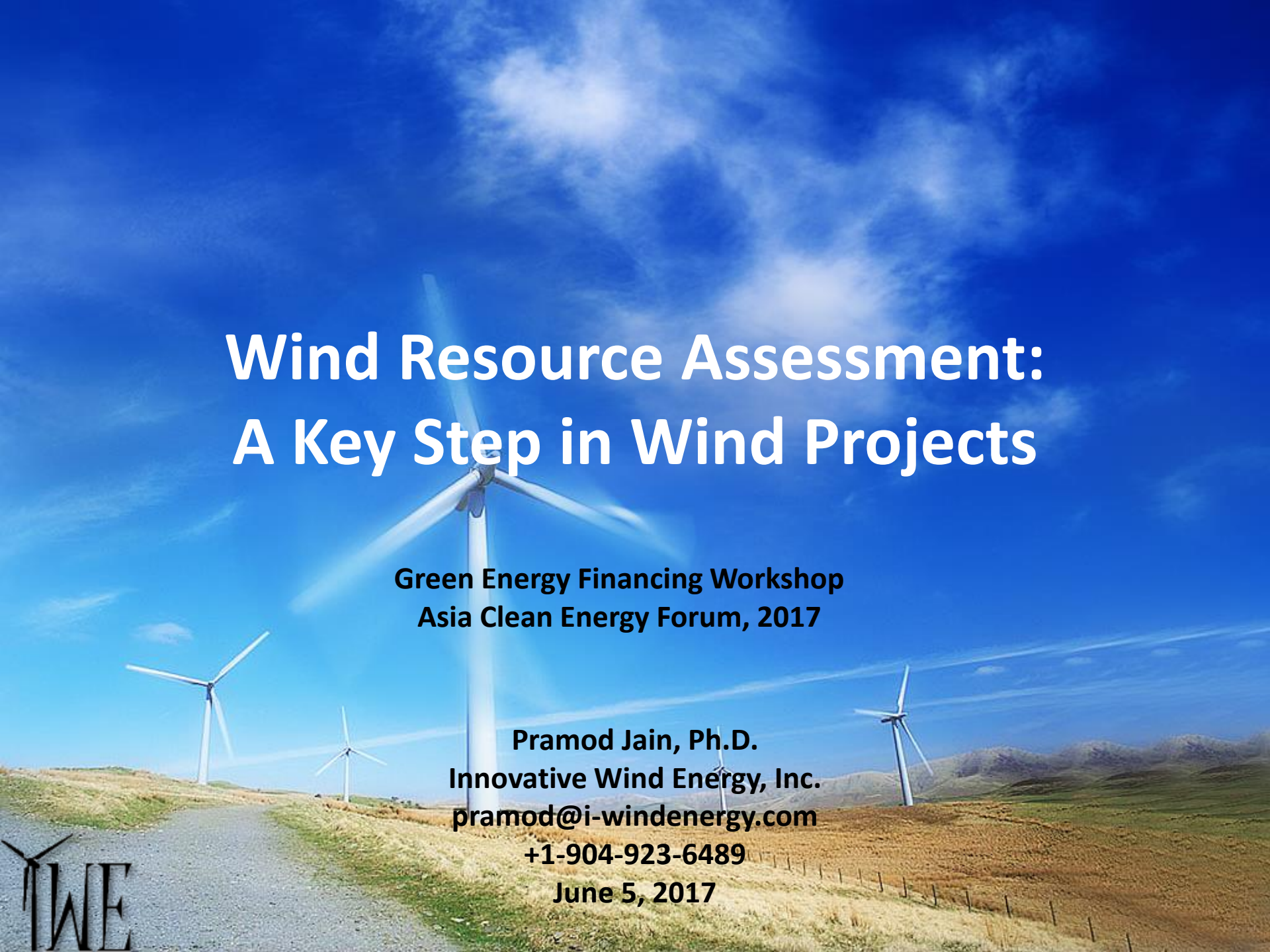

Wind Resource Assessment: A Key Step in Wind Projects

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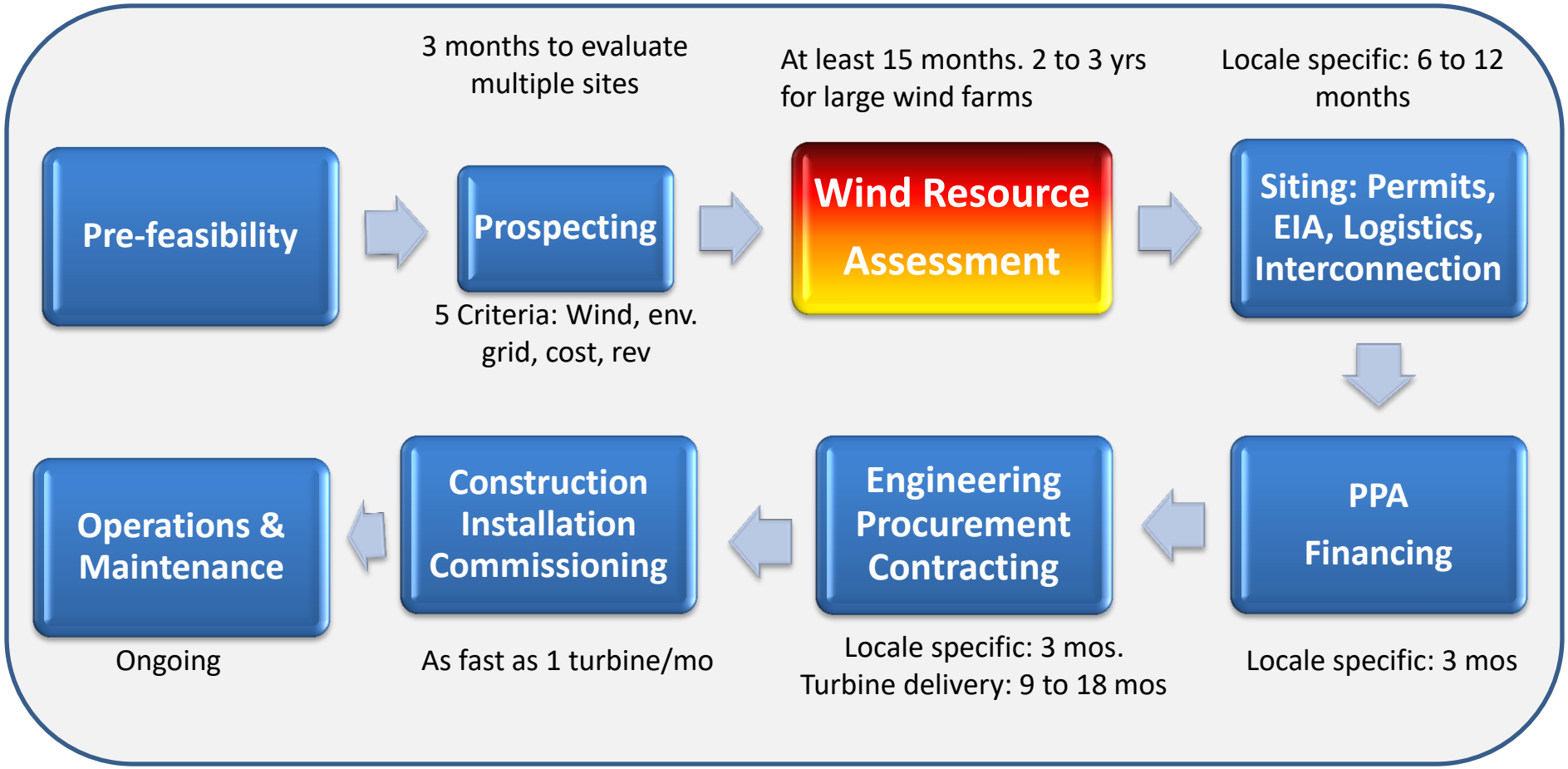
Agenda

- Wind Project Lifecycle
- What is wind resource assessment (WRA)?
- Types of WRA
- Why is WRA Key to a Wind Project?
- Checklist for WRA

Wind Project Lifecycle & Planning



Entire process: 24 to 48 months

Source: P. Jain, Wind Energy Engineering, 2016

What is wind resource assessment?

- Quantification of wind resources
- Inputs:
  - Wind speed data
  - Terrain: Elevation, roughness, obstacles
  - Turbine data: Quantity, layout and production curve
  - Others
- Output: Average annual energy production (AEP)

Types of WRA

- Level I WRA: Preliminary for prospecting
- Level II WRA: With measured wind data and long-term correction
- Level III WRA: CFD-based model for complex terrain
- Level IV WRA: Bankable wind resource assessment. Level II or III with long-term correction, and estimates for losses and uncertainty

What is Wind Resource Assessment?

