# *About the importance of (reliable) Wind Resource Assessment*

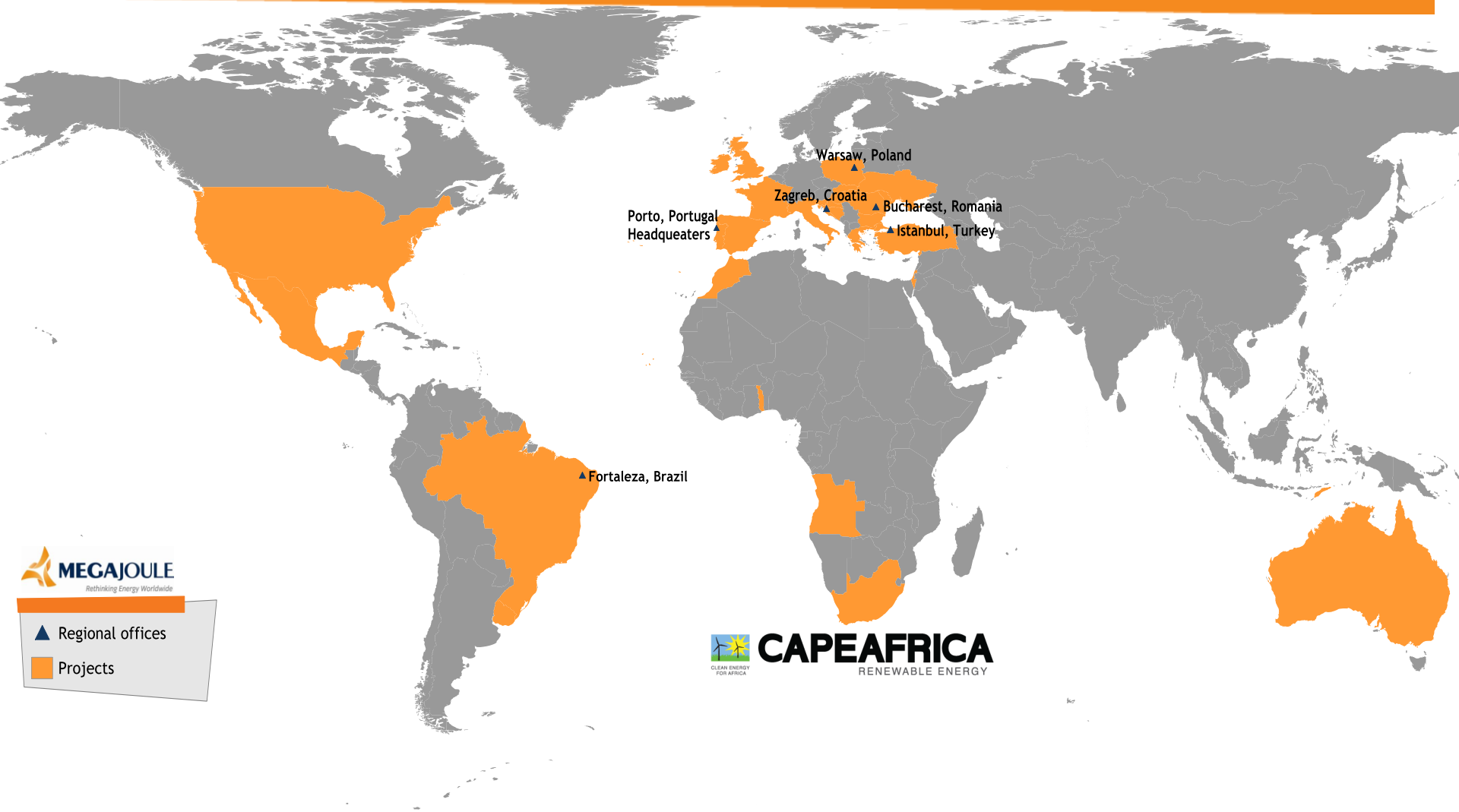
MEGAJOULE

Rethinking Energy Worldwide

**Ricardo André Guedes**
Chief Technical Officer

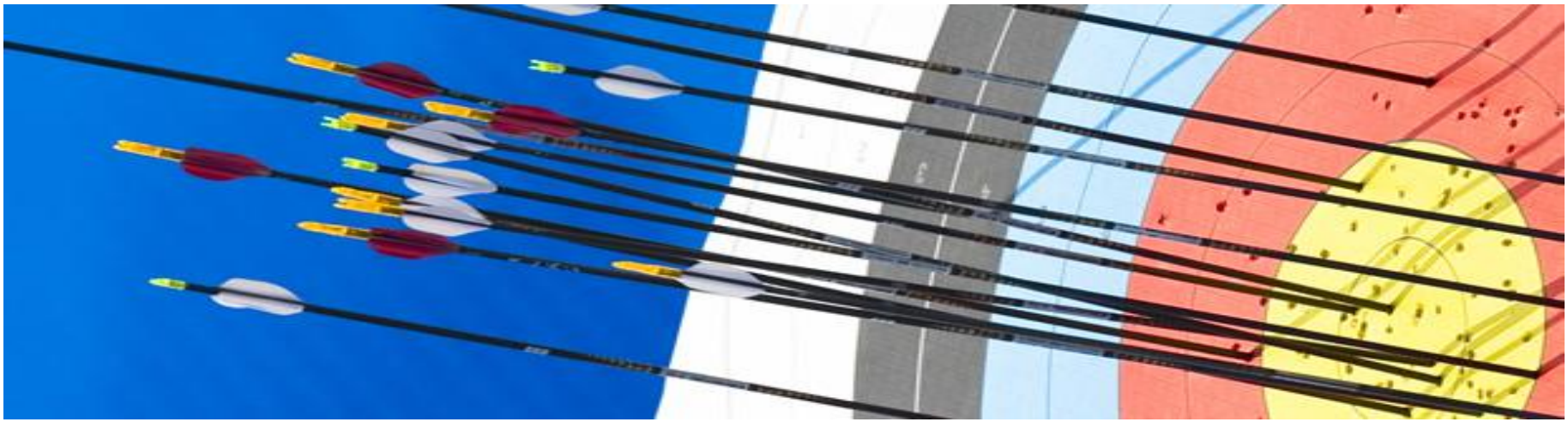
**Green Cape / Cape Town, 13-05-2013**

# MEGAJOULE – more than 16GW in 20 countries



# Topics

1. **Basic concepts of Wind Resource Assessment (WRA) and Uncertainty**
2. **Financial implications of WRA Uncertainty**
3. **Some thoughts about how we could minimize uncertainty**
4. **Example Project Finance model for different WRA scenarios**

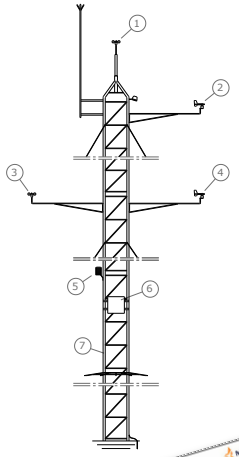


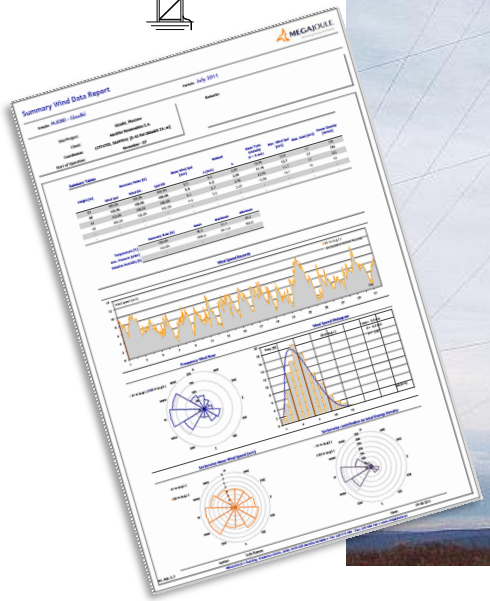
# Typical Wind Resource Assesssment (WRA)

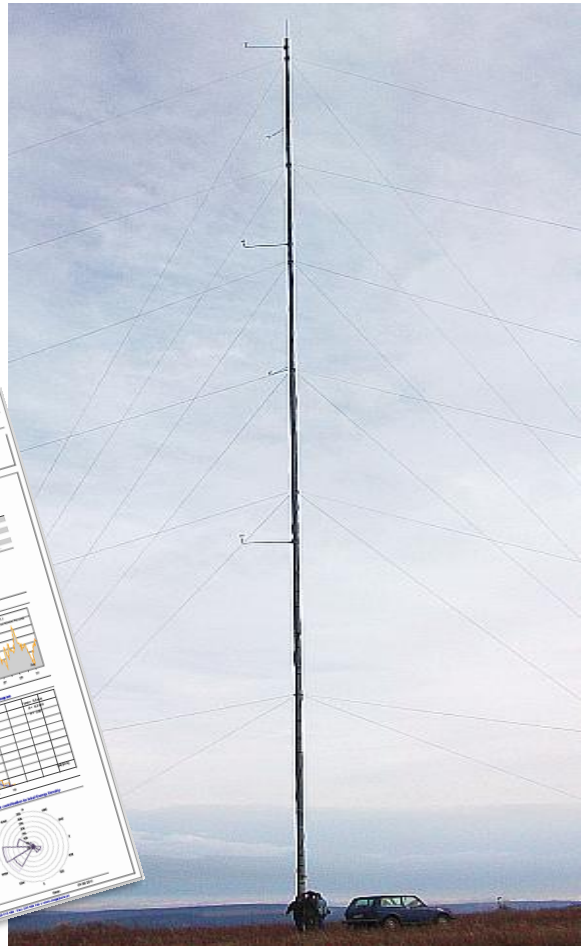
# WRA basics

Local Wind Measurements

Short Term Wind Climate
@ mast site



# WRA basics

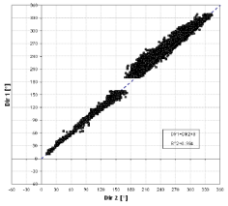
Local Wind Measurements

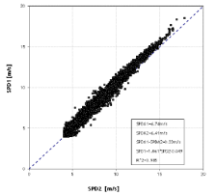
Auxiliary Long Term data

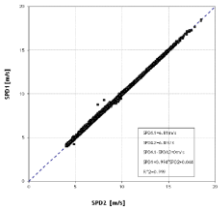
Short Term Wind Climate
@ mast site

Adjustment to Long Term climate average

Long Term Wind Climate
@ mast site







# WRA basics

Local Wind Measurements

Short Term Wind Climate @ mast site

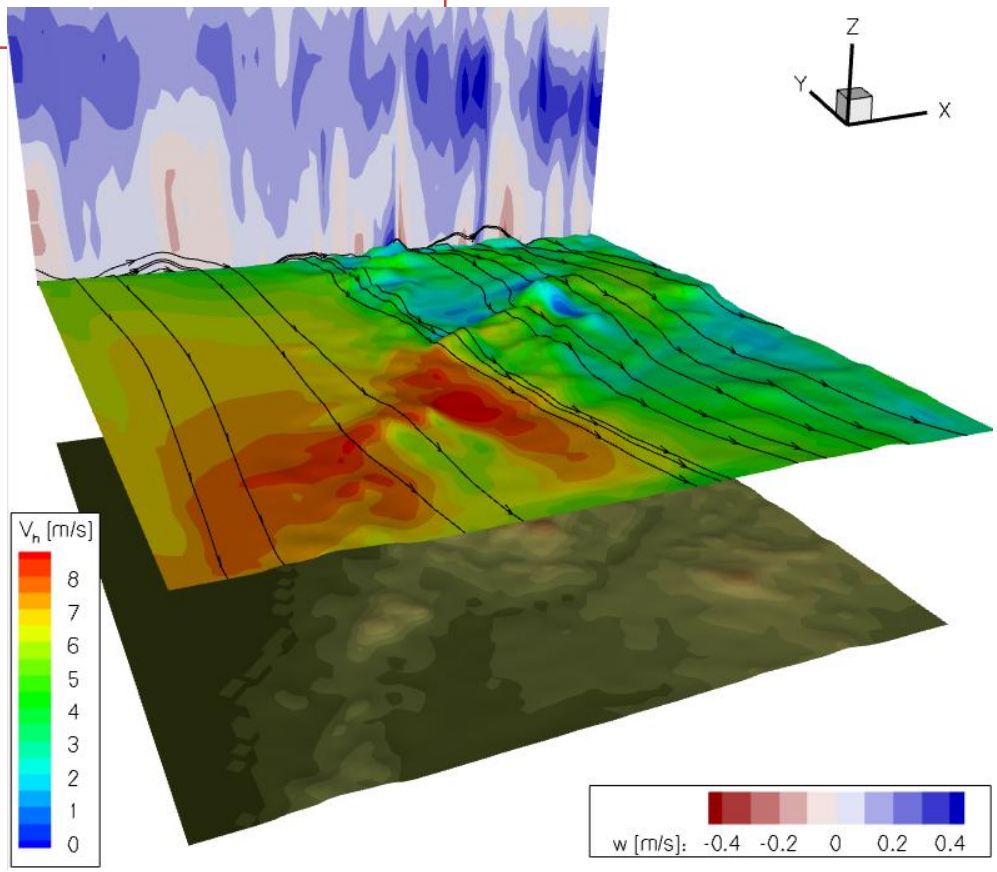
Adjustment to Long Term climate average

Auxiliary Long Term data

Long Term Wind Climate @ mast site

Wind Flow Modelling Horizontal and Vertical Extrapolation

Long Term Wind Climate @ WT site and HH



# WRA basics

Local Wind Measurements

Short Term Wind Climate @ mast site

Auxiliary Long Term data

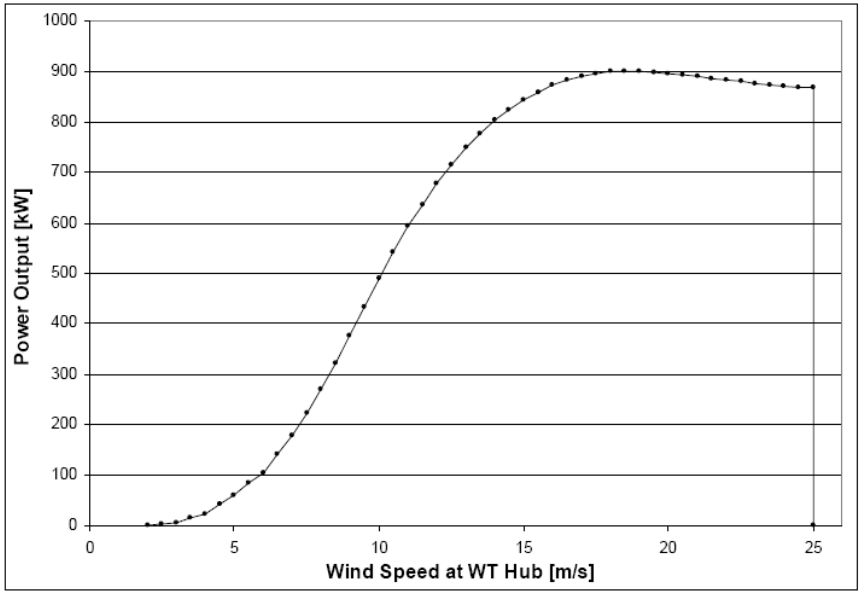
Adjustment to Long Term climate average

Long Term Wind Climate @ mast site

Wind Flow Modelling Horizontal and Vertical Extrapolation

Long Term Wind Climate @ WT site and HH

Wind Turbine Power Curve



# WRA basics

Local Wind Measurements

Short Term Wind Climate @ mast site

Auxiliary Long Term data

Adjustment to Long Term climate average

Long Term Wind Climate @ mast site

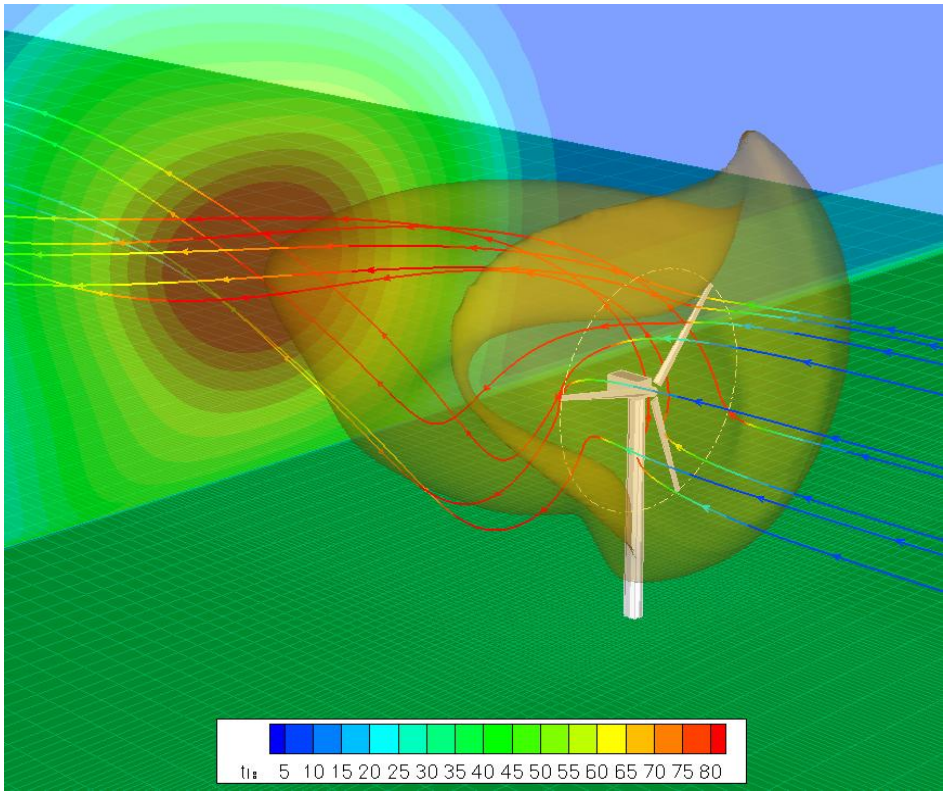
Wind Flow Modelling Horizontal and Vertical Extrapolation

