WIND RESOURCES & ASSESSMENT TECHNIQUES

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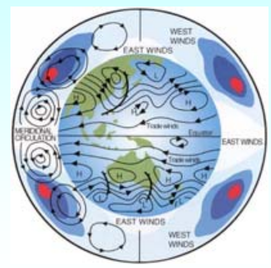
WIND RESOURCES & ASSESSMENT TECHNIQUES

What Causes Wind?

- Uneven heating of the earth's surface- PGF
- Earth's rotation- Coriolis force
- Local influences – sea breezes, slope winds, channeling through valleys, etc.



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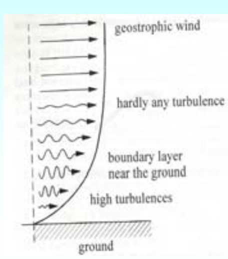
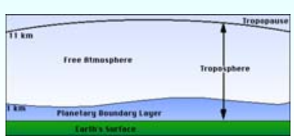
- Winds in PBL





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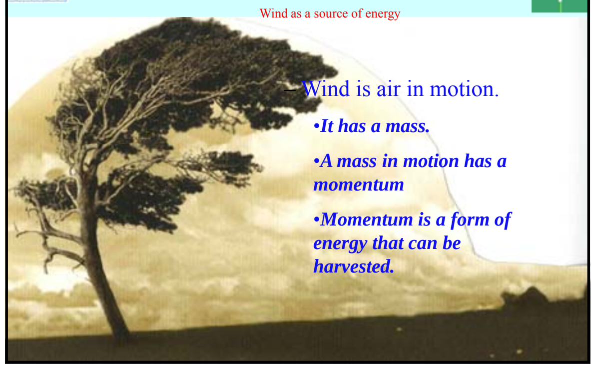
Wind as a source of energy



Wind is air in motion.

- ***It has a mass.***
- ***A mass in motion has a momentum***
- ***Momentum is a form of energy that can be harvested.***

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Wind Resources

The wind over a region can be considered as a resource similar to the "fossil fuel" resource beneath the earth's surface.

But unlike fossil fuel, the wind resource varies with time of day , season of year, and even to some extent from year to year.

Though it is inconsistent, human being started utilizing wind as a power source for hundreds of years.

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WIND AS A POWER

$KE = \frac{1}{2} m u^2$

$\dot{m} = \rho A u$

$P = \frac{1}{2} \rho A u * u^2$

$P = \frac{1}{2} \rho A u^3$.

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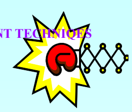
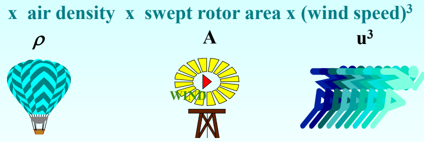


Power in the Wind (W/m²)

= 1/2 x air density x swept rotor area x (wind speed)³



Density = P/(RxT)	Area = π r²	Instantaneous Speed (not mean speed)
P - pressure (Pa) R - specific gas constant (287 J/kgK) T - air temperature (K)		
kg/m³	m²	m/s

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Wind resource assessment technique can include any or all of the following elements.

- **Large area Screening & Field visits.**
- **Wind measurements & Data Analysis**
- **Micro Survey & Micrositing.**

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- ***Large area Screening***
- large-area screening usually begins with a review of
  - existing wind resource maps,
  - data and other meteorological information (pressure, temperature etc.)
  - analysis of the climatology of the region along with the topographical maps (such as terrain form, land use and land cover, and other logistics like accessibility, grid availability etc.).