Wind Resource Assessment (WRA) is quantification of wind resources

Level 1

- Preliminary
- Purpose: Prospecting for areas with good resources, Selecting sites to install met-masts
- Tools: Online prospecting tools (3Tier), RetScreen
- Energy estimate: +/- 50

Level 2

- Purpose: Compute Annual Energy Production, micrositing
- Based on onsite measurement
- Modeling of terrain: elevation, roughness
- Linearized RANS model
- Measure-correlate-predict to extrapolate measurement
- Tools: WAsP, WindPRO, Wind Farmer
- Energy Estimate: +/- 15%

Level 3

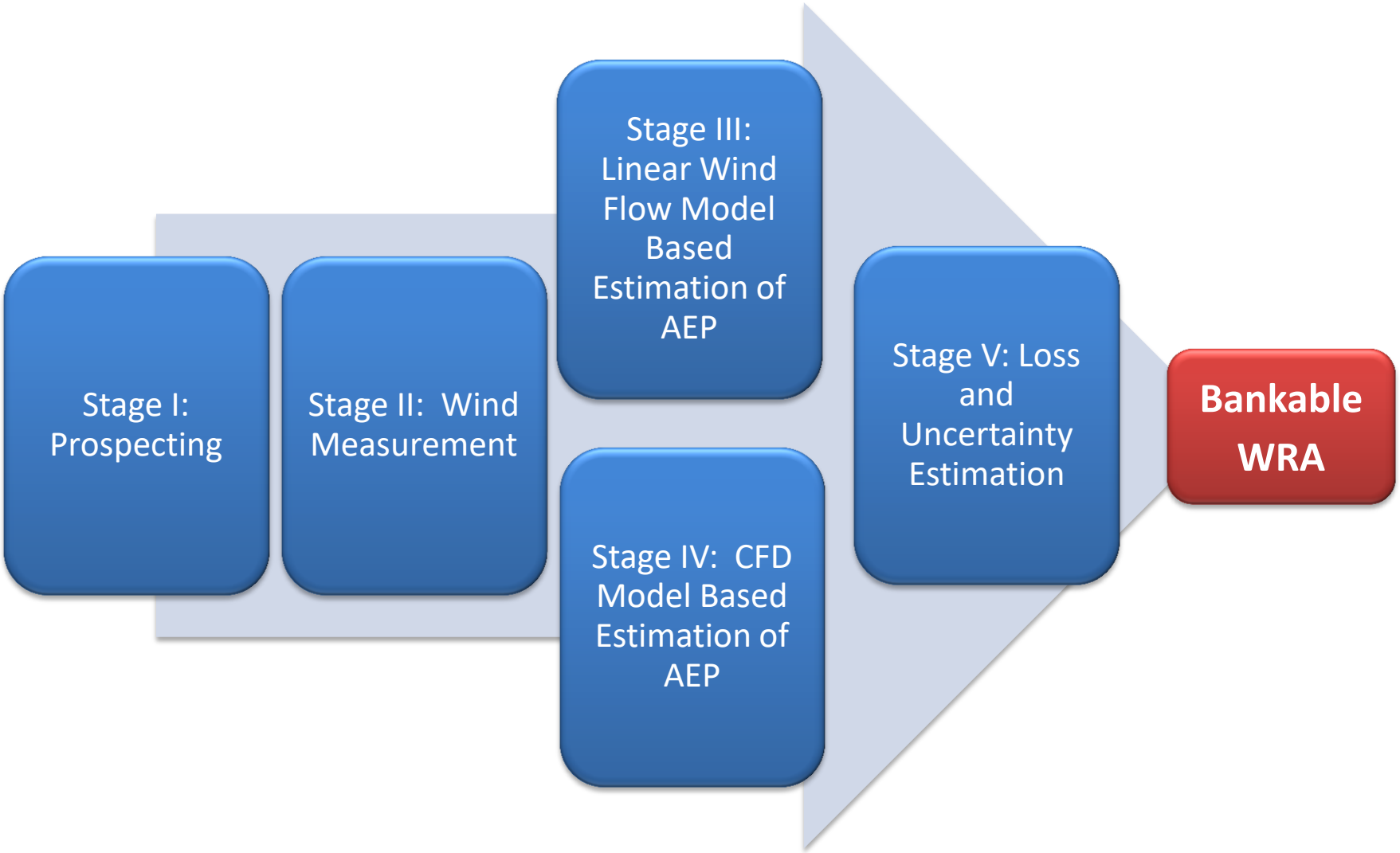
- CFD-based models
- Includes non-linear effects (flow separation)
- Includes non-linear terms
- Steep/complex terrain
- WAsP CFD/EllipSys
- Energy Estimate: +/- 10%

Level 4

- Bankable WRA
- Estimate of Uncertainty based on review of measurement practices, audit of data, and others
- Detailed accounting for all losses
- Computation of P50, P75, P90 and other estimates of AEP
- Financial parameter estimation
- Financial analysis

Why am I quantifying?