Long Term Wind Climate @ WT site and HH

Wind Turbine Power Curve

Wakes

Gross after Wake Annual Energy Production



# WRA basics

Local Wind Measurements

Auxiliary Long Term data

Short Term Wind Climate @ mast site

Adjustment to Long Term climate average

Long Term Wind Climate @ mast site

Wind Flow Modelling Horizontal and Vertical Extrapolation

Long Term Wind Climate @ WT site and HH

Wind Turbine Power Curve

Wakes

Gross after Wake Annual Energy Production

Turbine and Farm Technical Losses

Net Annual Energy Production

# WRA basics

Local Wind Measurements

Auxiliary Long Term data

Short Term Wind Climate @ mast site

Adjustment to Long Term climate average

Long Term Wind Climate @ mast site

Wind Flow Modelling Horizontal and Vertical Extrapolation

Assess Uncertainty on NET AEP

Long Term Wind Climate @ WT site and HH

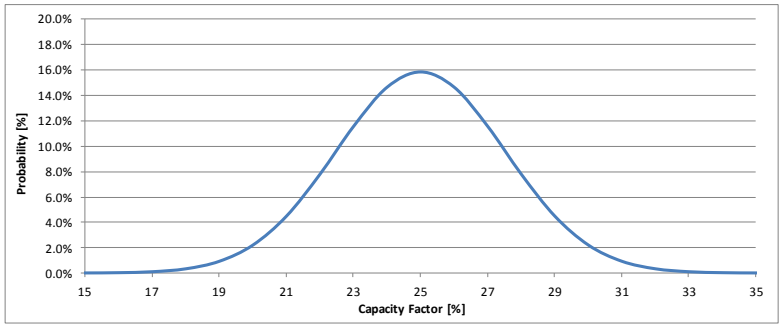
Wind Turbine Power Curve

Wakes

Gross after Wake Annual Energy Production

Turbine and Farm Technical Losses

Net Annual Energy Production



# Uncertainty in WRA

Wind Measurements

Long Term adjustment

Wind Variability

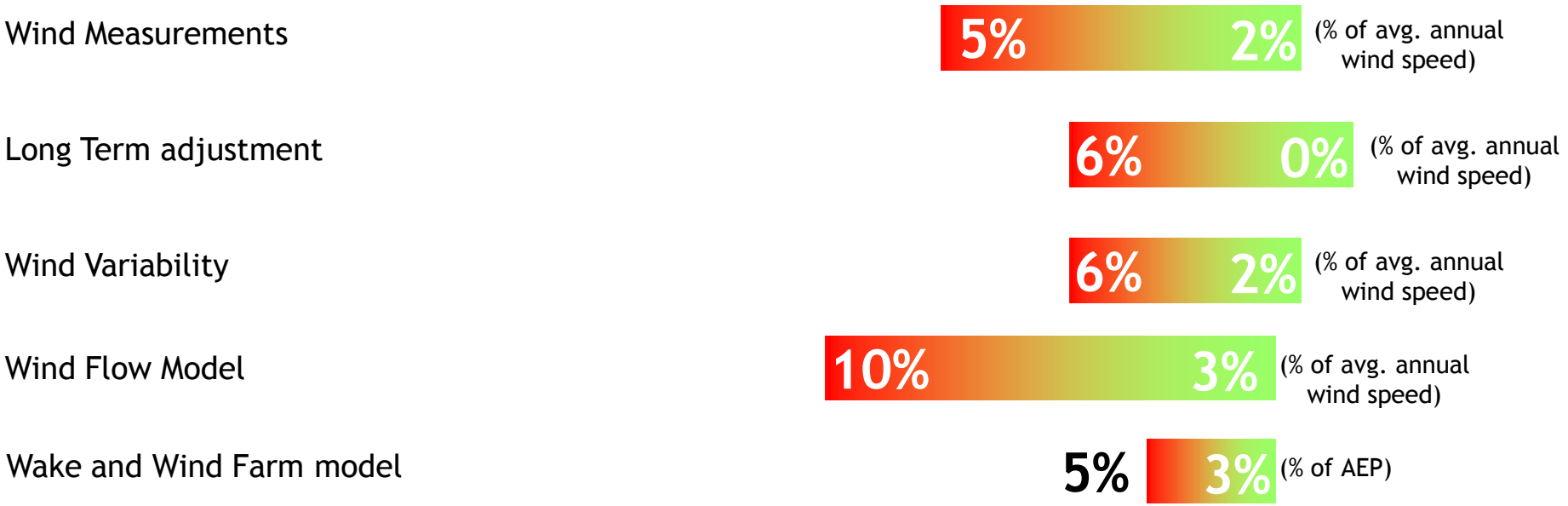
Wind Flow Model

Wake and Wind Farm model

---

**Global** (% AEP)

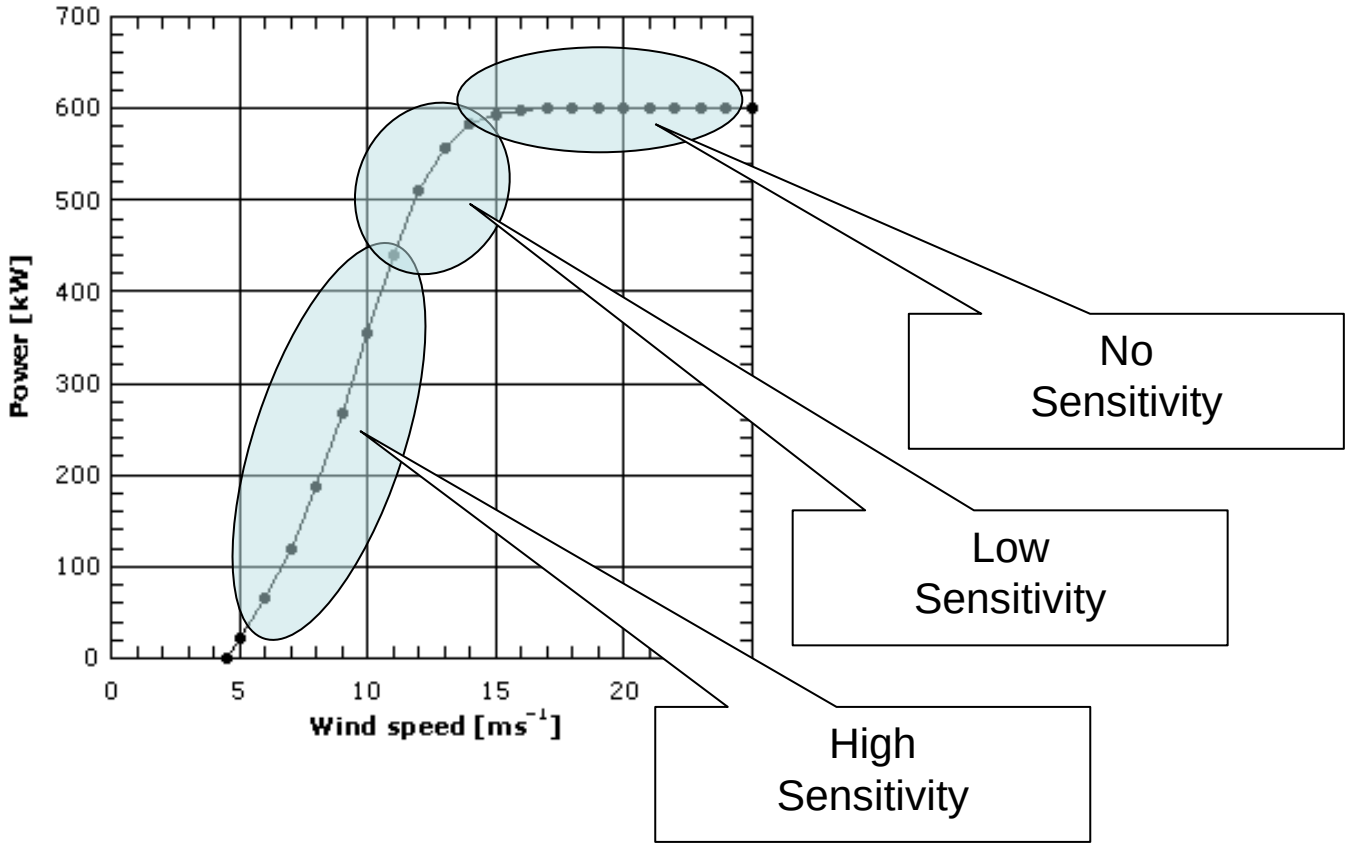
# Uncertainty in WRA



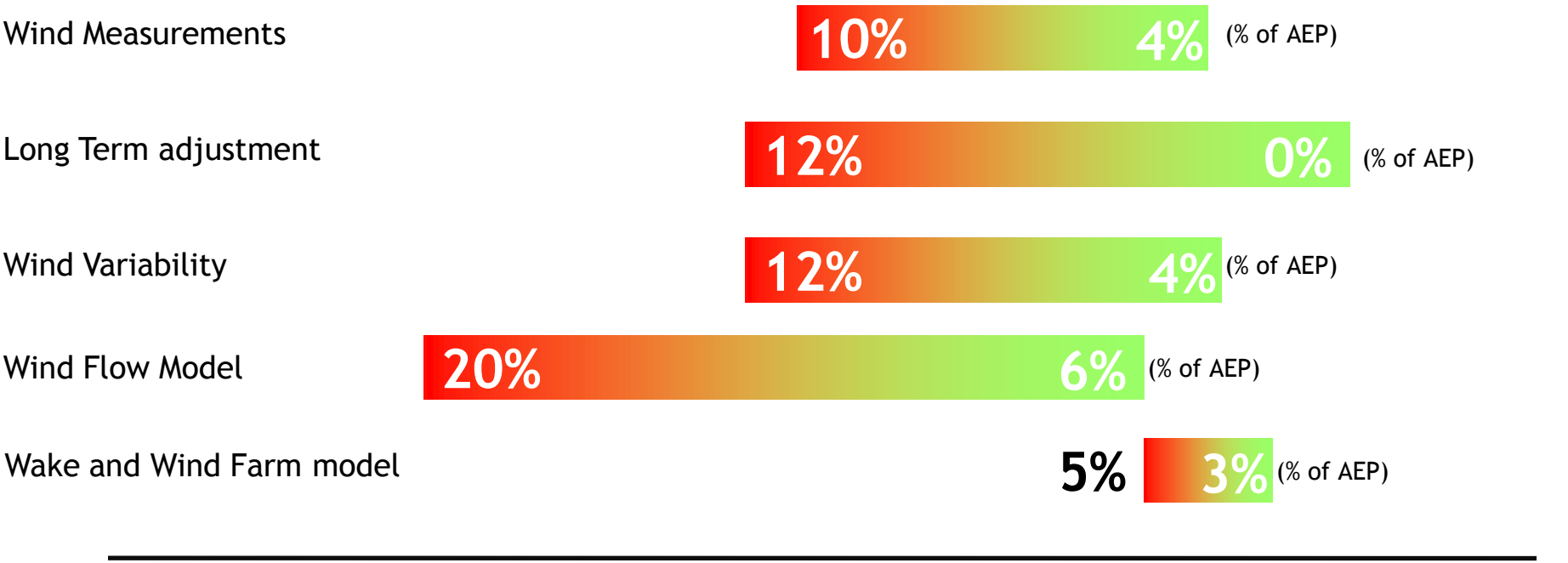
# Uncertainty in *m/s* to Uncertainty in *GWh*

Tipicaly:

U GWh [%] = 1.5 to 2.5 x U m/s

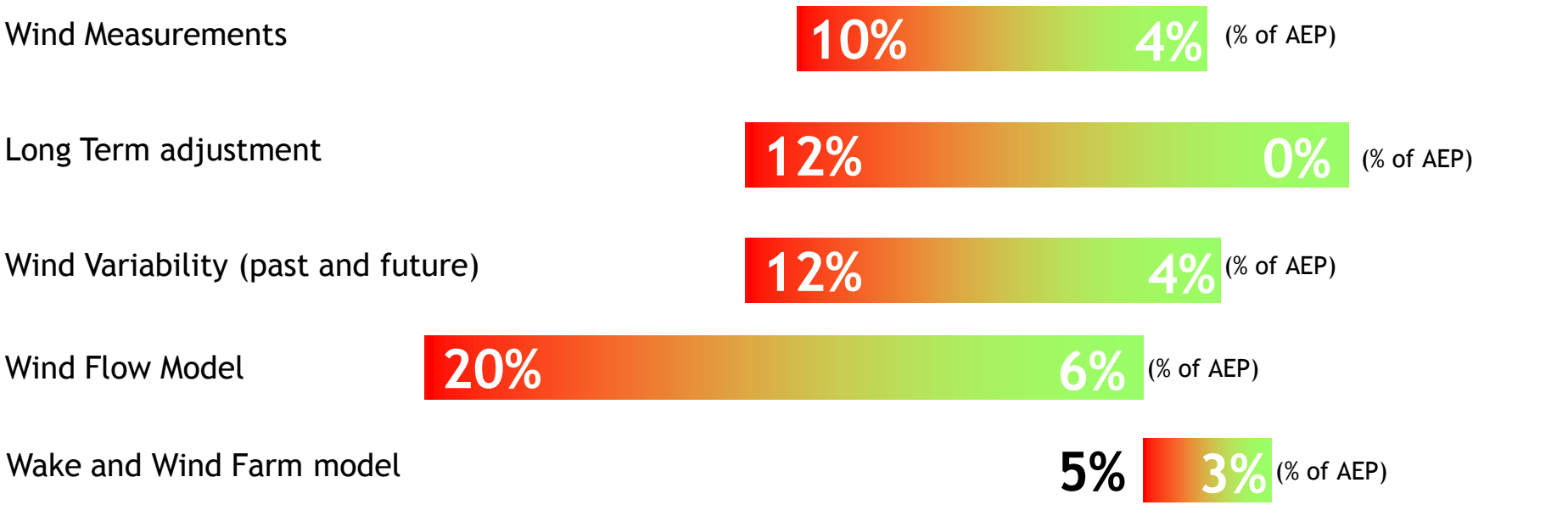


# Uncertainty in WRA




**Global** (% AEP)

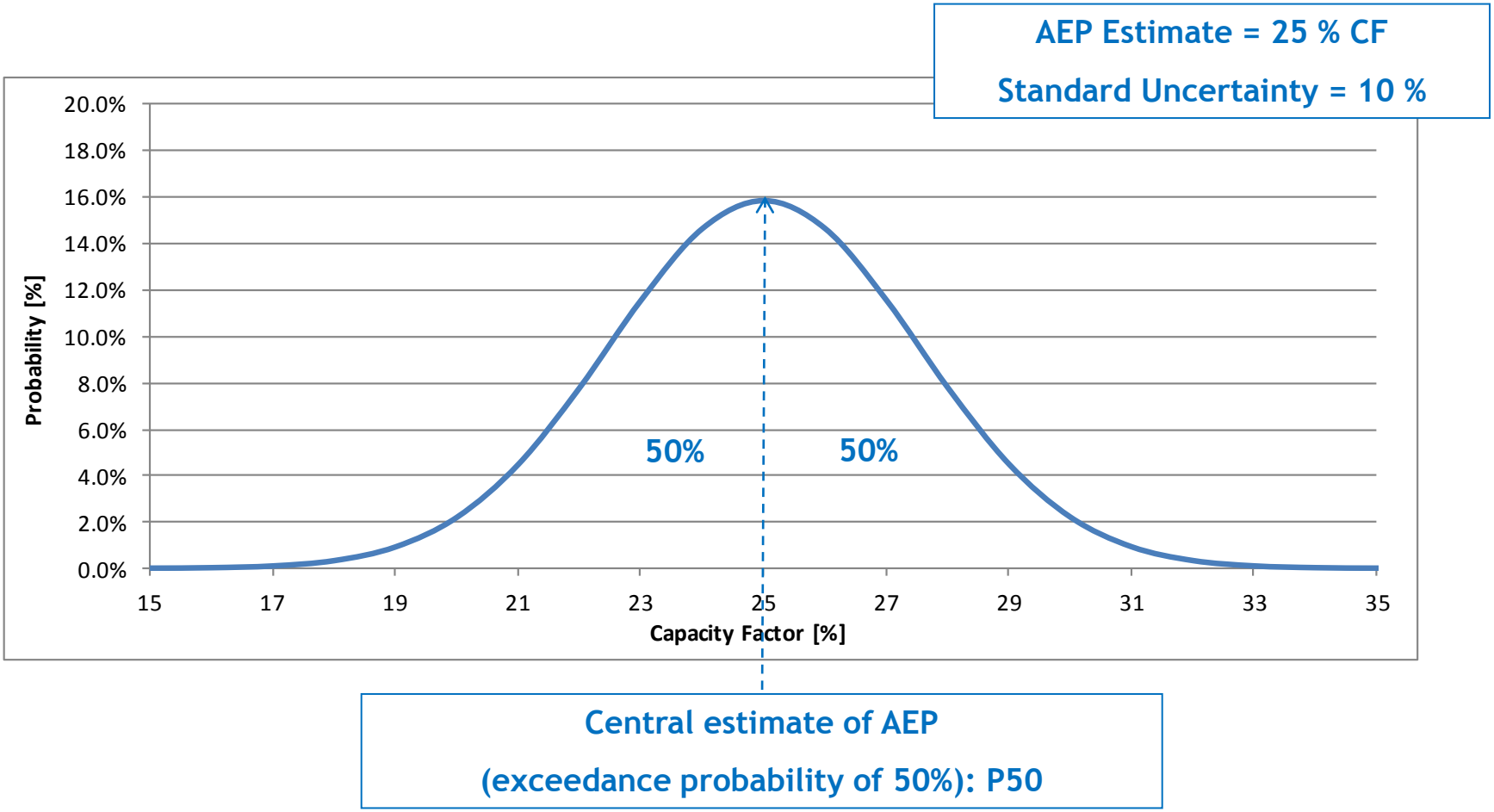
# Uncertainty in WRA



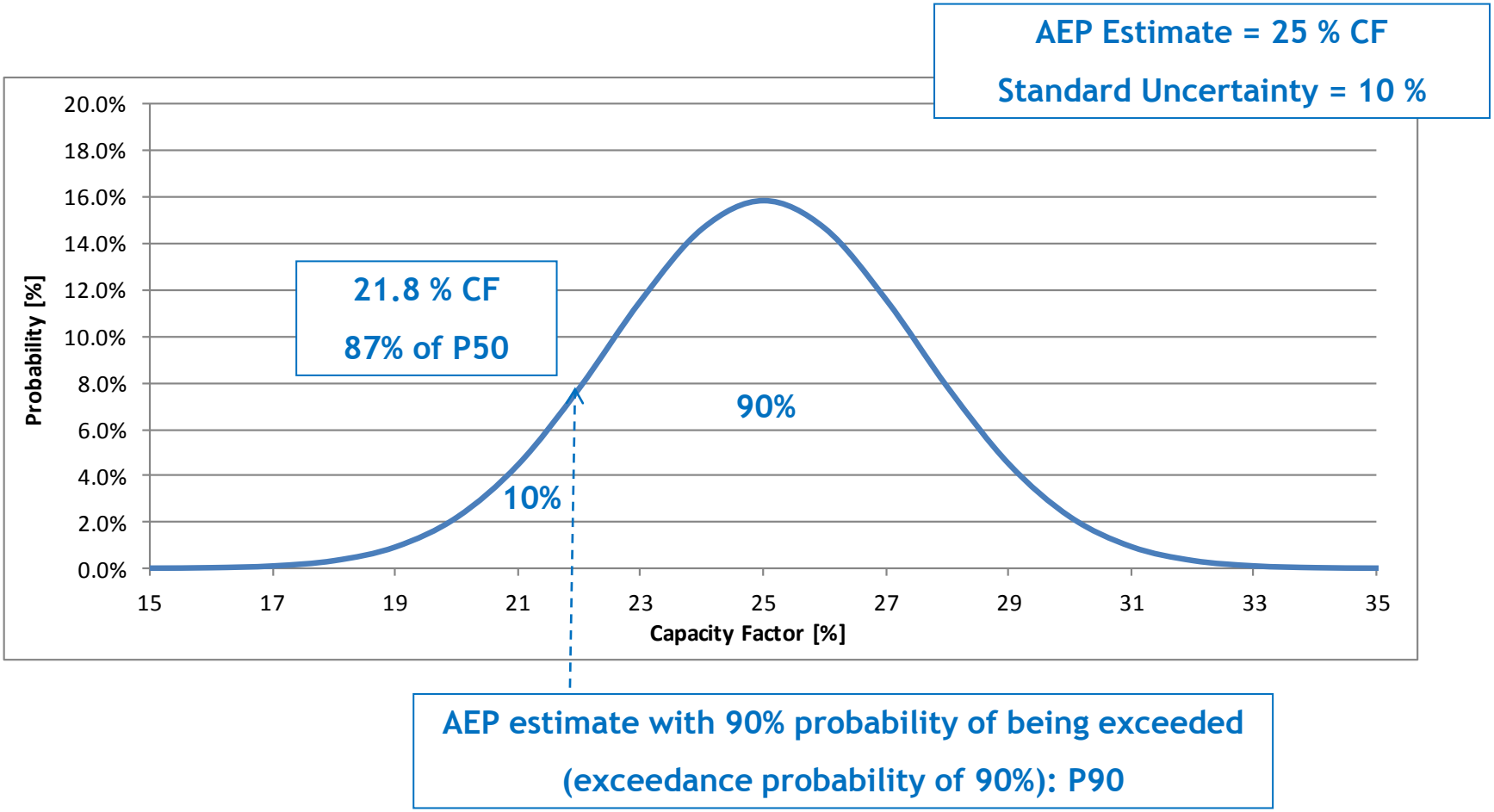


Uncertainties follow Gaussian distributions and are mutually independent. $U_{Global} = \sqrt{U_1^2 + U_2^2 + U_3^2 + \ldots}$

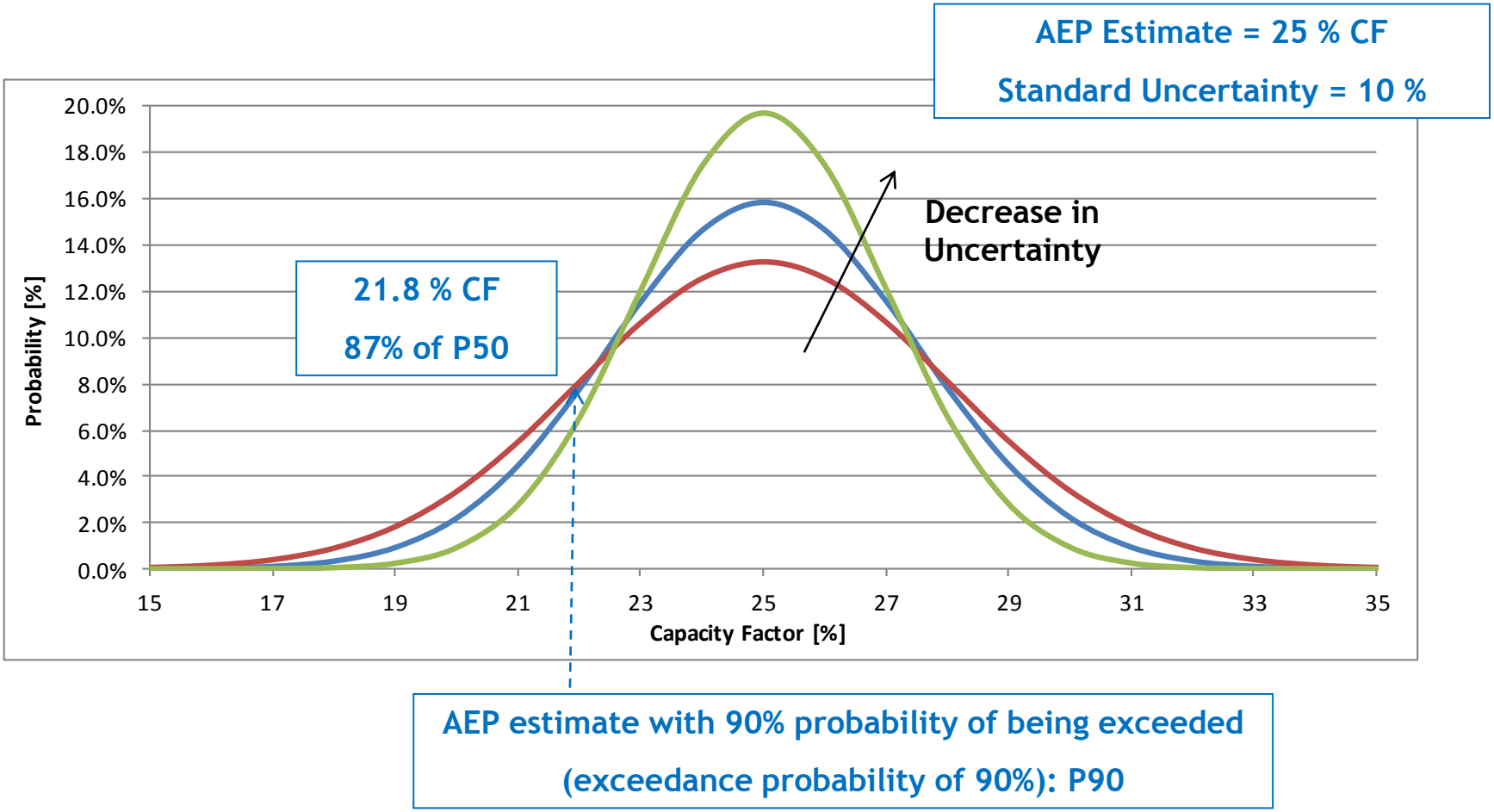
# Probability distribution of AEP estimates



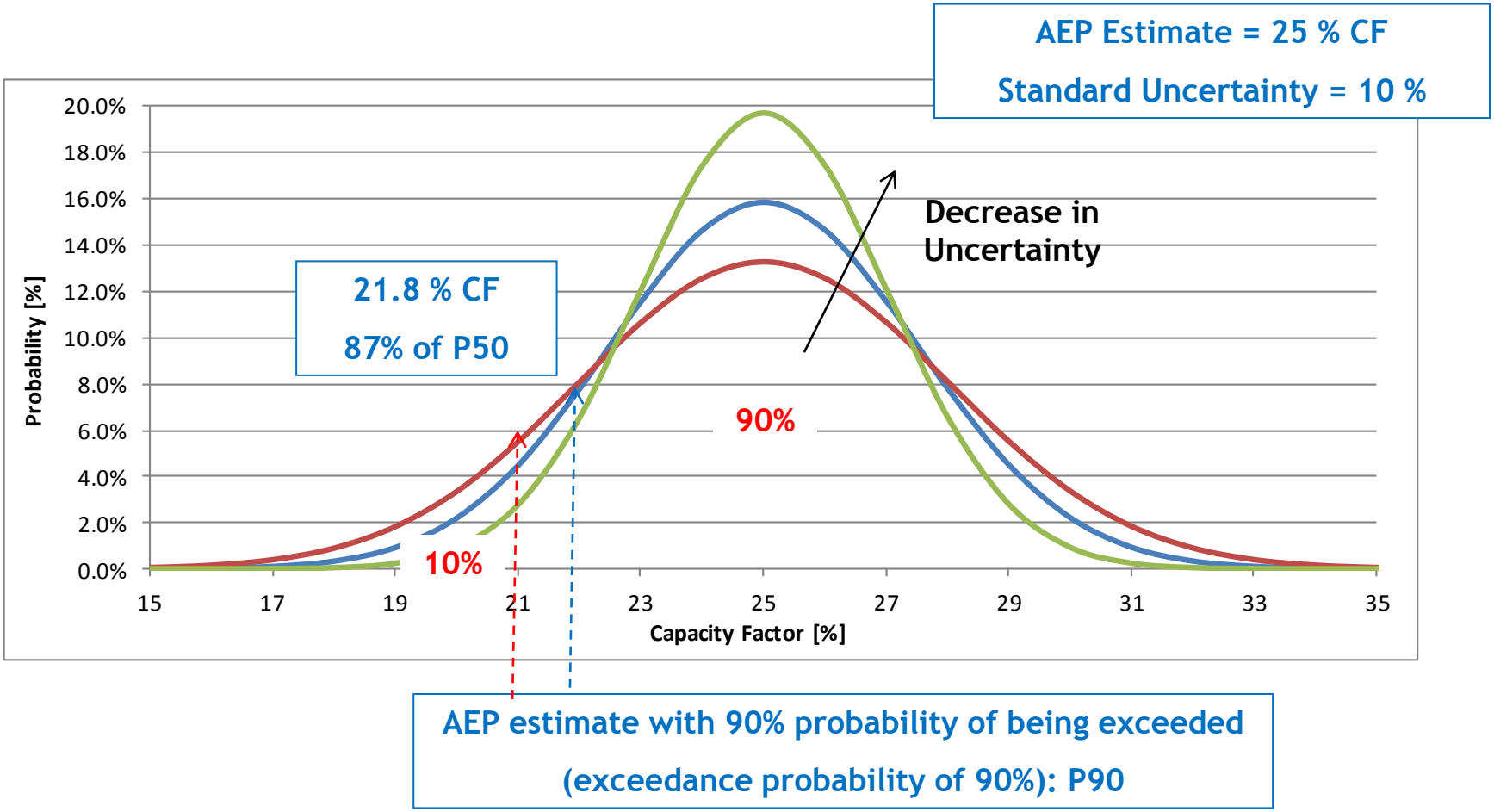
# Probability distribution of AEP estimates



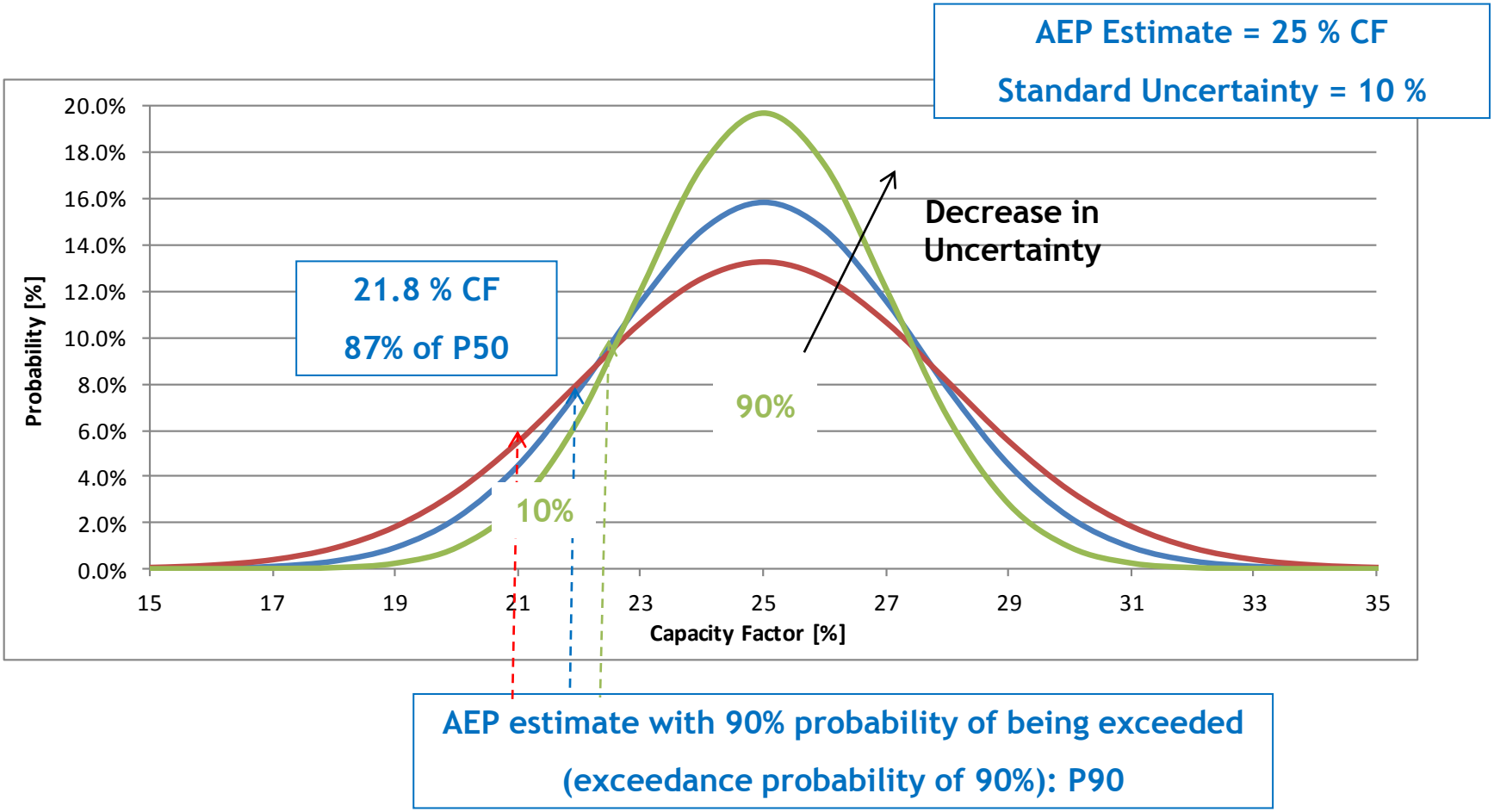
# Probability distribution of AEP estimates



