Methodology for studying and selecting a site for wind energy applications

Professor Papa Alioune Ndiaye,
Director of CIFRES
papaas.ndiaye@ucad.edu.sn/papealiounen@yahoo.fr

Outline

- Summary of world wind energy report 2010
- Method for studying wind potential
- Some examples of wind potential studies
- Conclusion

World Wind Energy Report 2010

http://www.wwindea.org

- Worldwide capacity reached 196,630 Megawatt, out of which 37,642 Megawatt were added in 2010,
- Wind power showed a growth rate of 23.6 %,
- All wind turbines installed by the end of 2010 worldwide can generate 430 Terawatthours per annum, more than the total electricity demand of the United Kingdom,
- The wind sector in 2010 had a turnover of 40 billion Euro and employed 670,000 people worldwide.

World Wind Energy Report 2010

- China became number one in total installed capacity and the centre of the international wind industry, and added 18,928 Megawatt within one year, accounting for more than 50 % of the world market for new wind turbines.
- Germany keeps its number one position in Europe with 27,215 Megawatt, followed by Spain with 20,676 Megawatt.
- The highest shares of wind power can be found in three European countries: Denmark (21 %), Portugal (18 %) and Spain 16 %).

World Wind Energy Report 2010

- **Asia accounted for the largest share of new installations (54.6 %), followed by Europe (27.0 %) and North America (16.7 %).**
- **Latin America (1.2 %) and Africa (0.4 %) still played only a marginal role in new installations.**

- **WWEA sees a global capacity of 600,000 Megawatt as possible by the year 2015 and more than 1,500,000 Megawatt by the year 2020.**

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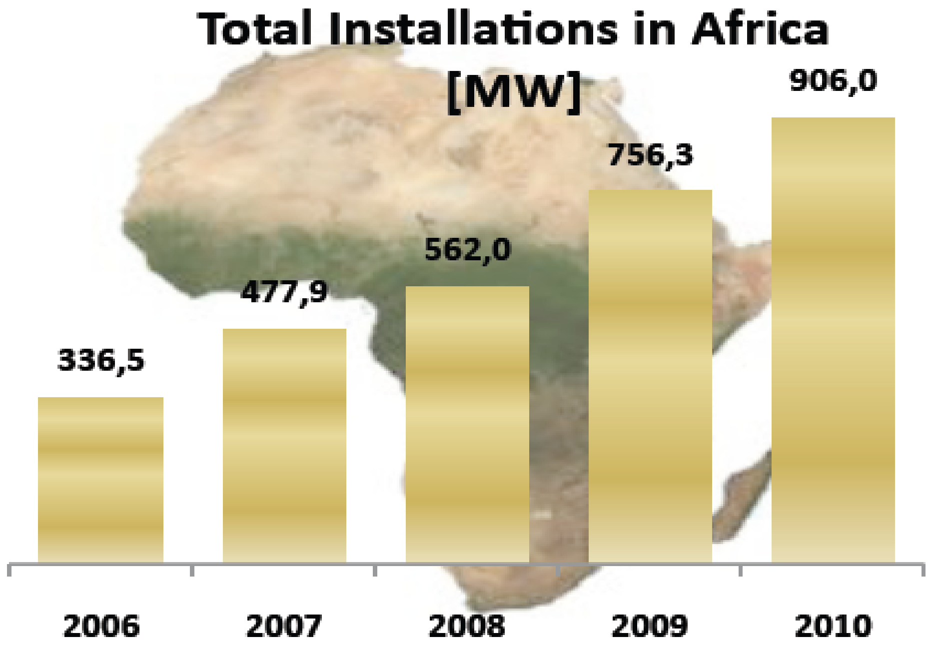
World Wind Energy Report 2010



Egypt (550 MW) and Moroco (286 MW) are the wind leaders on African Continent, Tunisia (54 MW)

World Wind Energy Report 2010

In Africa, North Africa represents still lion share of installed capacity, wind energy plays hardly a role yet in Sub-Sahara Africa.