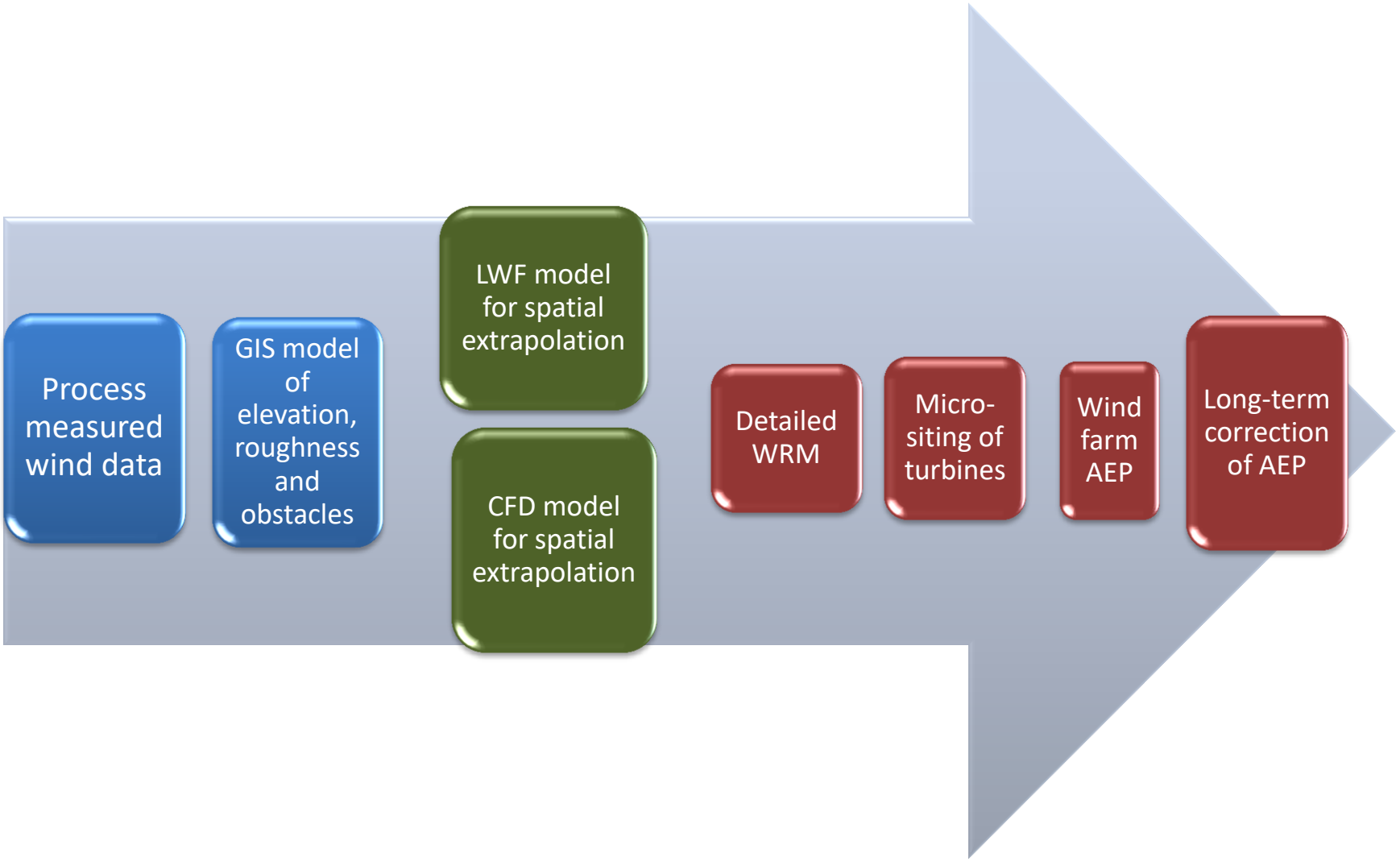
Stages of WRA



Why is WRA Key to a Wind Project?