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- ***Field visits***
- To look for physical evidence to support the wind resource estimate developed in the large-area screening.
- Another purpose of the site visit is to select a possible location for a wind monitoring station. *Consistently bent trees and vegetation, for example, are a sure sign of strong winds.*

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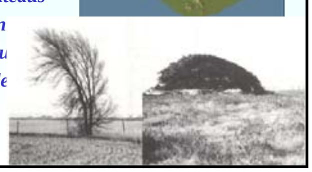
•Field visits

- *Indicators of Good Wind Topography*
- *Gap, passes , gorges and long valleys*
- *High elevation plains and plateaus*
- *Exposed ridges and mountain*
- *Wind deformed trees and shru*
- *Sand dunes and other wind de*



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- ***Wind Measurements***
- ***A wind measurement program provides data to improve wind resource assessments and to increase confidence in site evaluation. This includes precise information on wind speed, direction, standard deviation and also temperature and pressure details***

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- ***Wind Measurement Program duration***
- **The wind speed measurement period at the location must be long enough to cover all meteorological conditions in that region with a sufficient amount of data. Measuring over a period of one year can usually attain this. . To be sure of this around 2-5 years data is needed.**
- **Data Analysis**

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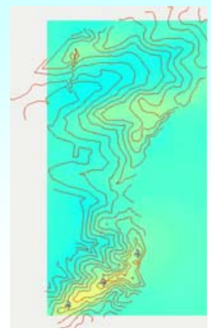
- **MICRO SURVEY & MICROSITING**
- **The most advanced stage of a wind resource assessment program is micrositing.**
- **This process involves conducting surveys and monitoring at individual sites to quantify the small-scale variations in the wind resource over the area.**
- **In complex terrain, micrositing may involve numerous wind speed measurements combined with computer modeling to predict speeds in areas where no measurements are taken.**
- **Once completed, the results of the micrositing survey are used to position the wind turbines in a wind power plant to maximize their energy output.**



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- **MODELING TECHNIQUE**
- **Physical Modeling**
- **Numerical Modeling**
  - **Macro Scale Modeling**
  - **Meso**
  - **Micro**

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Micro Scale Models predict accurate values, provided

- **Reference site and predicted site are in the same overall weather regime (climatology)**
- **Reference wind data are reliable**
- **Surrounding terrain (of both sites) is sufficiently gentle slope (below 17^{o}) and smooth to ensure mostly attached flows**
- **Topographical model inputs are adequate and reliable (roughness, orography and obstacle)**

- **Why Statistics ?**

- **Wind varies with the time of day, season, height above ground, and type of terrain .**
- **Instantaneous values of wind speed & direction can't give an exact idea**
- **So the best option is to describe the wind by statistical methods**

Mean Wind Speed & Standard Deviation

$$\bar{u} = \frac{1}{n}\sum_{i=1}^{n} u_i$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(u_i - \bar{u}\right)^2}$$

Turbulence Intensity

➢**The variations of the wind speed are generally called as gushiness and**
➢**it can be expressed in terms of the standard deviation σ_u of speed fluctuation measured over 10 to 60 minutes normalized by the frictional velocity or by the wind speed.**

This ratio is also called as turbulence intensity ie.,

$$I_u = (\sigma_u / u)$$

Time distribution

------------------------------ Data Information ----------------------------

Spd1	SD1	Dir1	Spd2	SD2	Dir2	Spd3	SD3	Anlg	Gust1	Time	Date
8.38	1.07	343	12.39	1.01	89	14.68	1.28	0	12	0000	020102
8.01	1.01	343	11.53	1.01	87	13.29	1.01	0	11	0100	020102
7.74	0.91	343	11.42	1.01	90	13.35	1.17	0	10	0200	020102
6.35	1.07	343	9.56	1.28	89	11.53	1.39	0	9	0300	020102
6.78	1.71	343	10.89	2.30	100	12.87	2.56	0	13	0400	020102
7.58	1.28	343	12.28	1.17	111	14.57	1.07	0	12	0500	020102
5.98	1.28	343	10.57	1.39	115	14.15	1.12	0	11	0600	020102
7.26	1.44	345	10.84	1.49	127	13.77	1.28	0	12	0700	020102
9.02	2.03	345	11.26	2.08	129	12.97	1.76	0	15	0800	020102
10.46	2.19	345	12.33	2.08	131	13.24	1.87	0	17	0900	020102
10.14	1.98	345	11.48	1.82	124	12.12	1.76	0	16	1000	020102