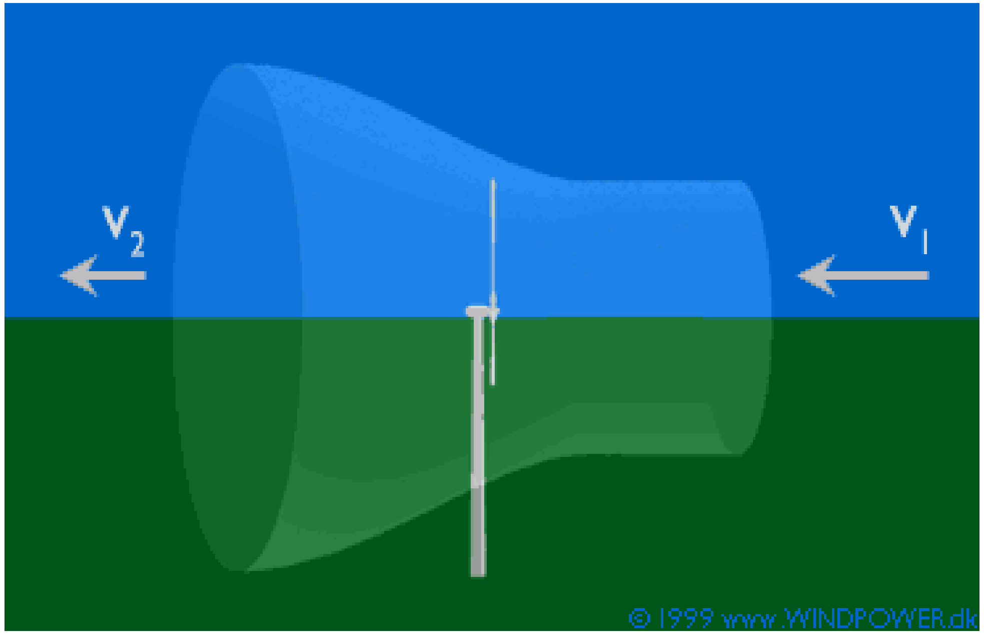
Wind energy

- The terms "**wind energy**" or "**wind power**" describe the process by which the wind is used to generate **mechanical power or electricity**.
- Wind turbines convert the kinetic energy in the wind into mechanical power.
- This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity

Wind Energy

The available wind power :

- $P_{wind} = 0.5\ \rho\ V^3 A \quad (W)$



The power from the wind increases with :
- the cube of the wind speed $(m/s)^3$
- the area of wind rotor being swept by the wind (m^2)
- the air density (kg/m^3)

10% more wind= 30% more power

Maximum extracted power is $0.593(0.5\rho V^3 A)$

The air density varies with altitude

Height above sea level	Density of dry air at 20° C	Density of dry air at 0° C
0	1.204 kg/m^3	1.292 kg/m^3
500	1.134	1.217
1000	1.068	1.146
1500	1.005	1.078
2000	0.945	1.014
2500	0.887	0.952
3000	0.833	0.894
3500	0.781	0.839
4000	0.732	0.786
4500	0.686	0.736
5000	0.642	0.689

4,3%

Source: E. Lysen – Introduction to Wind Energy

Air density estimation

The air density can be computed from the measured temperature and station pressure or is estimated by correcting standard air density for station elevation.