- Key driver to financing of a project
- Requirements:
  - At least one year of onsite wind measurement
    - With multiple met-masts
    - At multiple heights, and one measurement close to hub height
    - Quality data
  - Annual Energy Production
  - Reasonable estimate of losses
  - Rigorous uncertainty analysis
- Project financiers are interested in both, mean and standard deviation of AEP

Process for Estimating Annual Energy Production

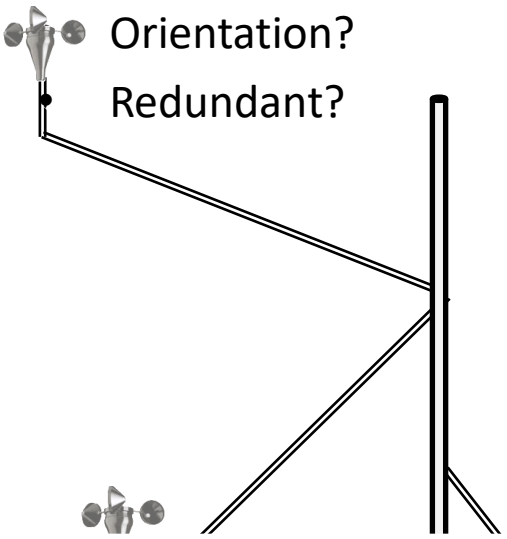


Measure wind speed: Do my profits measure up?

- 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
- Acceptable 75% of hub height