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Joint Frequency Distribution

Wind Speek mphd	N	NE	E	SE	S	SW	W	NW
8.00	79	296	249	20	57	244	24	11
9.00	93	348	293	23	67	286	28	13
10.00	79	296	250	20	57	244	24	11
11.00	13	122	88	4	31	497	18	1
12.00	11	103	75	4	26	418	15	1
13.00	10	92	67	3	23	375	14	1
14.00	2	14	3	0	13	496	18	0
15.00	2	13	3	0	13	471	17	0
16.00	2	12	3	0	12	433	16	0
17.00	1	2	0	0	7	358	15	0
18.00	1	1	0	0	5	254	10	0
19.00	0	1	0	0	3	173	7	0
20.00	0	1	0	0	2	105	4	0

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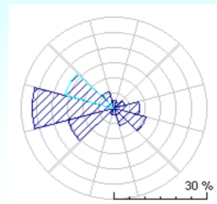
Wind Rose

Wind rose is a diagram that indicates frequency of occurrence of winds shown in each direction sectors and different wind speed classes for a given location for a given time. A wind rose diagram and numerical representation in table form are given below



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- PROBABILITY DENSITY FUNCTION

❑ ***Wind values change continuously***

❑ ***So it is better to model the wind speed frequency curve by a continuous mathematical function rather than a discrete values***

❑ ***When we do this, the probability values p(u) become a density function f(u)***
❑ ***The density function f(u) represents the probability that the wind speed is in a 1 m/s interval centered on u***

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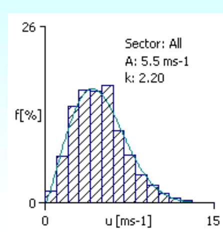
- Histogram & Corresponding Weibull distribution



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- PROBABILITY DENSITY FUNCTION

There are several density functions that can be used to describe the wind speed frequency curve.

The three most common are

1. **Gaussian (Normal) distribution**
2. **Rayleigh distribution and**
3. **Weibull distribution**

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Gaussian Distribution

$$f(u) = 1/\sigma\sqrt{2\pi}\ \exp\left[-\frac{(u-\bar{u})^2}{2\sigma^2}\right]$$

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Rayleigh Distribution

$$f(u) = \pi u/2\bar{u}^2\ \exp\left[-\pi/4\left(\frac{u}{\bar{u}}\right)^2\right]$$

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Weibull Distribution

$$f(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1}\exp\left(-\left(\frac{u}{c}\right)^k\right)$$

Where

u is the wind speed

c is the scale parameter with units of speed

k is the shape parameter and is dimensionless

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Wind Resources

Topographic Effects on Wind

The effects of the topography can be divided into three typical categories.

Roughness : The collective effect of the terrain surface and its roughness elements, leading to an overall retardation of the wind near the ground, is referred to as the roughness of the terrain.

Obstacle: Close to an obstacle, such as a building or shelterbelt, the wind is strongly influenced by the presence of the obstacle, which may reduce the wind speed considerably

Orography: When the typical scale of the terrain features becomes much larger than the height of the points of interest they act as a orographic elements to the wind. , Near the summit or the crest of hills, cliffs, ridges and escarpments, the wind accelerate while near the foot and valley it will decelerate..

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Wind Profiles

❖ **Wind shear is the variation of wind speed with height.**

❖ **The rate of increase with height strongly depends upon the roughness of the terrain and the changes in this roughness.**

❖ **The variation also depends on the atmospheric stability conditions.**

❖ **Even within the course of 24 hours, the wind profile will change between day and night, dawn and dusk**

❖ **This can be described by the so called logarithmic wind profile with stability correction**

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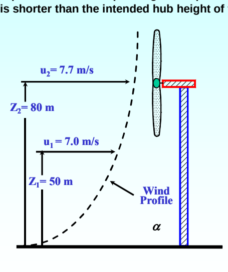
Wind Shear