# Probability distribution of AEP estimates



# Probability distribution of AEP estimates



# Disclaimer

*"In average, for 100 wind studies performed,*

*10 (10%) will see real production fall below the P90 estimate !"*

# Finantial Implications WRA Uncertainty

# For Equity deals…or for any deal at all

- Uncertainty in **WRA means RISK…**
  - **…of not reaching the desired AEP in the Long Term (10 years) average**
    - **P50 means 50% risk**
    - **P75 means 25% risk**
  - **…of not having an optimum Wind Farm layout**
  - **…of rejecting a good site…**


*"You've obviously overestimated your risk tolerance."*

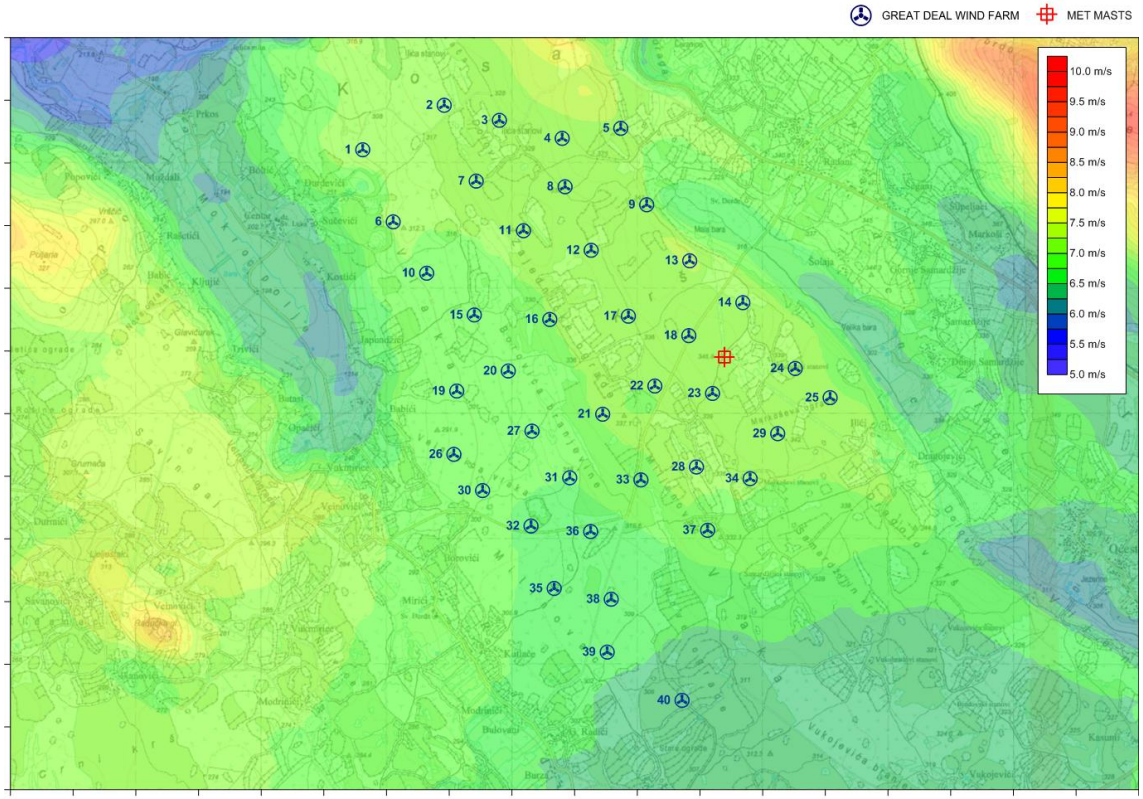
# For debt deals in Project Finance

- **PF finance models (typically) define debt based on a 10 year PXX scenario (P90, P95, P99)**
- **The project must generate enough cash (revenue minus OPEX) to service the debt at the defined scenario with a "safety" margin – Debt Service Coverage Ratio**
- **A typical DSCR for a P90 scenario is DSCR = 1.2**
- **If it does not…the loan is reduced until is does … or the deal is off !**
- **Meaning, for the same P50 a WRA with higher uncertainty means a lower loan !**

# Example - #1

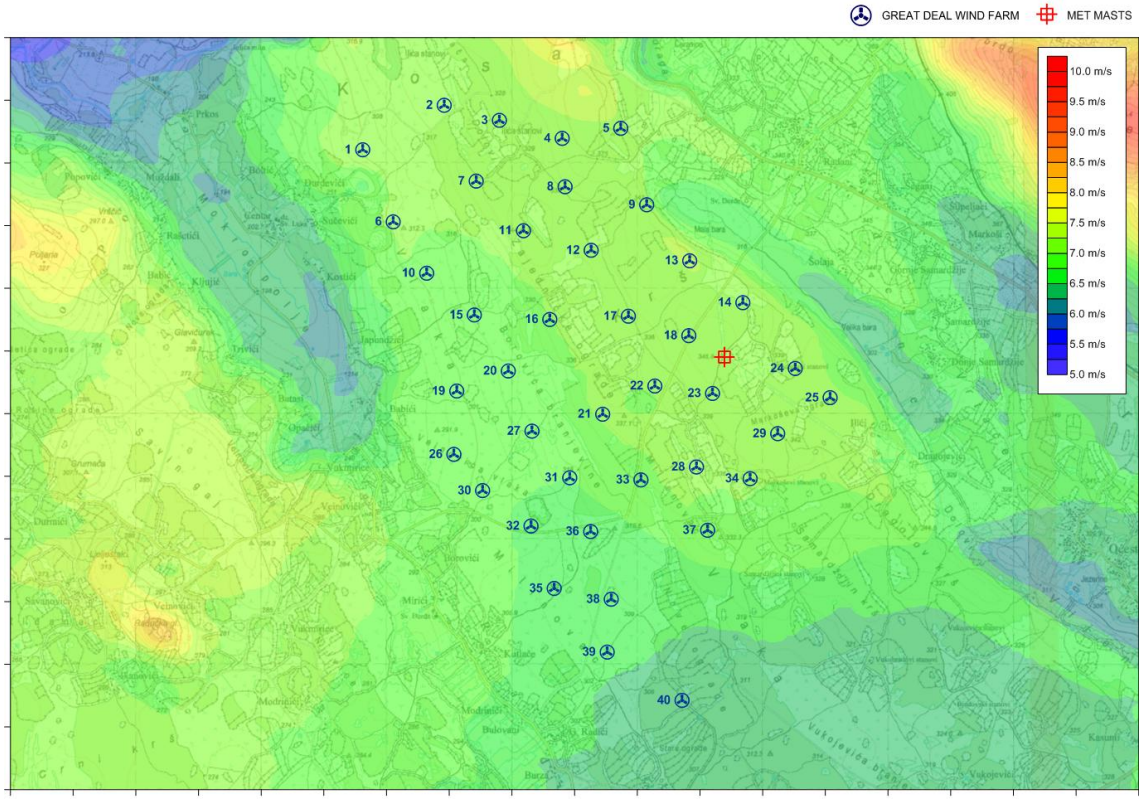
# Great Deal Wind Farm

- 40 x 2 MW = 80 MW
- Total investment R 1 120 million
- Fixed tariff R 0.80/kWh



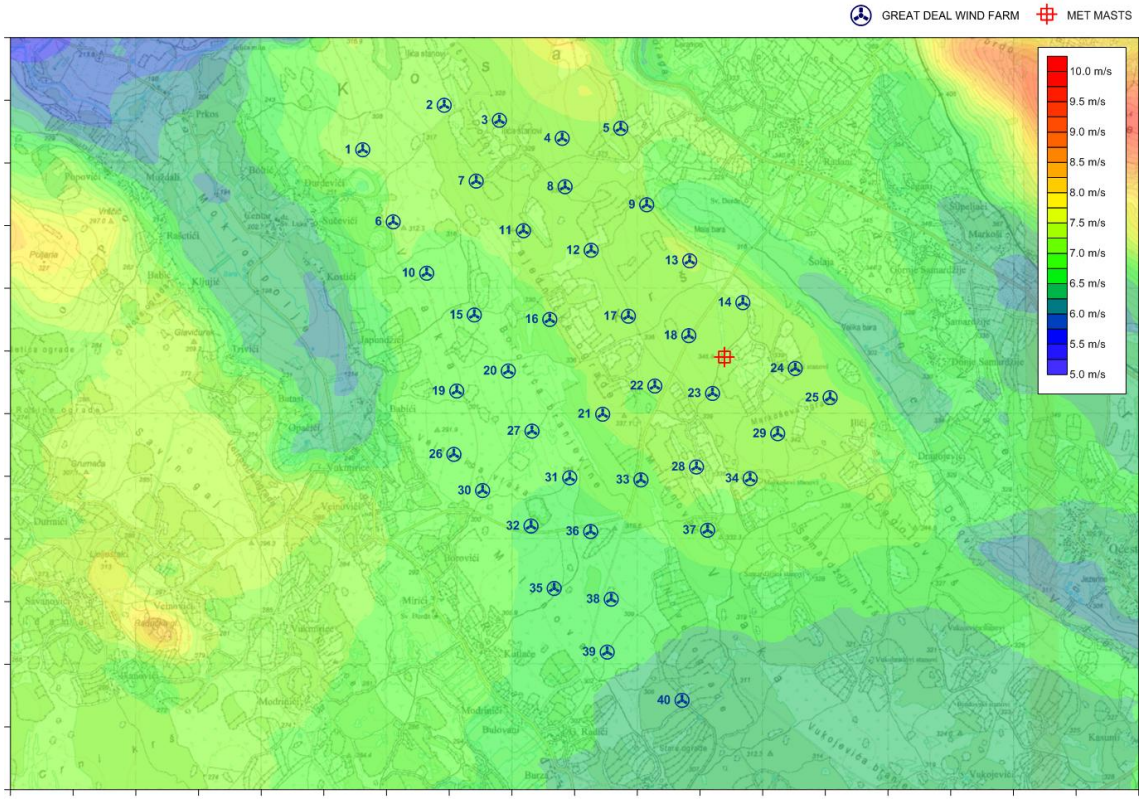
# Great Deal Wind Farm

- Interest rate plus margin – 7.5 %
- 15 year loan
- Finance model case based on P90 and DSCR = 1.2

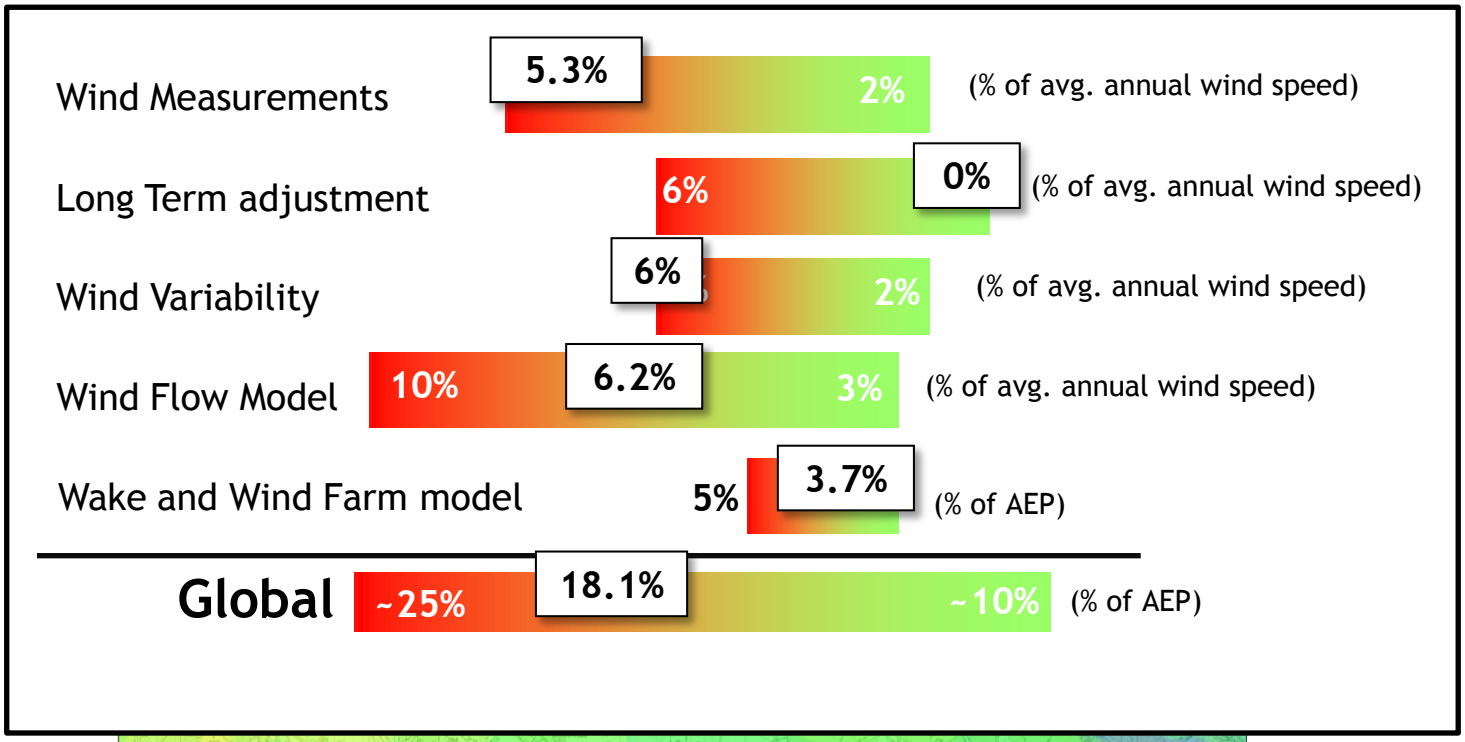


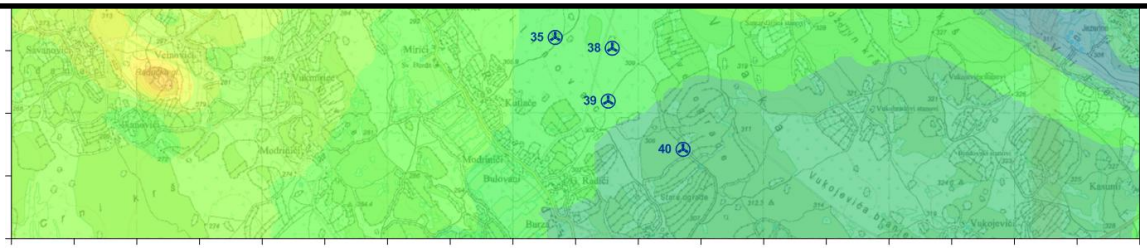
# WRA – Base Case

- 12 months measurements in a poor met. mast measuring lower than hub height
- No adjustment to Long Term
- Flow modeling with WAsP linear model
- AEP P50 = 230.0 GWh/year / 32.8 % CF



