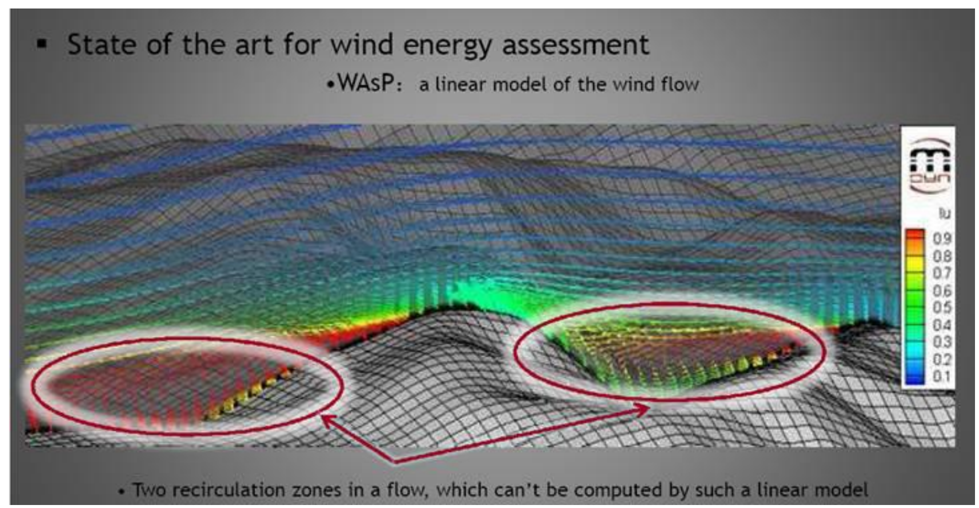
Source: P. Jain, Wind Energy Engineering, 2010

Roughness & terrain: Are my profits in rough terrain?

- Terrain can have a large impact on wind speed and direction
- Roughness is used to predict shear. Models are “rules of thumb” for classifying different surface friction due to vegetation and habitation







- **Most models used for WRA are linear, not accurate for rough terrain**
- **CFD based models may improve WRA**

Source of grid graphic: Meteodyn WT Workshop, G. DuPont, 2010

Losses: How much profits will I lose?

Loss category	Loss estimate	Comments
Wake losses	5 – 15%	WindPRO and WindFarmer have tools to compute wake losses
Plant availability	2 – 5%	Turbine related, BPO related, Grid unavailability
Electrical losses	2 – 4%	Transformer losses, Transmission losses, Internal power consumption
Turbine performance	1.5 – 5%	Power curve loss, High wind hysteresis, Wind modeling
Environmental	1 –3%	Outside operating range, Icing, Wildlife, Lightning, Roughness change
Curtailment	1 – 3%	Grid , Wind sector
Others		Earthquake: Seismic database may be used estimate frequency

Source: P. Jain, Wind Energy Engineering, 2010

Uncertainty: How uncertain are my profits?

- Uncertainty is a key component of Bankable WRA
- In wind projects uncertainty is expressed in terms of:
  - P50
  - P90
  - P95
- Key: Valuation depends on P90, P95

PN formula	PN Revenue estimate	Meaning of PN
P50 = μ	$2000	Revenue of at least $2000 will be realized with 50% certainty
P84 = $\mu - \sigma$	$1700	Revenue of at least $1700 will be realized with 84% certainty
P95 = $\mu - 1.645\sigma$	$1506	Revenue of at least $1506 will be realized with 95%

Methods to reduce uncertainty:

- Higher quality measurement instruments
- 2 to 3 year of wind speed measurement
- Measurement close to hub height
- Layout to reduce affect of wake

Component of Uncertainty	Sensitivity Factor	Amount of Uncertainty (%)	Net Uncertainty of AEP Because of Component (%)
Wind speed measurement	1.5	5	7.5
Wind speed spatial extrapolation	1.5	3	4.5
Wind speed long-term correction	1.5	3	4.5
Wind shear, height extrapolation	1.5	2	3
Air density	1	0.3	0.3
Power curve	1	0.6	0.6
Wake losses in wind farm	1	1.7	1.7
Unaccounted for Loss	1	1	1
Total uncertainty of AEP assuming components are uncorrelated is square root of sum of squares			10.5%

Source: P. Jain, Wind Energy Engineering, 2010

Checklist for Bankable WRA

Properties of Bankable Wind Resource Assessment

- Wind measurements at multiple height
- Duration of measurement is one year or more
- Wind measurement is done within acceptable distance of site
- Proper location and configuration of met-towers
- Average, max, min and standard deviation of wind speed are recorded every 10 minutes
- Quality and calibrated wind measurement instruments
- Auditable wind data management
- Documented logic for processing wind speed data
- Long-term correction has been applied
- Losses have been quantified
- Uncertainty has been quantified
- Average Annual Energy Production is computed along with P50, P95, P99, and others

Table of Contents of Bankable Wind Resource Assessment

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   i. Selection of reference data and hindcasting
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6. Wind resource map
7. Wind turbine class selection and vendor options
8. Layout of proposed wind farm
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12. Preliminary financial analysis
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15. Appendix I: Charts of data
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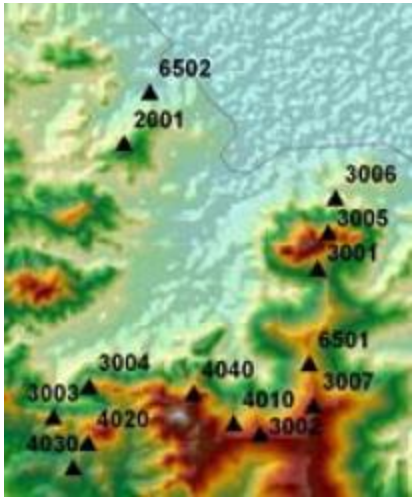
QUESTIONS?

Case Study: Island Nation

- Land concessions were granted by government for wind farm development
- Wind data was collected from 13 sites from Jan 2001 to Aug 2004



Background Data

- Average wind speed: 6.5 m/s
- Wind direction: Trade winds, single direction
- PPA+Incentives: $150/MWh
- Interconnection: No problem
- Environmental: Not done, but see no problem
- Logistics: 200m elevation; flat ridges; no major issues
- Total installed cost: $1,800 to $1,900/kW
- 7 year payback

Is this a bankable wind project?

- Wind data is hourly
- Documentation of instruments, met-tower configuration are not available
- Duration of measurement is variable: 1.5 years, 1 year, 6 months
- Data is not auditable: Raw data is not available

Result

- Low valuation
- Measurement has to be redone

Conclusions

- Wind development requires attention to details, a lot of details
- If done well, it can reduce overall cost and reduce time to completion
- If wind resource is very good, but the WRA was not done with rigor, expect a bank to apply a very high uncertainty, which will:
  - Reduce project's P90, P95
  - Reduce project's valuation
  - Increase Bank's risk, therefore reduce your return