Wind Shear is important when extrapolating wind speed data from a met. mast that is shorter than the intended hub height of the turbine



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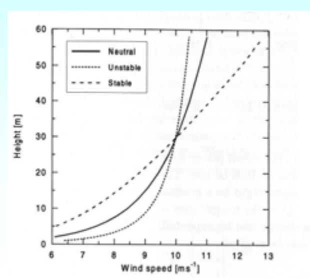
Wind profiles for neutral, stable and unstable conditions



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LOGARITHMIC EQUATION

$$u(z) = \frac{u_x}{k}\left(\ln\frac{z}{z_0} - \psi\right)$$

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- Monin-Obukhov length

$$L = -\frac{\rho C_p T u_*^3}{kgH}$$

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Logarithmic velocity profile

Neutral surface layer over a flat and homogeneous surface

$$\frac{\bar{u}}{u_*} = \frac{1}{\kappa}\ln\frac{z}{z_0}$$

Logarithmic velocity profile, which is valid for $z > h_0 >> z_0$ (*i.e.* wind measurements should be made at greater than 7 z_0 but less than ~100 m)

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Power law equation

$$\frac{u_{z1}}{u_{z2}} = \left(\frac{z_1}{z_2}\right)^{\alpha}$$

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What is Roughness length ?

Roughness length is a parameter **that is a measure of terrain roughness as "seen by" surface wind. It is the height at which the logarithimic wind profile is zero. This parameter represents the bulk effects of roughness elements in the surface layer.**

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ROUGHNESS LENGTH & POWER LAW INDEX

Zo m	Terrain surface characteristics	R Class	α
1.00	City,forest	4	0.32
0.5	suburbs	3	0.19
0.30	Shelter belts		
0.2	Many trees/bushes	2	
0.1	Farm -closed appearance-		
0.05	Farm - oppen	1	
0.03	Farm- with few buildings, trees, Airport areas with buildings		
0.01	Airport runways, mown grass		0.13
0.005-001	Bare soil, Snow surface		0.10
0.0003	Sand surface -smooth	0	
0.0001	Water areas, open sea		

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ROUGHNESS LENGTH & POWER LAW INDEX

- The variation of the exponent with surface roughness is given approximately by

$$Zo = 15.25 \exp(-1/\alpha)$$

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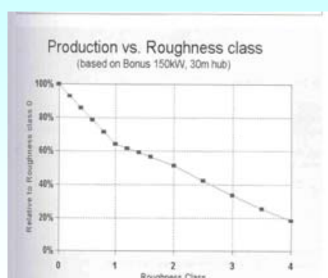

In areas with hedges, following figure can be used to estimate the Roughness Class/length.

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Effects of air density on the Energy yield of WTGs

ρ = (p/RT) kg/cu.m $\rho(z)$ - ρ o(1-0.000226z)^4.25532

u	1.225	1.06	1.09	1.12	1.15	1.18	1.21	Air Density
4.5	19.04	12	13.3	14.7	16.0	17.4	18.8	kW
6	145	121	125	130	134	139	143	
8	421	358	369	381	392	404	415	
10	836	716	738	760	781	803	825	
12	1267	1107	1139	1169	1199	1226	1253	
14	1474	1396	1419	1434	1451	1468	1468	
16	1500	1491	1494	1496	1497	1500	1500	

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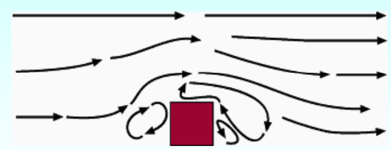
- *Obstacles*



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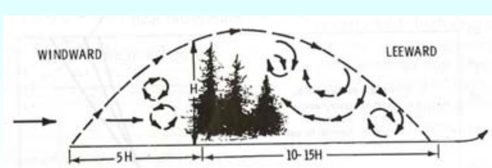
- **OBSTACLES**: Windward, it can be assumed that a cluster of the trees of a height it causes disturbances of the air stream five times the height, H in downward direction, disturbances of the air stream can reach fifteen times the height H