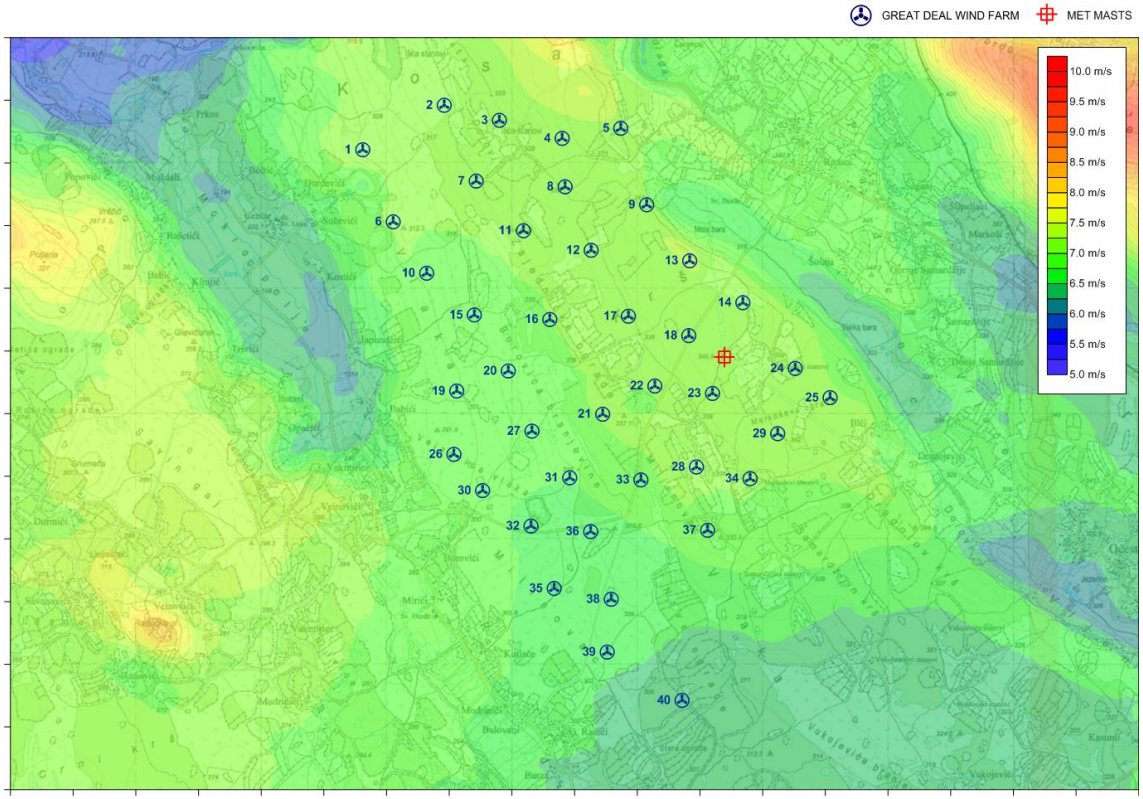
# Uncertainty – Base Case



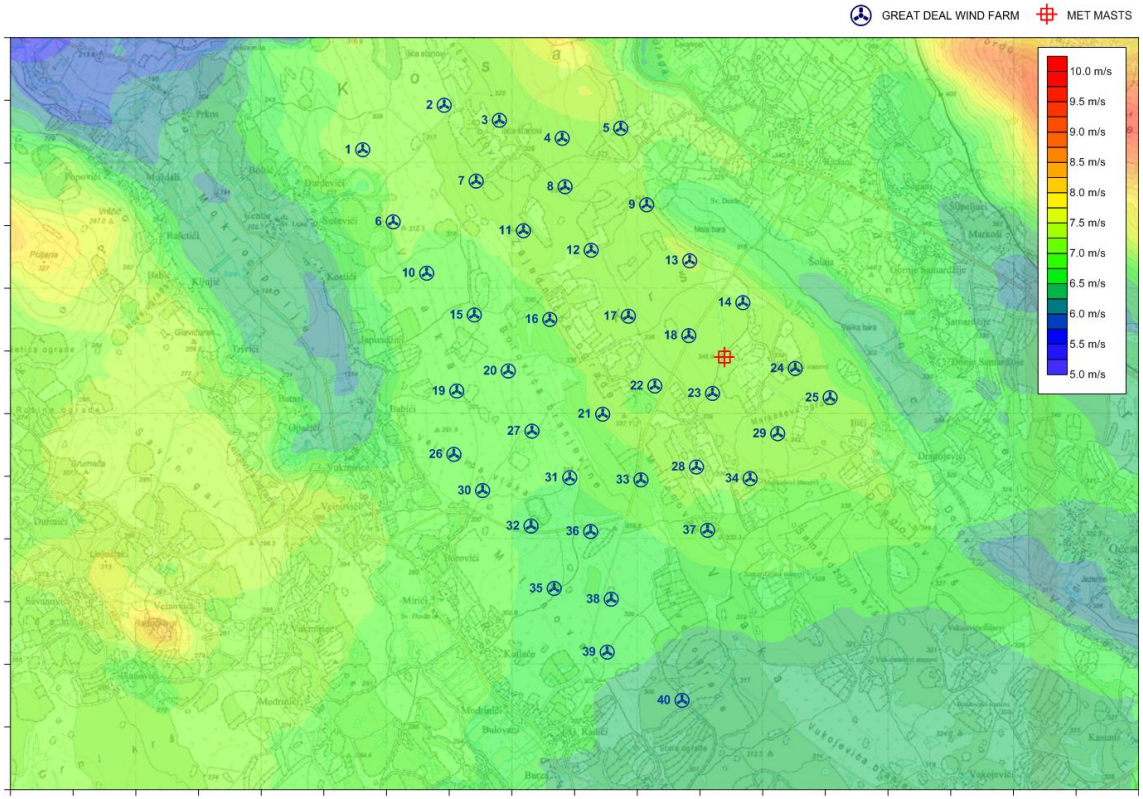
# WRA – Base Case

- **AEP P50 = 230.0 GWh/year / 32.8 % CF**
- **U = 18.1 %**
- **P90 = 176.6 GWh/year (77% P50)**



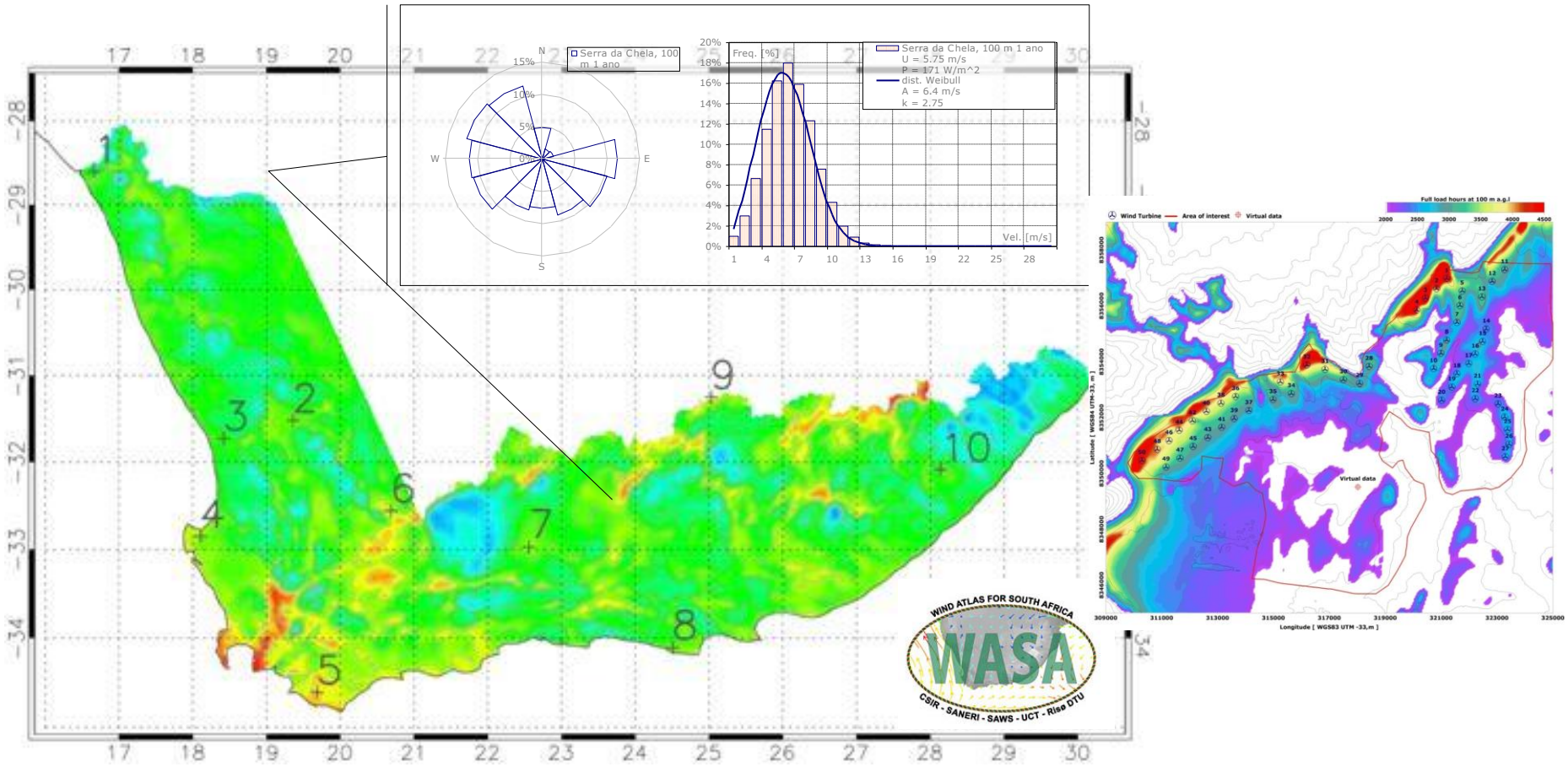
# Project Finance - Base Case

- **Investment = R 1 120 million**
- **Loan = R 900 million**
- **Equity = R 220 million**
- **IRR = ~27 %**



# Going minimal…
# A few thoughts about reliable WRA

# Pre-Feasibility Studies



# Wind Measurements

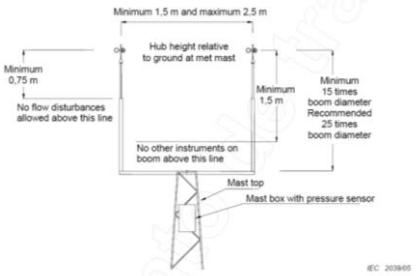
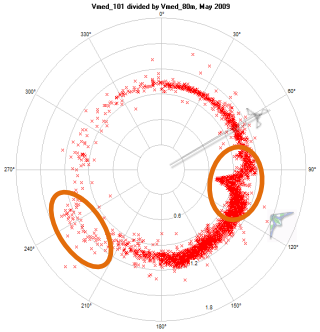
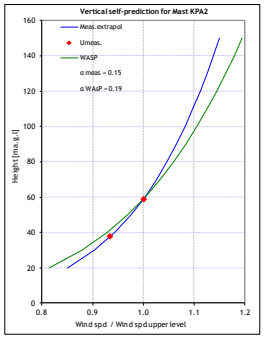
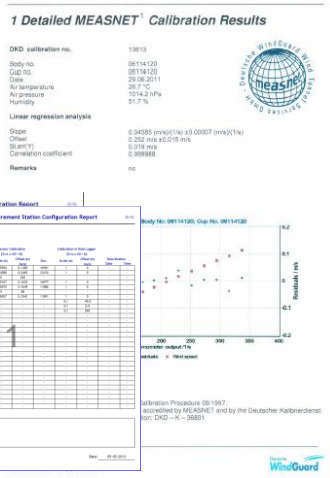



**Figure G.2 – Example of alternative top-mounted primary and control anemometers positioned side-by-side and wind vane and other instruments on the boom**