- Air density is calculated from measured temperature (T) and station pressure (P) by

$$\rho = \frac{P}{RT}$$

P = air pressure (in units of Pascals or Newtons/m^2)
R = the specific gas constant (287 J kg^{-1} Kelvin^{-1})
T = air temperature in degrees Kelvin (deg. C + 273)

- If temperature or station pressure is not available, air density is estimated as a function only of station elevation (Z) by

$$\rho = 1.225 - (1.194 * 10^{-4}) * z$$

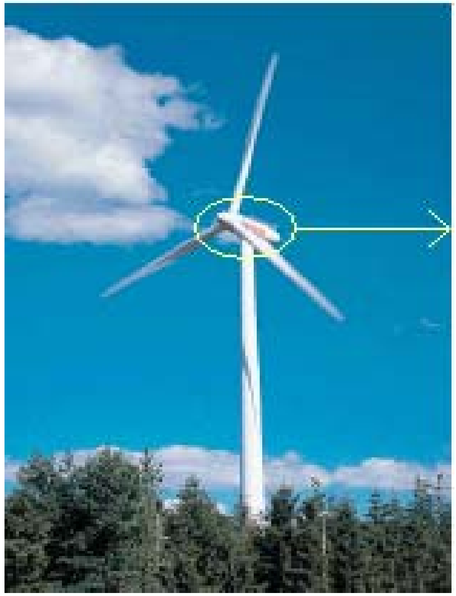
- If we have temperature data but not pressure data

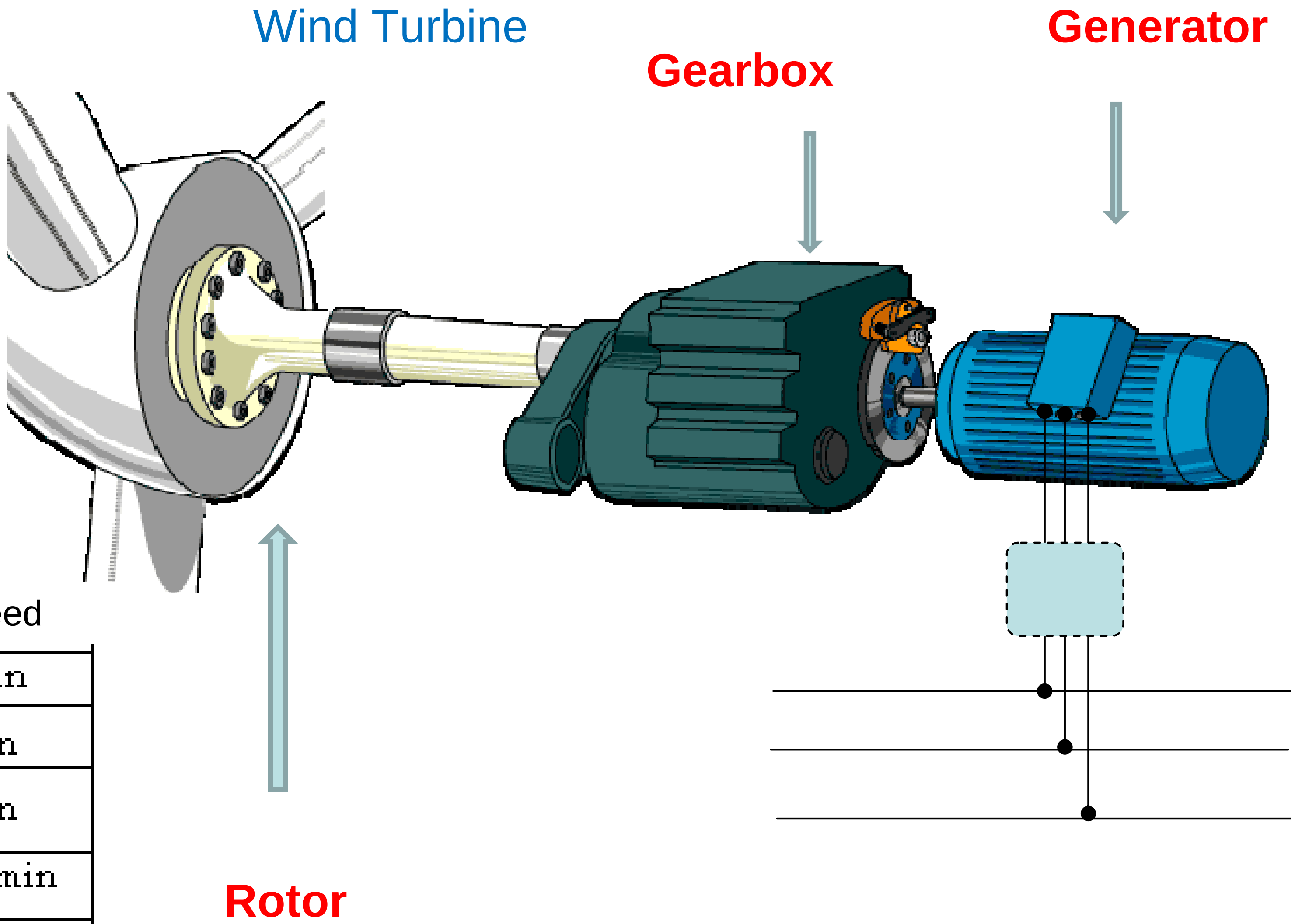
$$\rho = (P_o / RT) * \exp(-g * z/RT) \quad (kg/m^3)$$