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Annual Energy Production

❖**To estimate the annual energy production from a given machine at a site, power curve method can be used since this method gives most realistic results.**

❖**The wind speed frequency distribution will be used to estimate the annual energy production of a wind turbine by multiplying the number of hours in each interval with the power output that the windmill generates at that wind speed interval.**

❖ **If the frequency distribution of wind speed at the hub height is not available, the wind speed at the hub height level is to be generated by the power law equation.**

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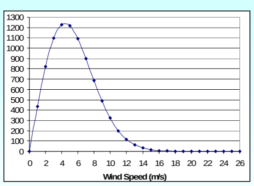
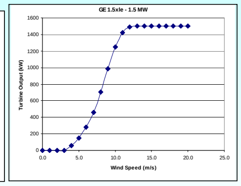
Data Analysis

Wind Speed (m/s)	Hours/ Year
0	0.0
1	434.4
2	823.4
3	1,098.6
4	1,228.7
5	1,216.5
6	1,092.3
7	900.8
8	687.5
9	487.9
10	323.0
11	200.0
12	115.9
13	63.0
14	32.1
15	**15.4**
16	6.9
17	2.9
18	1.2
19	0.4
20	0.2
21	0.1
22	0.0
23	0.0
24	0.0
25	0.0
26	0.0

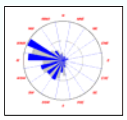


Speed Frequency Distribution



Wind Turbine Power Curve: Output As a Function of Speed

Wind Direction Rose



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Annual capacity factor *=*

*(Actual energy produced during year) / (capacity * 8760)*

OR

Annual Energy production of a Turbine *=*

Capacity factor X Capacity of Turbine X 8760 kWh

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MICROSITING

- **FIRST TASK IS DEFINE THE CONSTRINTS**
- **Site Boundary**
- **Availability of roads, overhead lines**
- **Turbine minimum spacing**
- **Constraints associated with communication signals (Microwave towers)**
- **Location of noise sensitive if any**
- **Location of visually sensitive if any**

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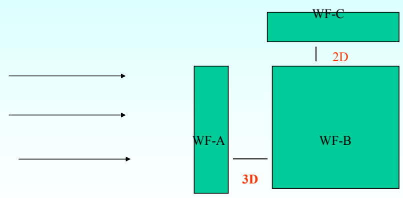
- **BASIC INPUTS**

- **Details of Topography**
- **Wind Data**
- **Turbine characteristics**

- ***WIND FARM –Offsets from property boundary***



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- **BASIC INPUTS**
- **Details of Topography (Uniform & Complex Terrain)**

- **Orography in terms of Contour lines**
- **Roughness in terms of Roughness length**
- **Obstacles in the near surrounding (in terms of dimensions)**

WIND RESOURCES & ASSESSMENT TECHNIQES

- **BASIC INPUTS**
- **Details of Topography**

Uniform Terrain (Homogeneous)

- **Slopes less than 30%**

Complex Terrain (Heterogeneous)

- **Slopes less than 30%**

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Table 1 Generation as a function of Spacing and wind regime

	Land required (hectares)	84.5	180.3	169	197
	Land per MW	5.33	11.38	10.67	12.44
Winds ll	Array >>	3D by 5D	4D by 8D	3D by 10D	5D by 7D
(m/s)					
9.95	Gross	78.139	78.293	78.108	78.487
	Net	72.333	74.537	75.212	75.644
	% loss	**7.43**	**4.80**	**3.71**	**3.62**
7.54	Gross	48.127	48.284	48.061	48.496
	Net	42.205	44.388	44.88	45.487
	% loss	**12.30**	**8.07**	**6.62**	**6.20**
7.19	Gross	45.517	45.639	45.47	45.813
	Net	38.466	41.214	40.938	42.17
	% loss	**15.49**	**9.70**	**9.97**	**7.95**
6.91	Gross	43.081	43.213	43.017	43.405
	Net	35.903	37.843	38.326	38.84
	% loss	**16.66**	**12.43**	**10.90**	**10.52**
6.38	Gross	37.056	37.142	36.999	37.289
	Net	32.42	34.192	34.693	34.9
	% loss	**12.51**	**7.94**	**6.23**	**6.41**