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

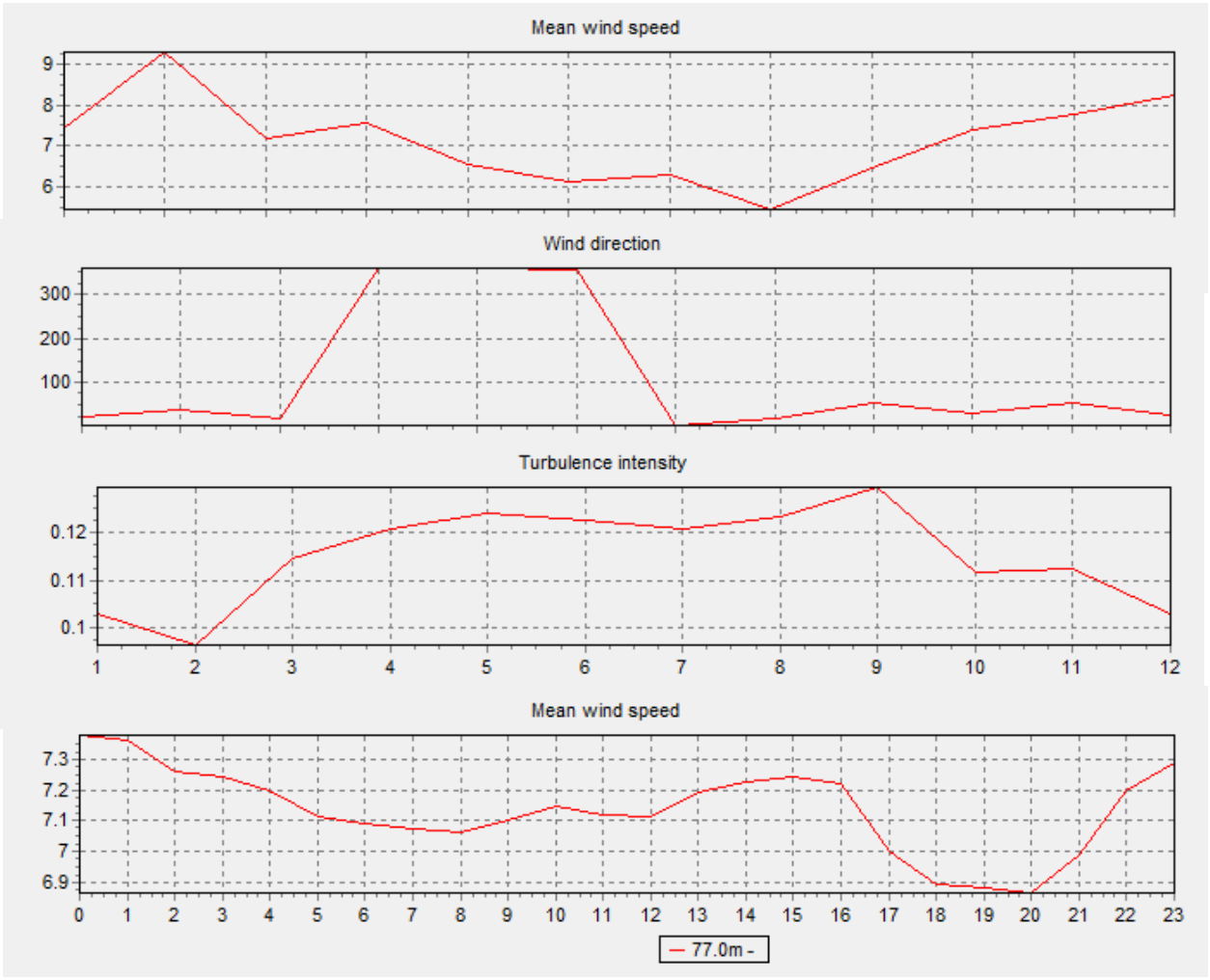
Data Processing

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

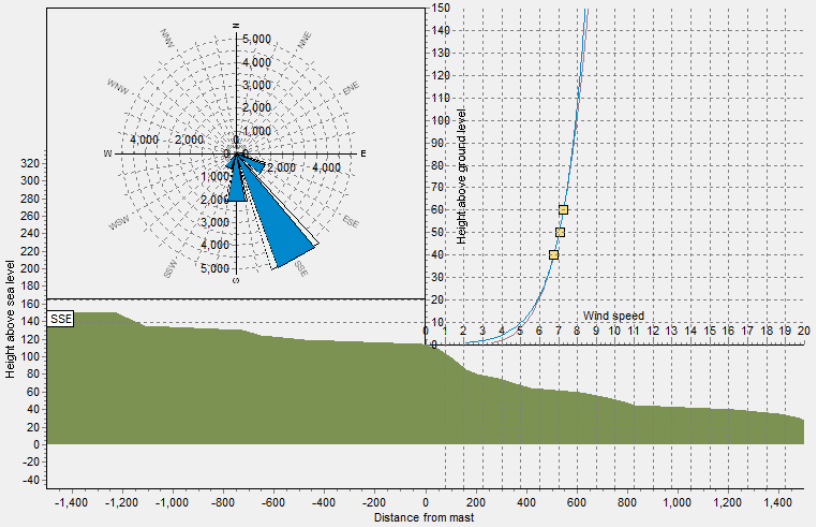
Is data trustworthy?