where P_o = std. sea level atmospheric pressure (101,325 Pascals)
g = the gravitational constant (9.8 m/s^2); and
z = the region's elevation above sea level (in meters)

Wind turbines

- Wind turbines, like aircraft propeller blades, turn in the moving air and power an **electric generator** that supplies an electric current.
- Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity



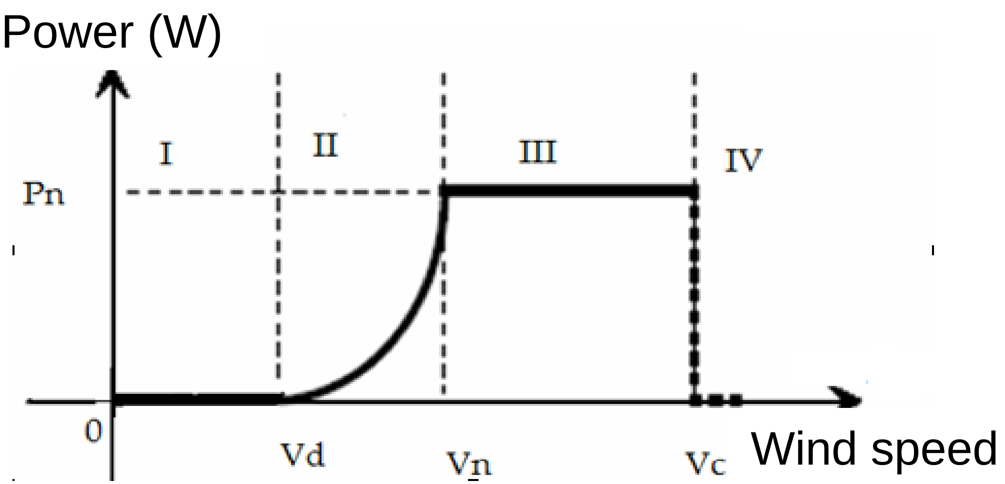


Power	Rotation speed
300 W	2000 tr/min
1 kW	600 tr/min
10 kW	200 tr/min
80 kW	60 à 120 tr/min
750 kW	15 à 35 tr/min
1 à 2 MW	10 à 22 tr/min

Wind turbine rotation speed

The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

Wind turbine power Curve



$$P = \begin{cases} P(V) & \text{si } V_d \leq V(t) \leq V_n \\ P_n & \text{si } V_n \leq V(t) \leq V_c \\ 0 & \text{si } V(t) \leq V_d \text{ ou } V(t) \geq V_c \end{cases}$$

There are various important wind speeds to consider:

- Cut-in wind speed – the wind speed at which the rotor can be loaded
- Rated wind speed – the windspeed at which the machine is designed to run (this is at optimum tip-speed ratio
- Furling wind speed – the windspeed at which the machine will be turned out of the wind to prevent damage

Wind turbine applications

Scale	Rotor diameter	Power rating
Micro	Less than 3 m	50 W to 2 kW
Small	3 m to 12 m	2 kW to 40 kW
Medium	12 m to 45 m	40 kW to 999 kW
Large	46 m and larger	More than 1.0 MW

Wind generation for developing countries

The more immediate demand for rural energy supply in developing countries is for smaller machines.
These can be connected to small, localised micro-grid systems and used with solar photovoltaïc systems.

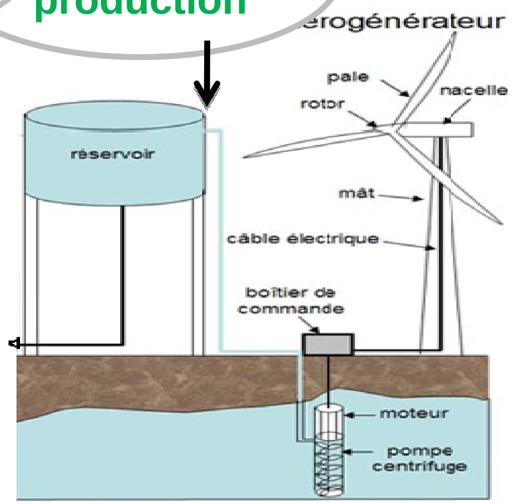
Wind turbine applications

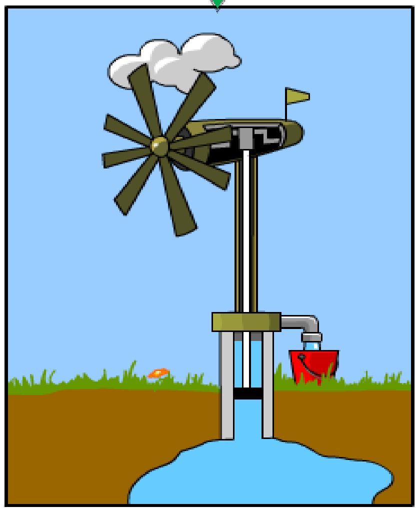
Resources (wind : speed, direction,…)

Mechanical energy conversion

Electricity
- **Grid connected**
- **Stand alone system**
- **Water production**

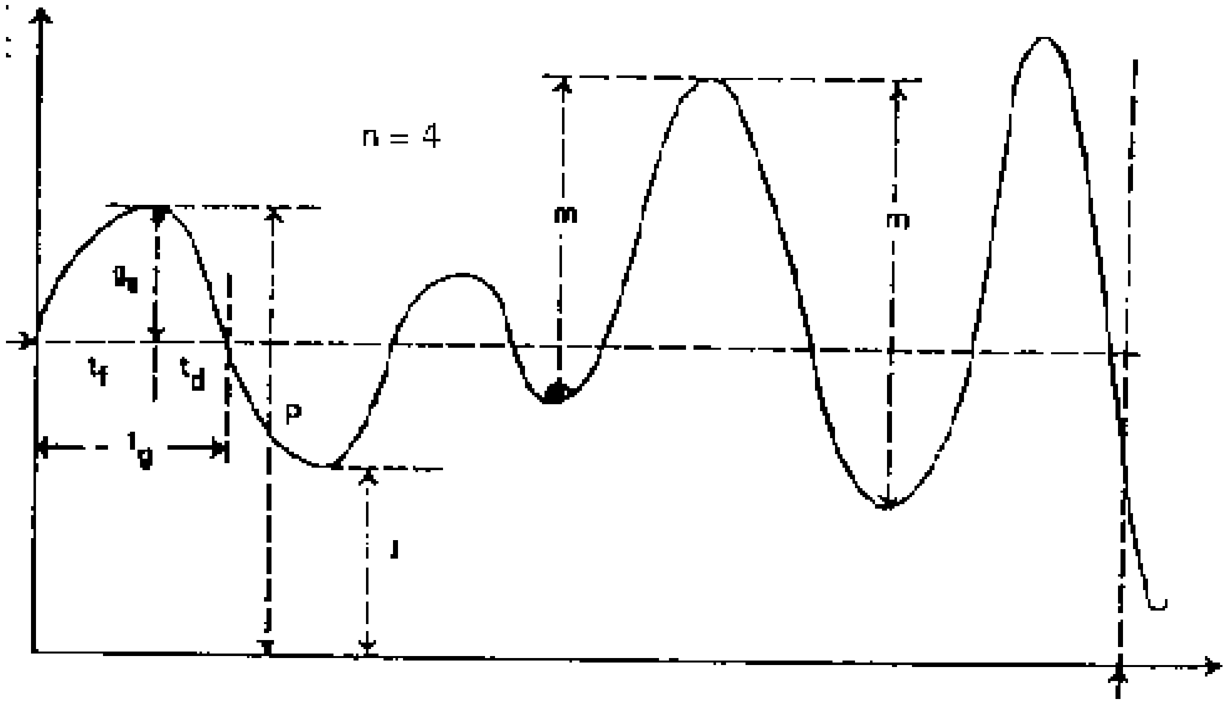
Water pumping (mechanical)