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Table 2 Effect of Spacing and Wind Speeds on Generation					
Generation figures in million kWh/year					
Spacing	HH W.S.>>	9.95	7.54	6.91	6.38
3 by 5	Maximum	3.17	2.06	1.75	1.54
	Minimum	2.92	1.73	1.47	1.24
	% Diff.	**8.74**	**19.24**	**19.29**	**24.19**
4 by 8	Maximum	3.19	2.07	1.75	1.54
	Minimum	3.04	1.85	1.57	1.35
	% Diff.	**5.01**	**11.77**	**11.47**	**14.42**
3 by 10	Maximum	3.23	2.09	1.79	1.55
	Minimum	3.07	1.87	1.59	1.38
	% Diff.	**5.01**	**11.59**	**11.98**	**11.78**
5 by 7	Maximum	3.23	2.09	1.78	1.55
	Minimum	3.09	1.91	1.63	1.39
	% Diff.	**4.50**	**9.16**	**9.15**	**11.62**

Micrositing

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The annual energy production

Standard correction factors

1 Grid availability
2 Machine availability
3 Electrical losses
4 Air density correction

Uncertainty factors)

1 Wind Measurement (sensors, mounting etc),
2 Inter annual variation
3 Extrapolation (vertical l)
4 Extrapolation (horizontal)
5 Input file accuracy (Orography + Roughness)
6 Power curve

RMS Value 7-20 %

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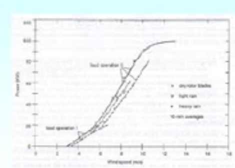
WIND POWER METEOROLOGY -BASICS

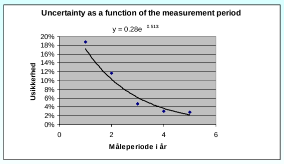
The influence of heavy rain

- **Moderate rain does not influence much the performance of WTG**
- **During heavy rain however massive drop impacts occur at the rotor blades through which the flow around the profile is disturbed considerably.**
- **Power losses up to 30% could be happened according to the intensity of rain**
- **The comparison of power curves with and without rain is not illustrated in Fig.**



WIND RESOURCES & ASSESSMENT TECHNIQES

- σ= 0.28*exp(0.513*measurement period in years),



Formula made using a German Wind Index

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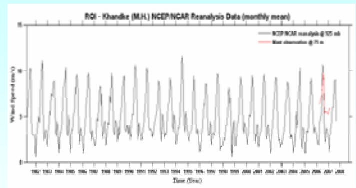
Long term data



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Sources of Uncertainty:

Uncertainty value for Wind Shear

+/- 20-25%

RiX, Correlation

Terrainslope < 30 degrees
σ= 8%
Terrainslope > 30 degrees
σ= 18%

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Sources of Uncertainty:
Turbine Power Curve

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Table 2 – Example of presentation of estimated annual energy production

Estimated annual energy production
Reference air density: 1,225 kg/m³
Cut-out wind speed: 25 m/s
(extrapolation by constant power from last bin)

Hub height annual average wind speed (Rayleigh) m/s	*AEP*-measured (measured power curve) MWh	Uncertainty of measured power curve in terms of standard deviation of *AEP* MWh, %		*AEP*-extrapolated (extrapolated power curve) MWh
4	412	111	27 %	412
5	911	154	17 %	911
6	1 536	191	12 %	1 536
7	2 207	219	10 %	2 214
8	2 847	236	8 %	2 880
9	3 395	245	7 %	3 487
10	3 812	248	6 %	4 001
11	4 092 incomplete	245	6 %	4 403

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The Annual Energy Production

Finally annual energy production will be given in different confidence level with normal distribution .

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William Arthur Ward

- ***Thank you***