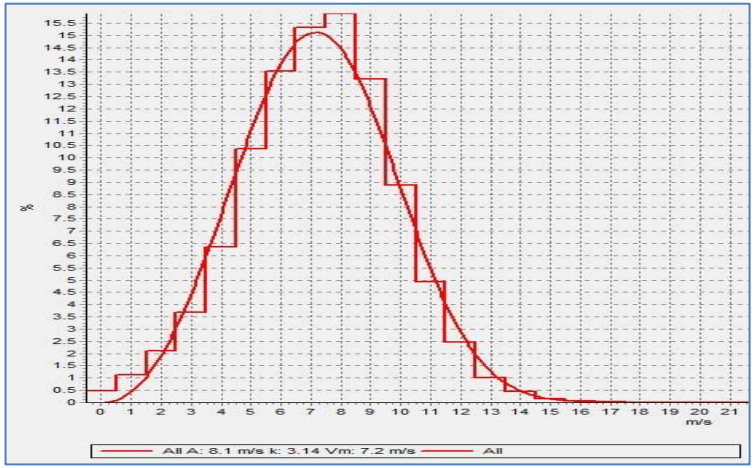
Wind Measurements

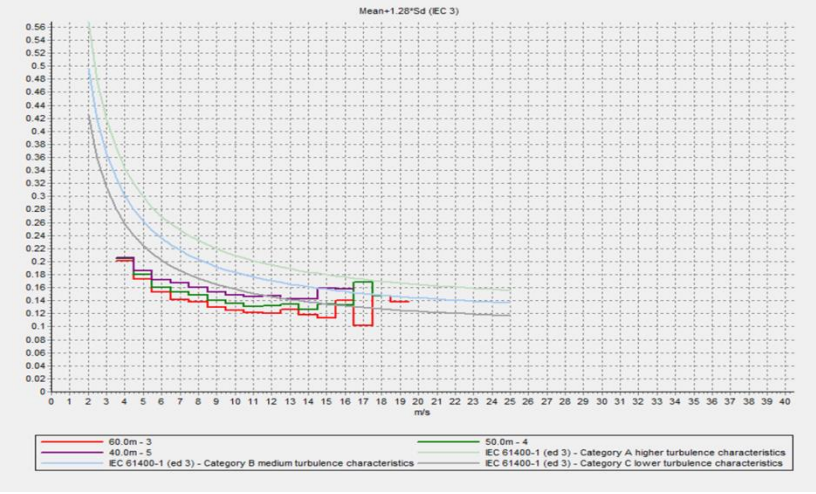
- Tall towers (¾ of turbine hub height)
- Remote sensing—SODAR and LiDAR

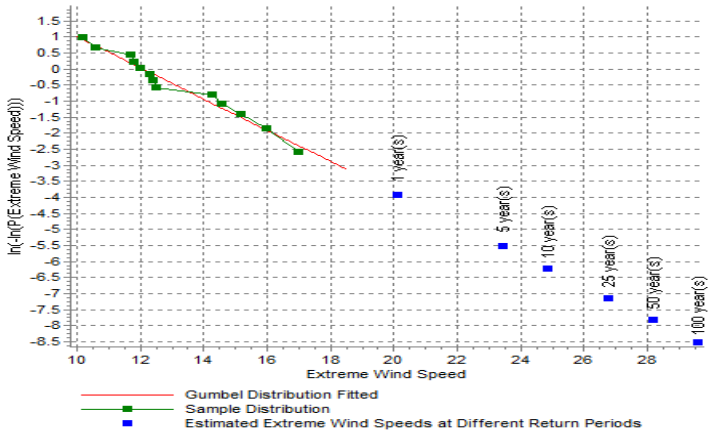


Wind data analytics









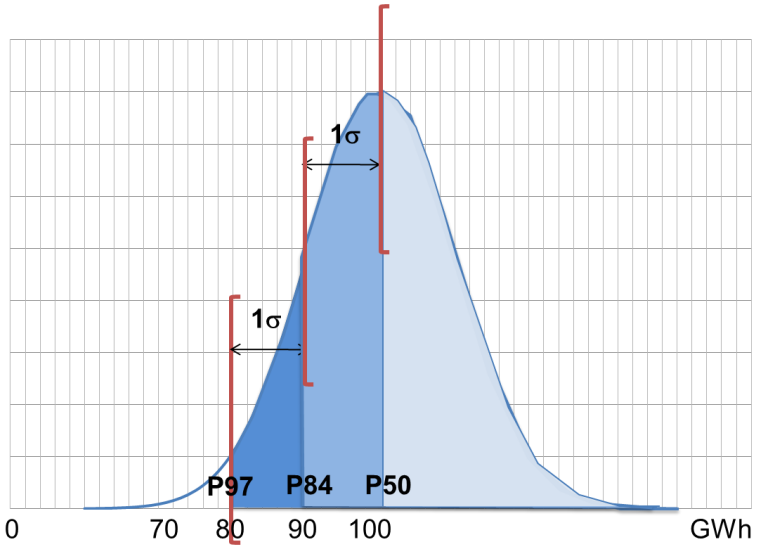
Losses: How much profits will I lose?

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, 2016

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



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, 2016

Checklist for Bankable WRA

Properties of Bankable Wind Resource Assessment

- Wind measurements at multiple height
- Duration of measurement is one year or more
- Class 1 calibrated anemometers and other quality and calibrated instruments
- 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
- Auditable wind data management
- Documented logic for processing wind speed data
- Wind modeling with appropriate consideration for terrain, roughness, convection, stability and others
- 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