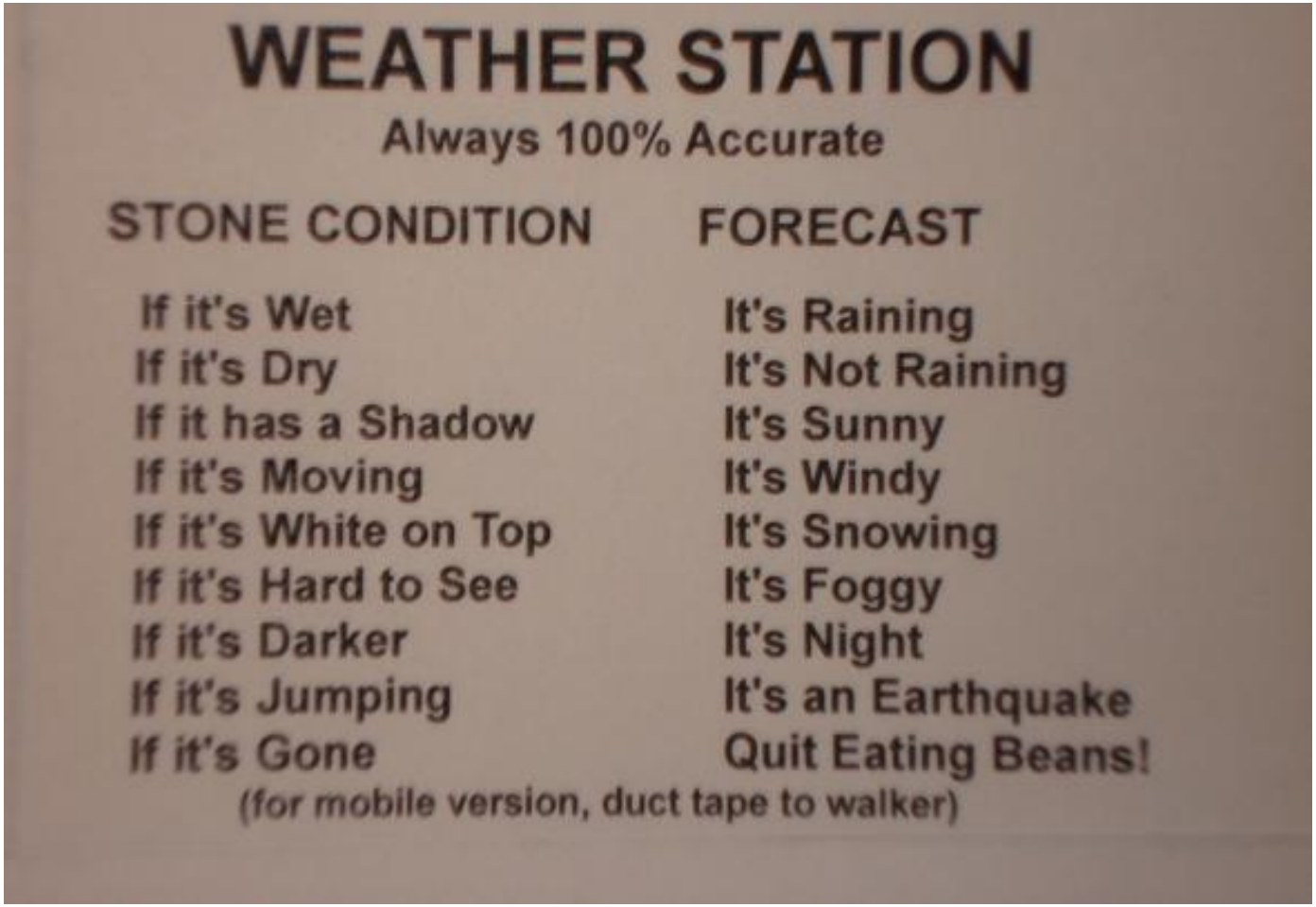





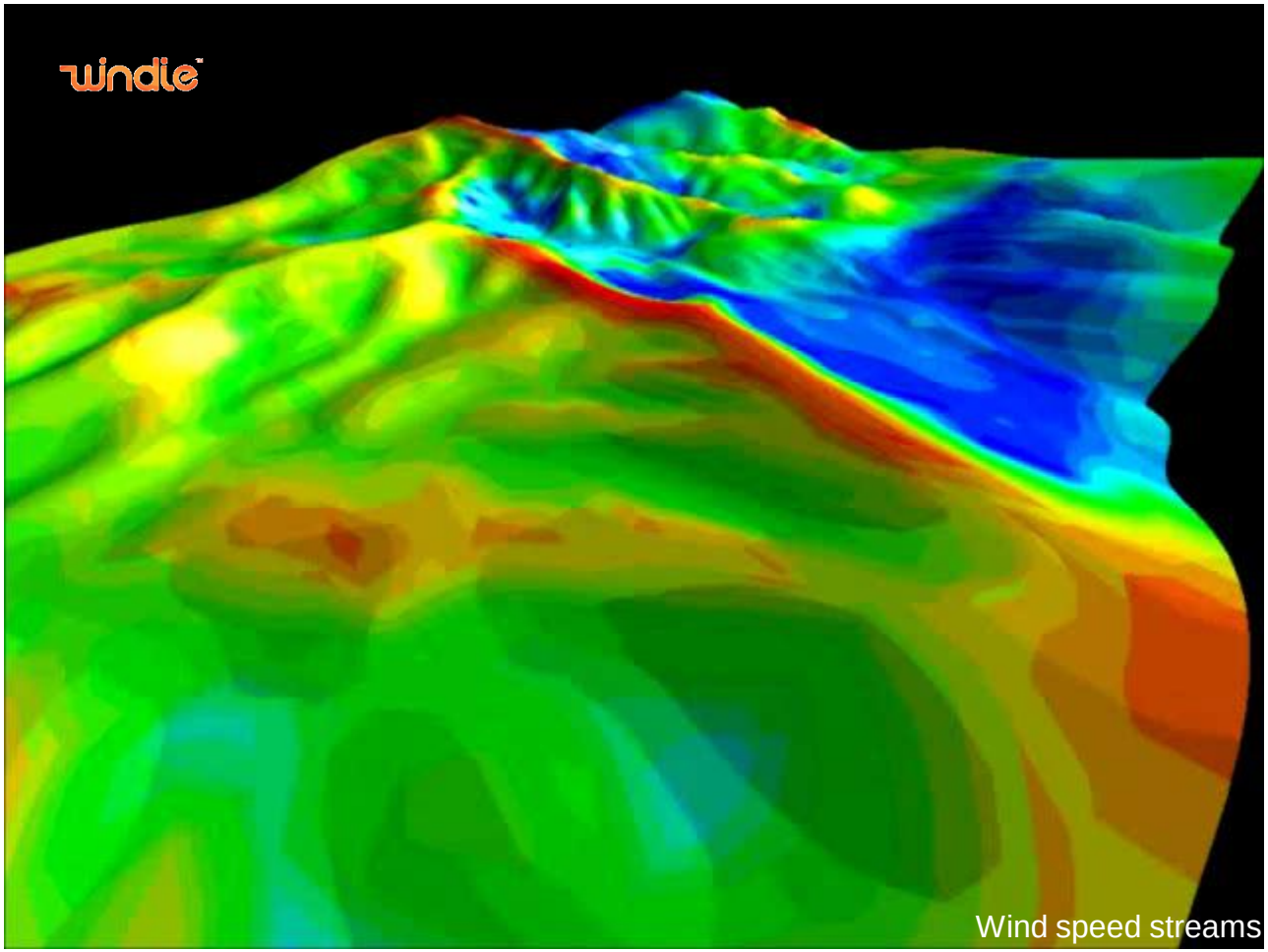


# Remote Sensing

# Long Term adjustment



# Wind Flow Modelling

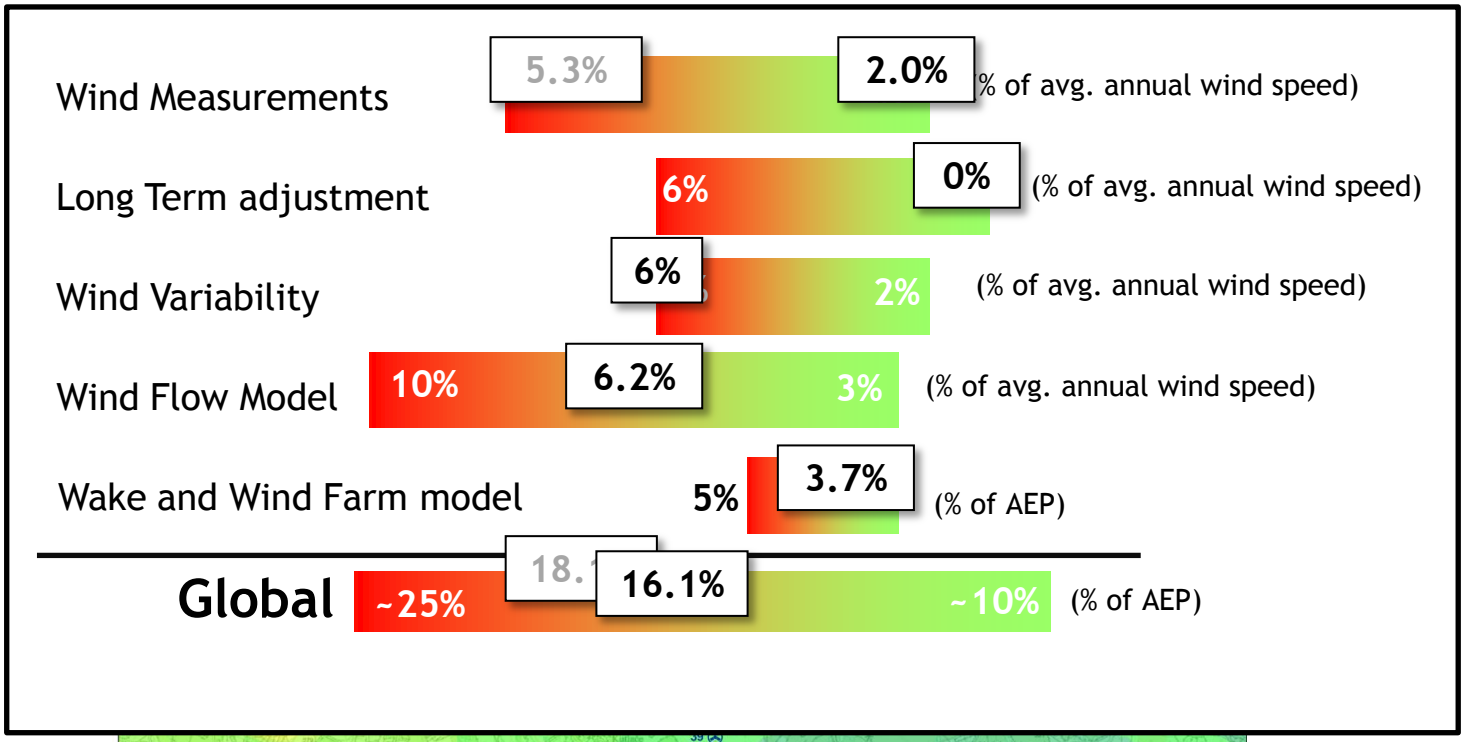


# Ideal vs Real Turbine and Wind Farm performance

# Example - #2

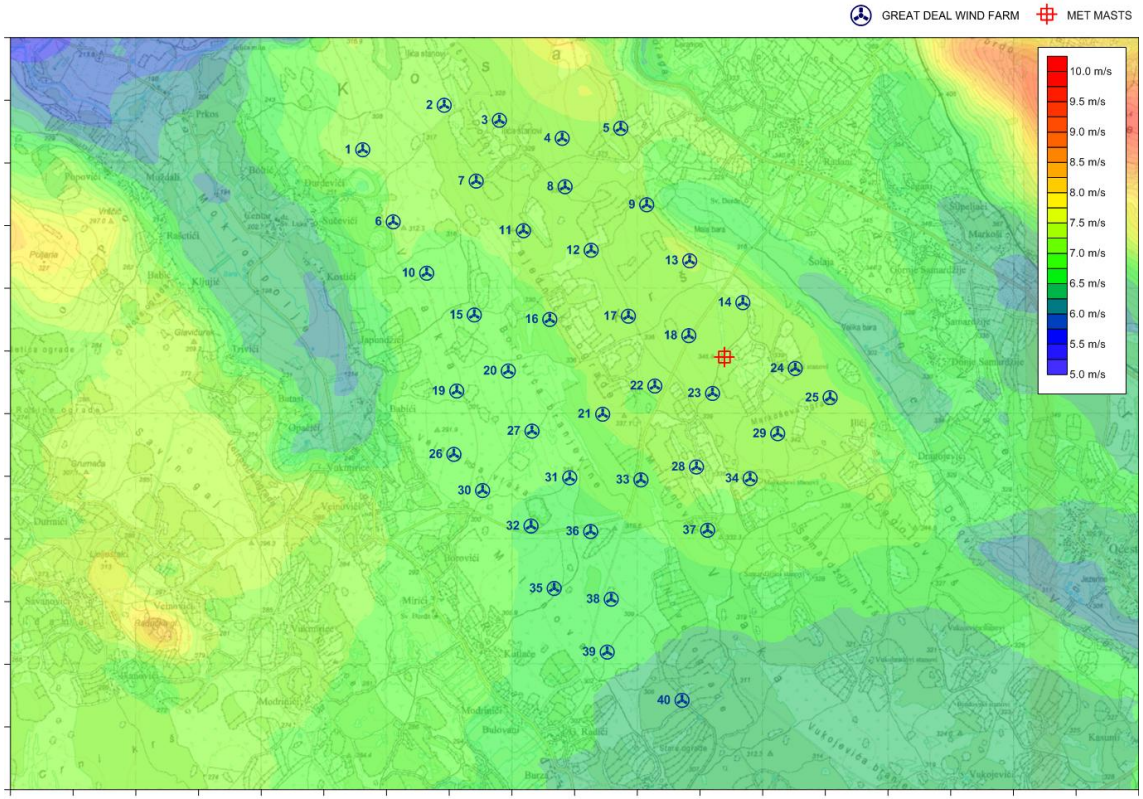
# Uncertainty – Alternative Case 1

- Mast fully compliant with IEC and measuring at hub height for a year



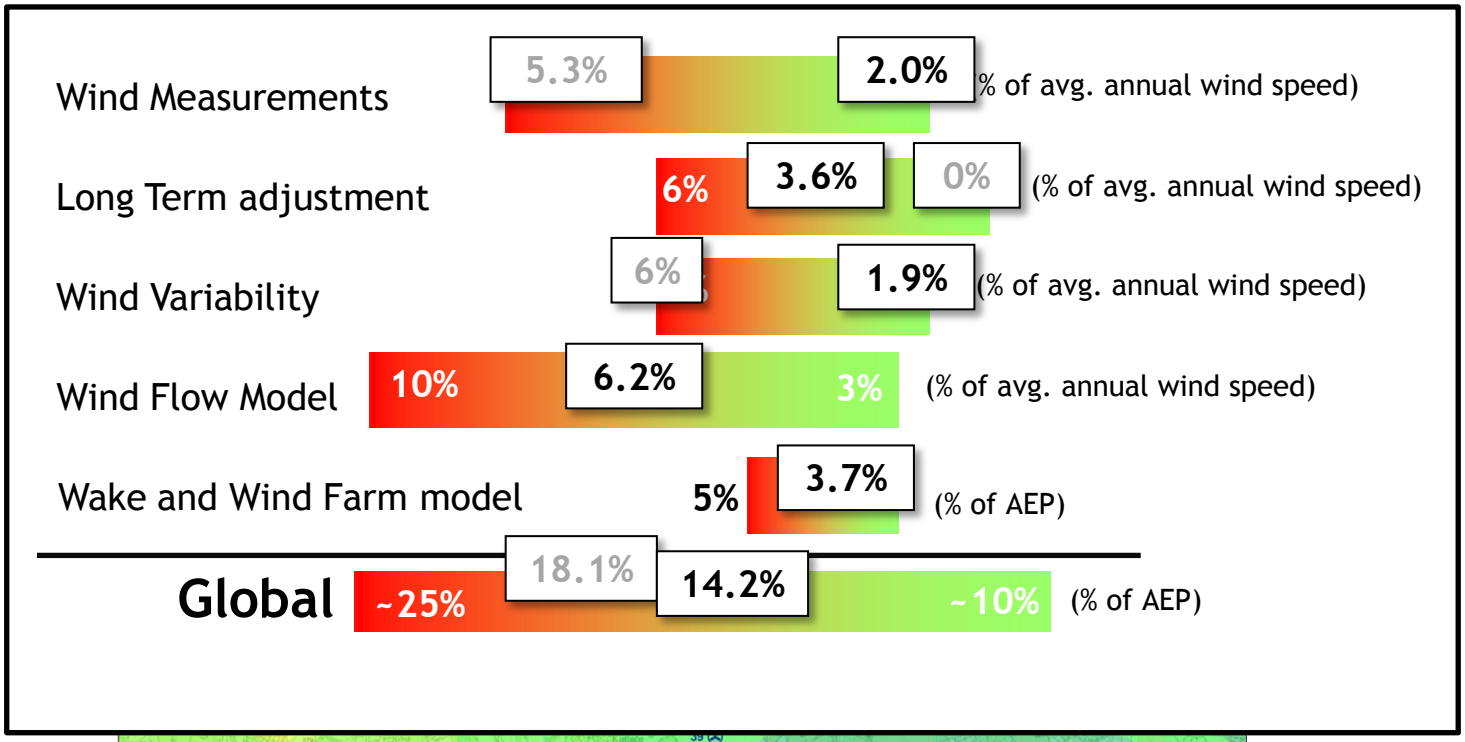
# WRA – Alternative Case 1

- **AEP P50 = 199.6 GWh/year / 28.5 % CF**
- **U = ~~18.1 %~~ 16.1%**
- **P90 = ~~176.6 GWh/year (77% P50)~~ 182.5 GWh/year (79% P50)**



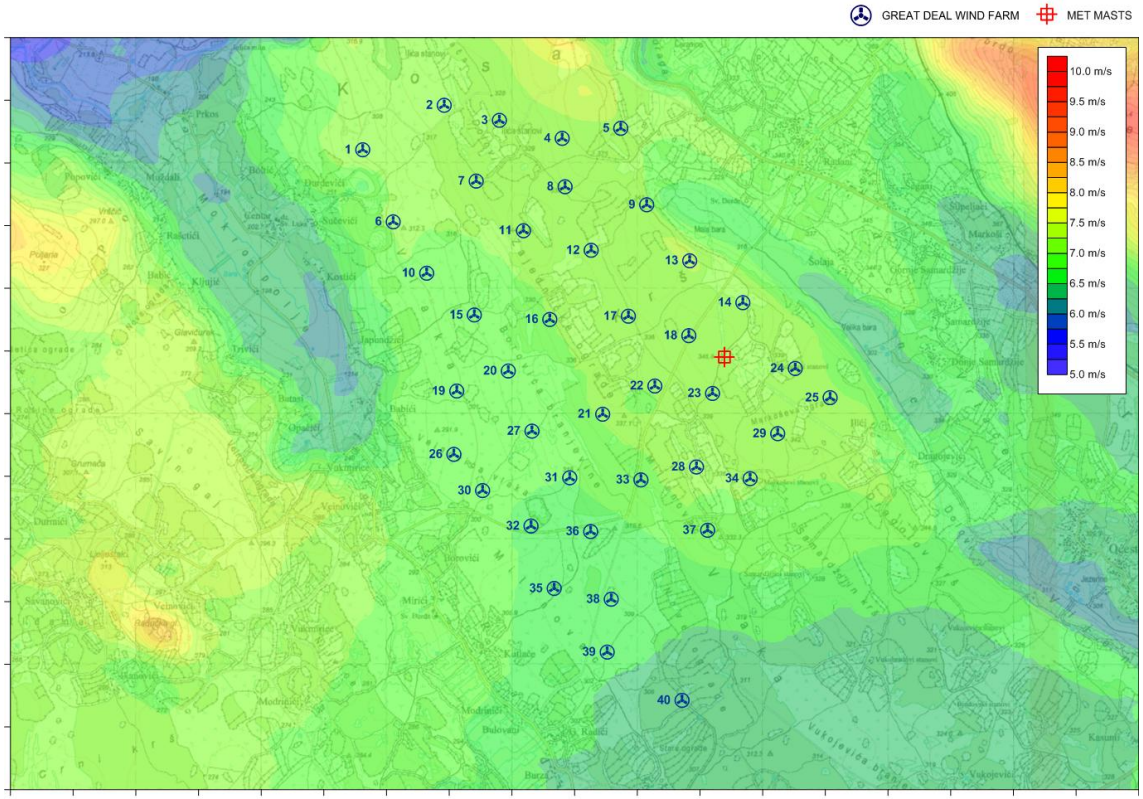
# Uncertainty – Alternative Case 2

- 10 year “Virtual” reference data is used to adjust local measurement to the Long Term



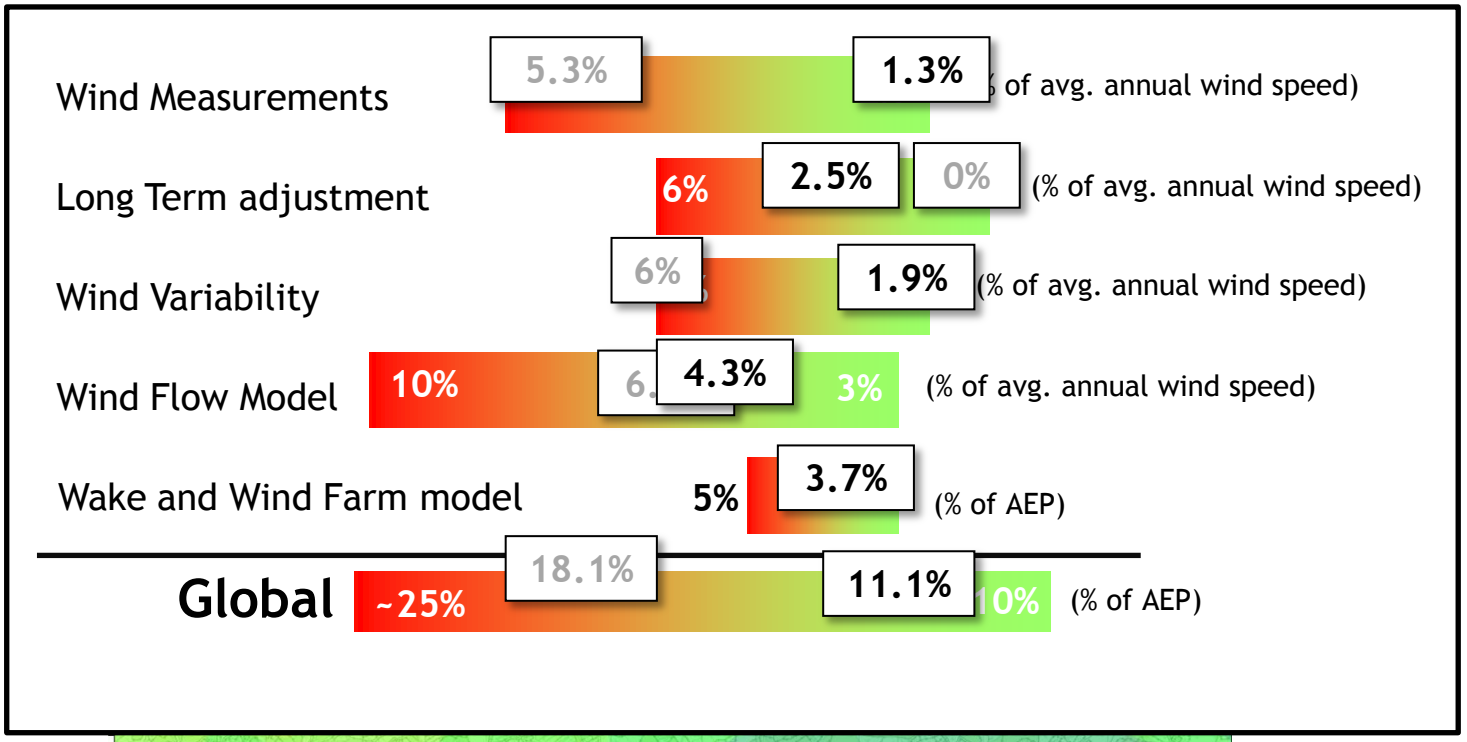
# WRA – Alternative Case 2

- **AEP P50 = 199.6 GWh/year / 28.5 % CF**
- **U = ~~18.1 %~~ 14.2%**
- **P90 = ~~176.6 GWh/year (77% P50)~~ 188.1 GWh/year (82% P50)**



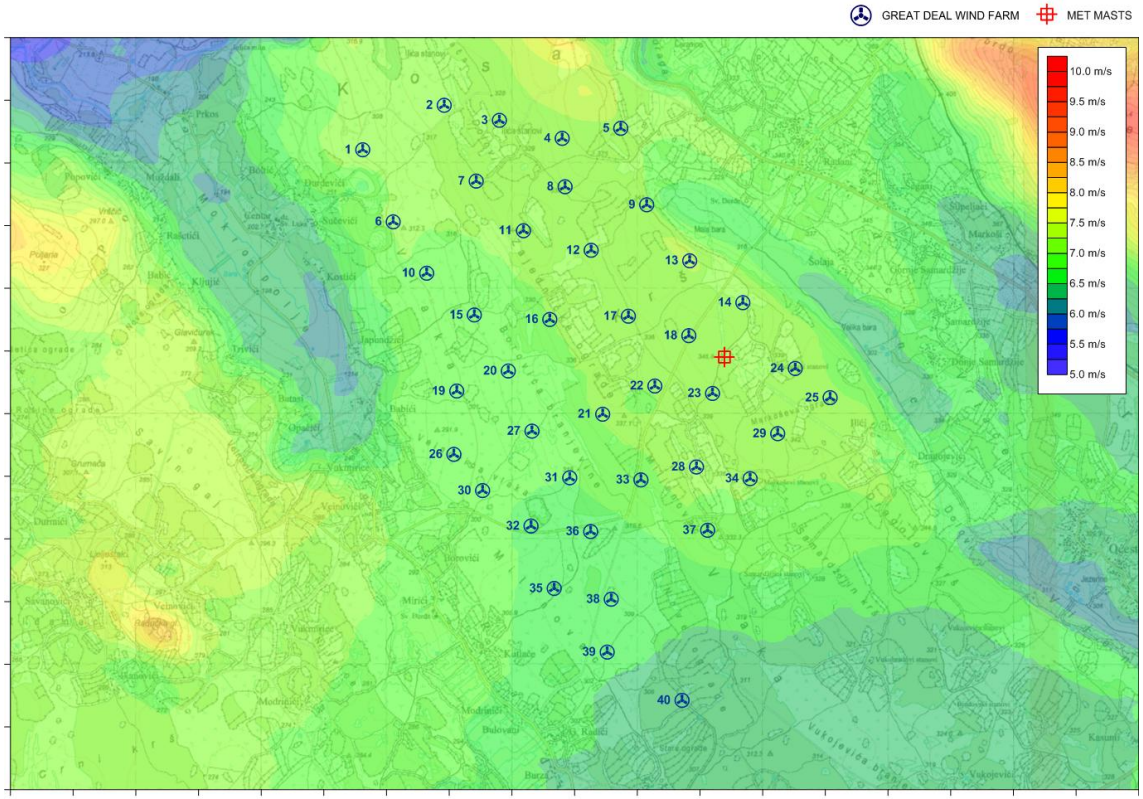
# Uncertainty – Alternative Case 3

- A second mast, equally compliant and at hub height, is installed at the same time



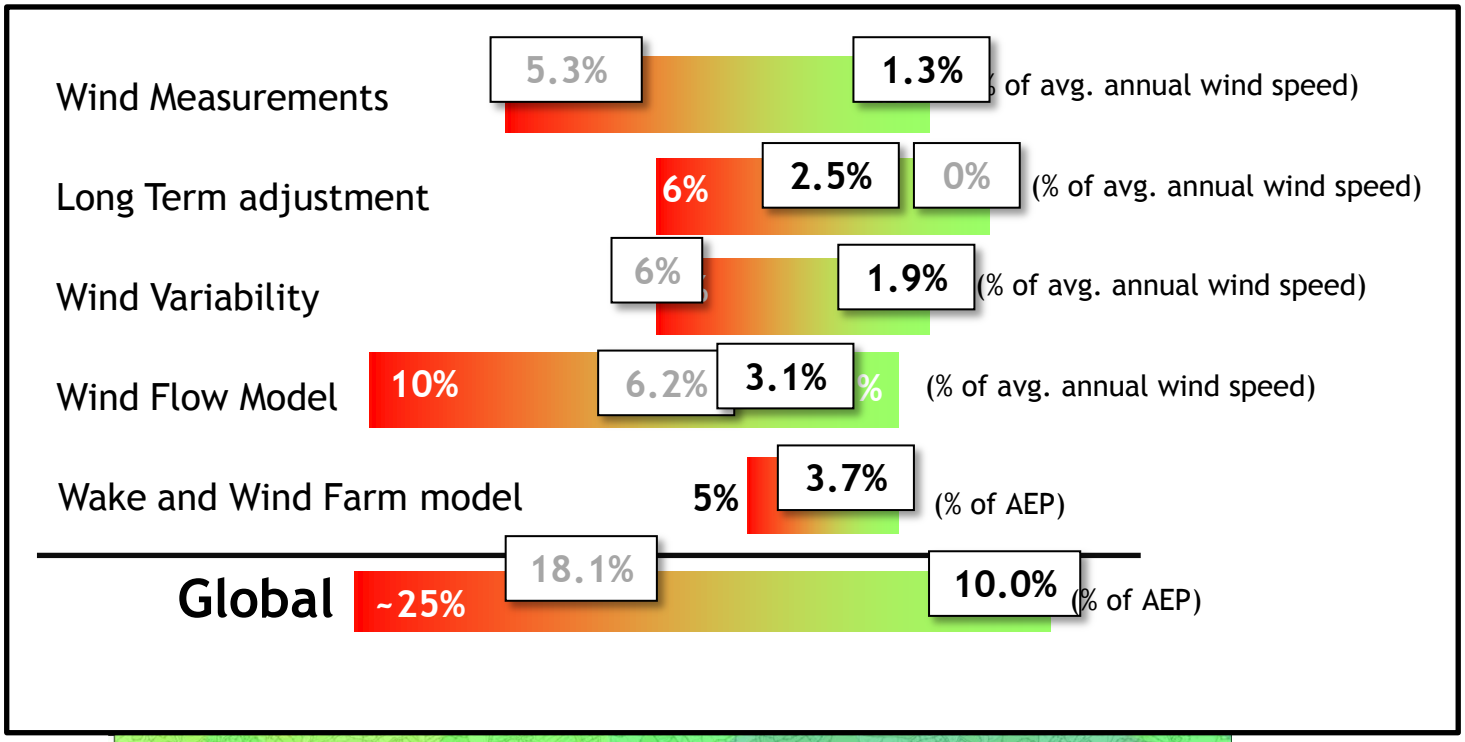
# WRA – Alternative Case 3

- **AEP P50 = 199.6 GWh/year / 28.5 % CF**
- **U = ~~18.1 %~~ 11.1%**
- **P90 = ~~176.6 GWh/year (77% P50)~~ 197.3 GWh/year (86% P50)**