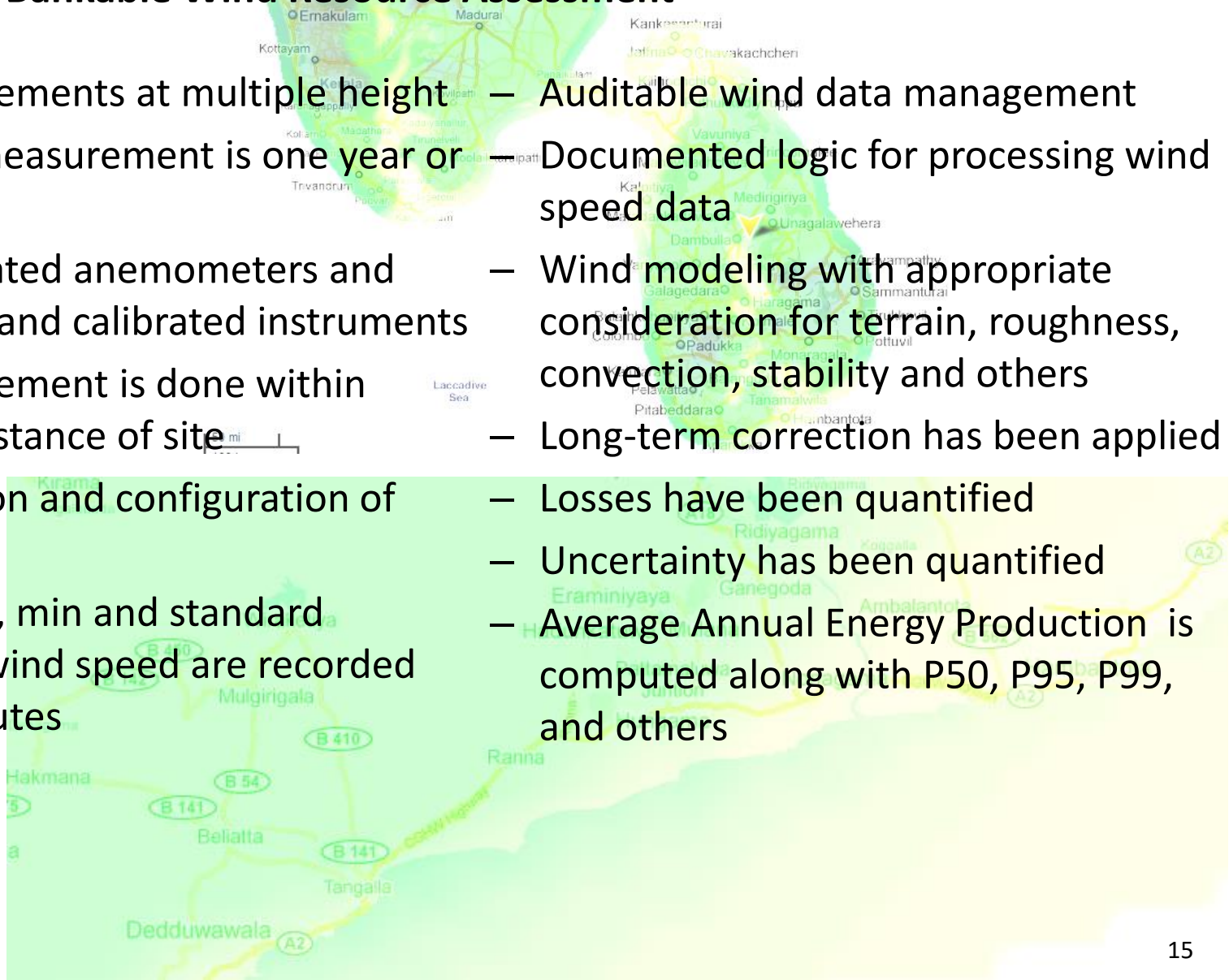


Table of Contents of Bankable Wind Resource Assessment

Further Reading

1. Pramod Jain, **Wind Energy Engineering,** second edition, McGraw-Hill, New York, 2016
2. Michael Brower, **Wind Resource Assessment**, John Wiley, 2012
3. Burton, Jenkins, Sharpe, Bossanyi, **Wind Energy Handbook**, second edition, John Wiley, 2011
4. Pramod Jain, "Guidelines for Wind Resource Assessment: Best Practices for Countries Initiating Wind Development", ADB Publication, TIM146446, May 2014

Other ADB wind energy publications of interest:

1. "Policy Enablers for New Wind Energy Markets," ADB Sustainable Development Working Paper Series. Authors: P. Jain, Bo An
2. "Grid Integration of Wind Power: Best Practices for Emerging Wind Markets," April 2016, ADB Sustainable Development Working Paper Series. Authors: P. Jain, P. Wijayatunga
3. "Energy Storage in Grids with High Penetration of Variable Generation," February 2017, ADB Sustainable Development Working Paper Series. Author: P. Jain.