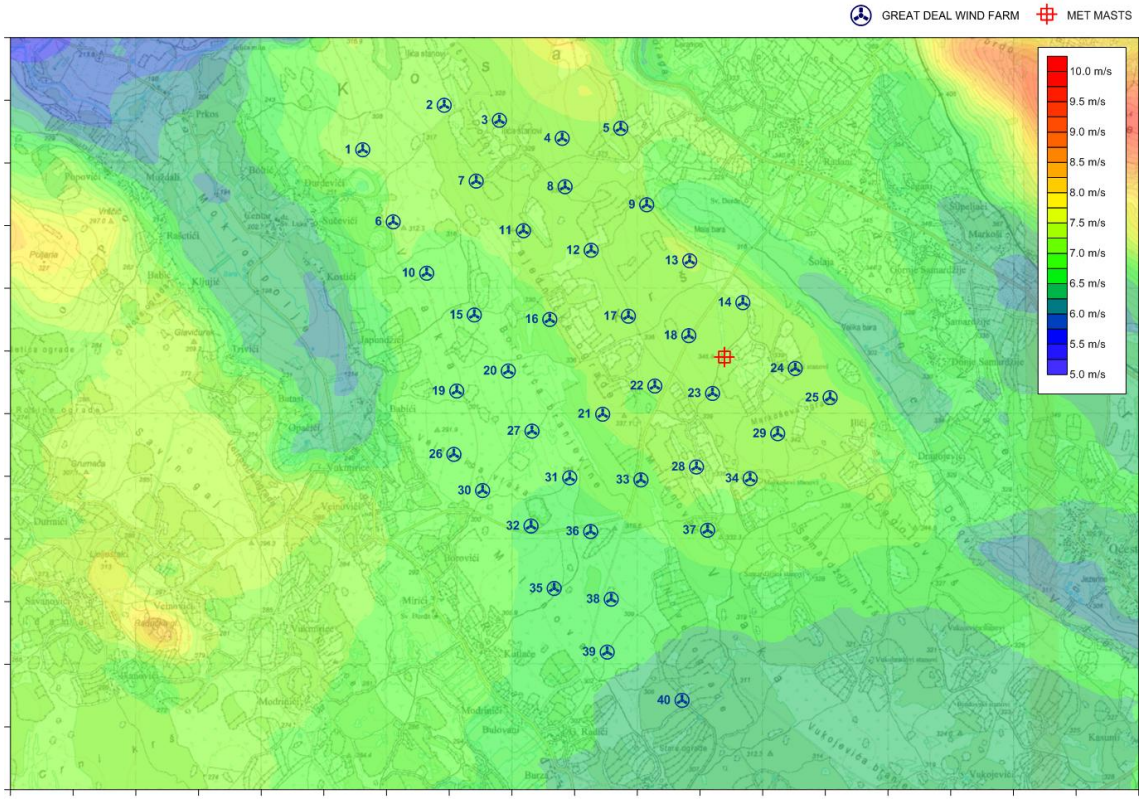
# Uncertainty – Alternative Case 4

- A CFD model is used instead of WAsP

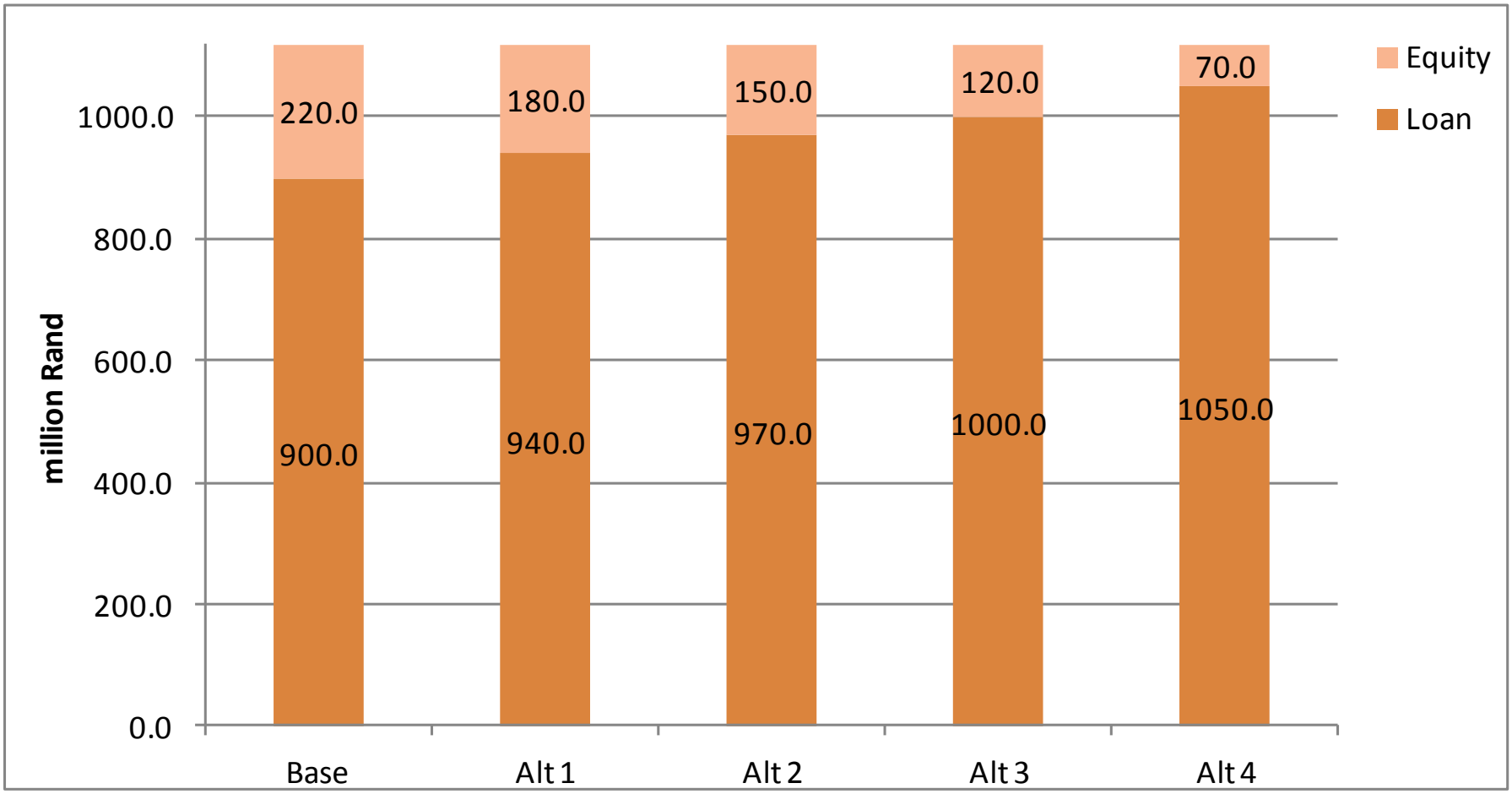


# WRA – Alternative Case 4

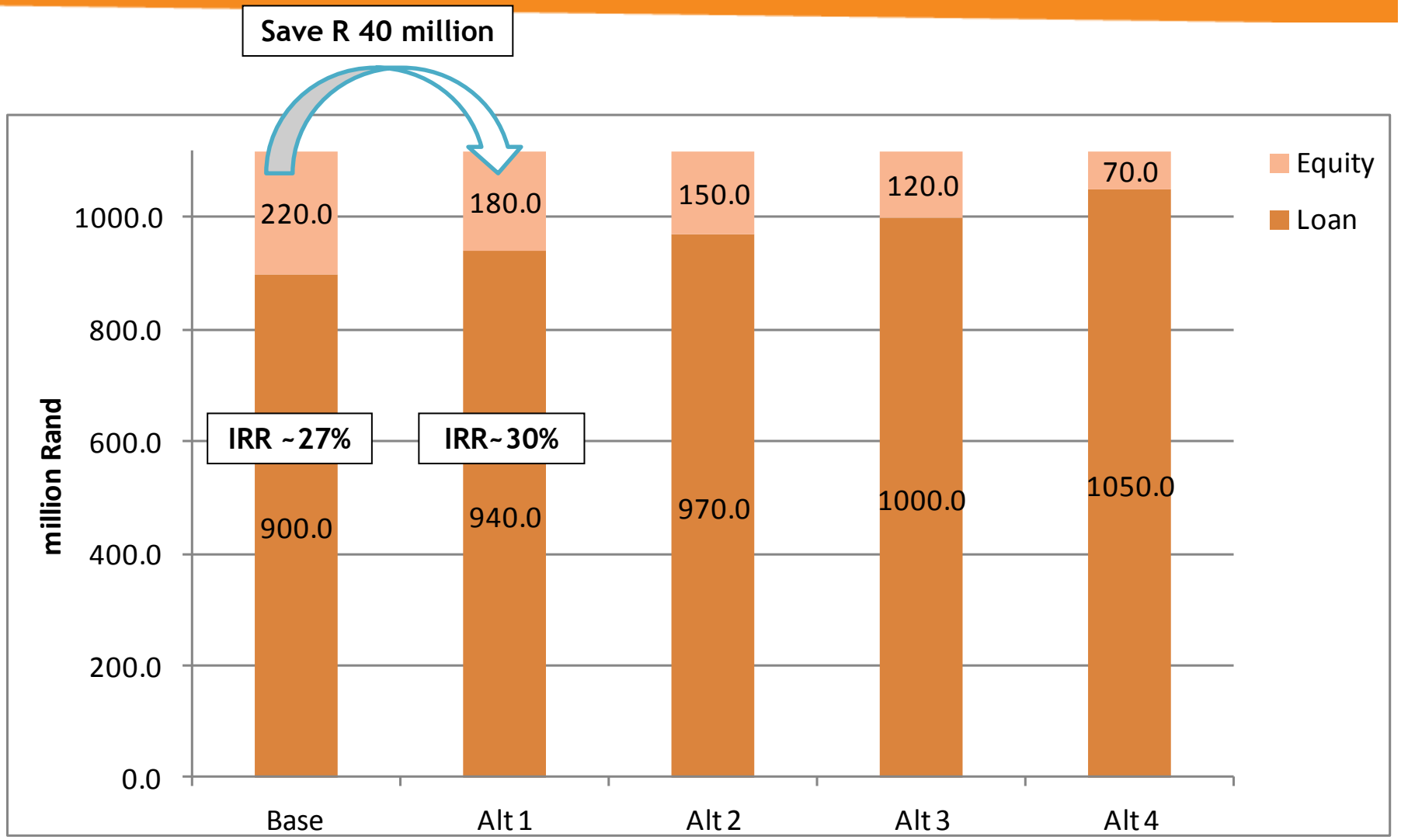
- **AEP P50 = 199.6 GWh/year / 28.5 % CF**
- **U = ~~18.1 %~~ 10.0 %**
- **P90 = ~~176.6 GWh/year (77% P50)~~ 200.8 GWh/year (87% P50)**



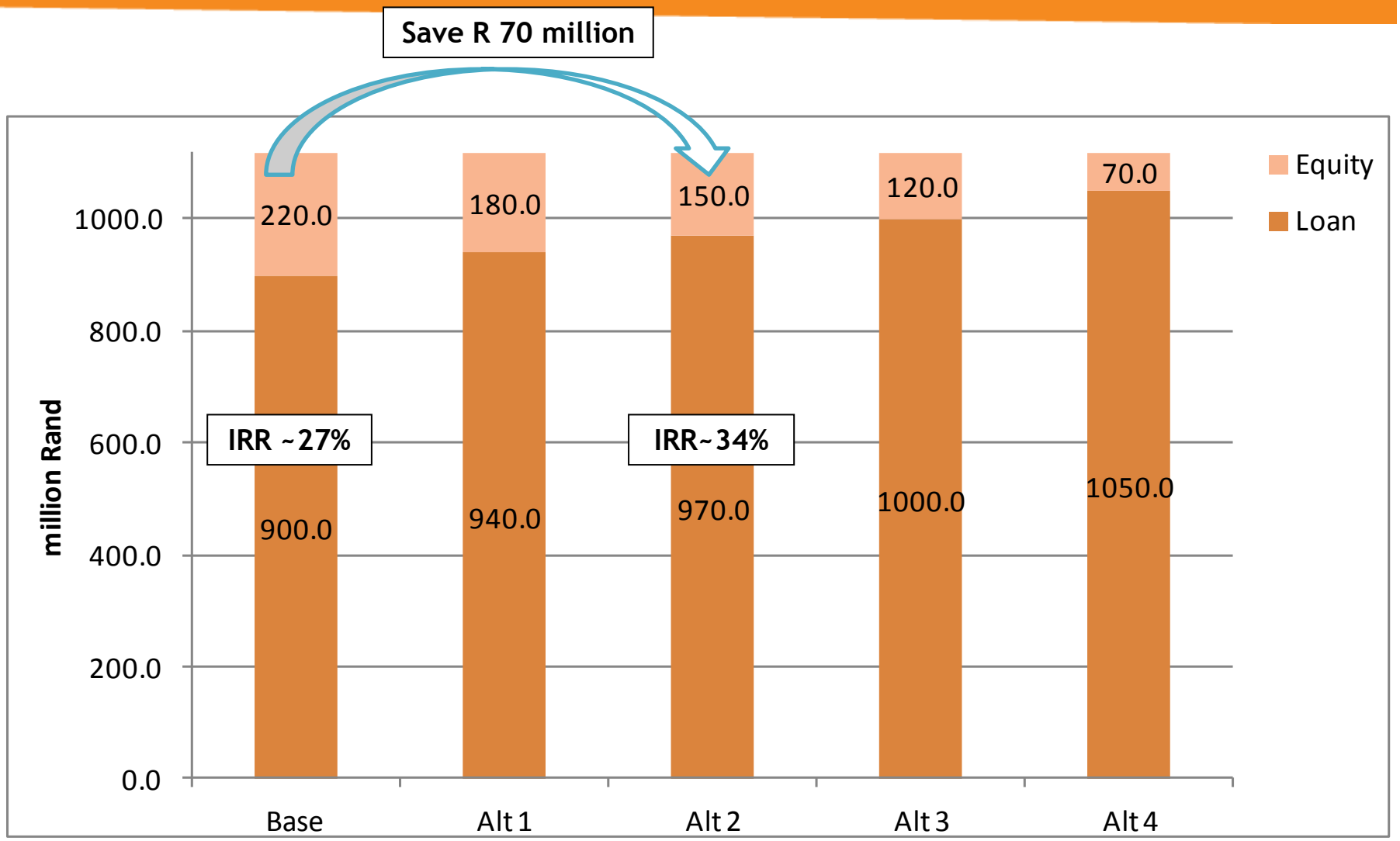
# Impact in finance model



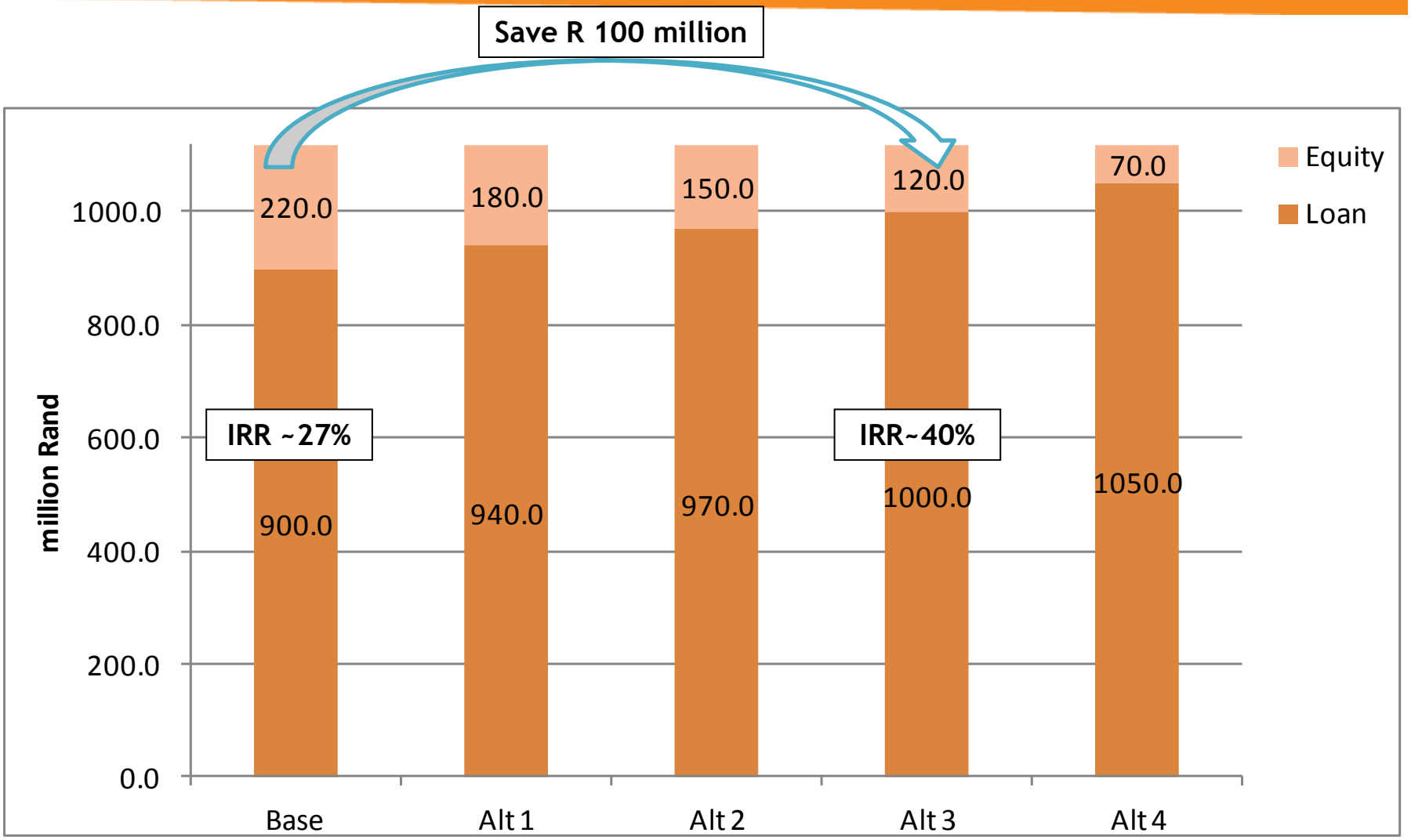
# Impact in finance model



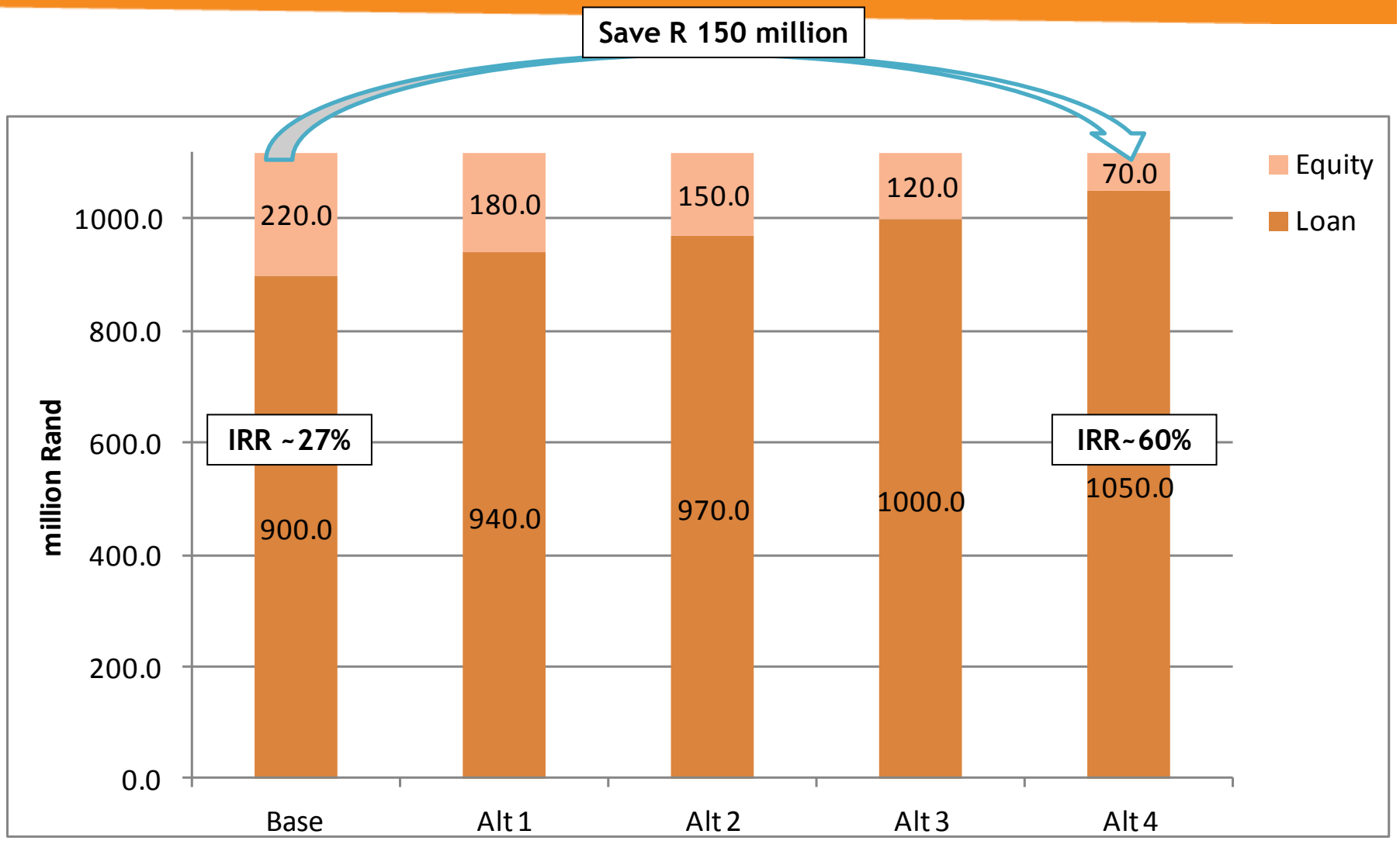
# Impact in finance model



# Impact in finance model



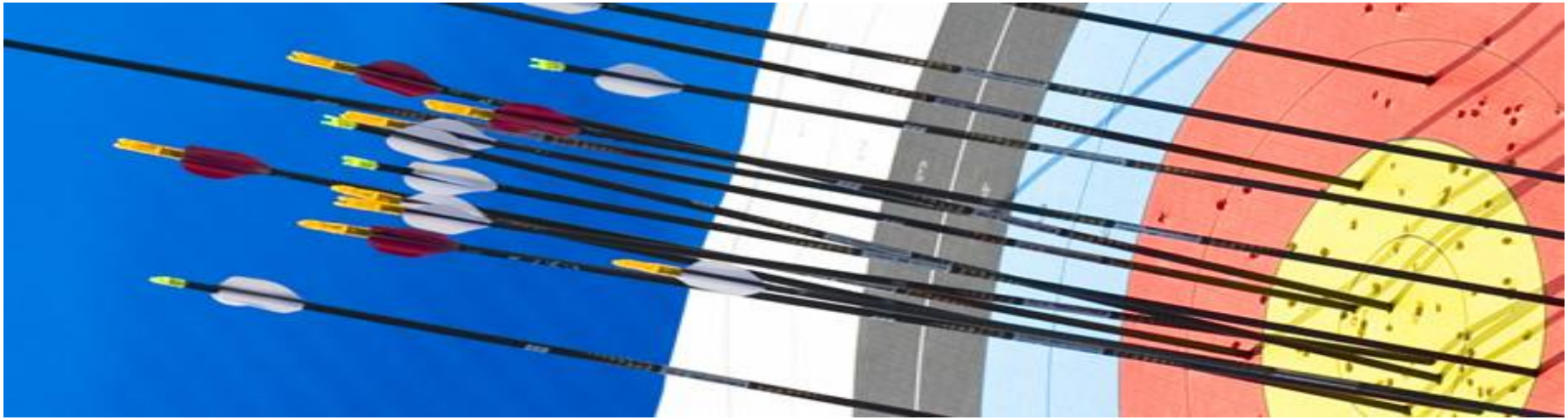
# Impact in finance model



# Conclusions

# We can be certaint that…

- Options made in WRA setup WILL shape future uncertainty associated with the wind project
- Uncertainty in WRA WILL have an impact on the project financial model
- Most of the investment in WRA WILL pay off later



# *Thank you !*

*(ricardo.guedes@megajoule.pt)*

MEGAJOULE

*Rethinking Energy Worldwide*

Portugal Brazil Poland Romania Turkey Croatia South Africa

www.megajoule.pt