Method for studying wind potential

Wind speed measurement



10 minutes

Masurement period : 10 minutes

Wind Speeds

1 m/s = 3.6 km/h = 2.237 mph = 1.944 knots

1 knot = 1 nautical mile per hour = 0.5144 m/s = 1.852 km/h = 1.125 mph

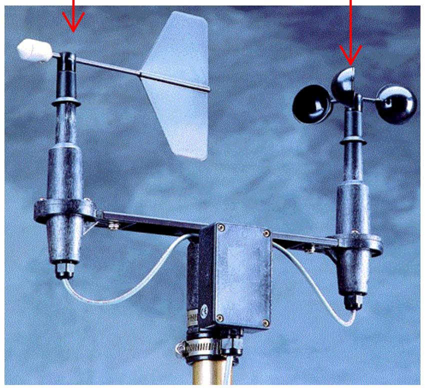
Wind Speed Scale

Wind Speed at 10 m height m/s	Wind Speed at 10 m height knots	Beaufort Scale (outdated)	Wind
0.0-0.4	0.0-0.9	0	Calm
0.4-1.8	0.9-3.5	1	
1.8-3.6	3.5-7.0	2	Light
3.6-5.8	7-11	3	
5.8-8.5	11-17	4	Moderate
8.5-11	17-22	5	Fresh
11-14	22-28	6	Strong
14-17	28-34	7	
17-21	34-41	8	Gale
21-25	41-48	9	
25-29	48-56	10	Strong Gale
29-34	56-65	11	
>34	>65	12	Hurricane

Data acquisition system

Weather Cock (Wind direction)

Anemometer (wind speed)



Data acquisition

Datalogger

Battery

Sensors input

The Mast

- The sensors are installed on a measurement mast which can be either freestanding or guyed.
  - For a first analysis,a 10 meter high mast is used
  - For a more detailed analysis, the mast will be 40 to 60 meters high with sensors at different heights to determine the vertical profile of wind speed.

Methodology

- The main measurement characteristics are:

Over a period of 10 minutes, a number of samples are measured.

The sampling time is 1 second, or 600 data over the 10 minute period .

From these, the following three (or four) characteristic quantities are extracted :

– the average speed

– the standard deviation of the speed

– the maximum speed (minimum speed)

***The central data acquisition calculates the mean, standard deviation and the maximum value*.**

For large wind farms, measurements are carried out for a year , then corrected by comparing them to measurements made over several years by weather stations in the region

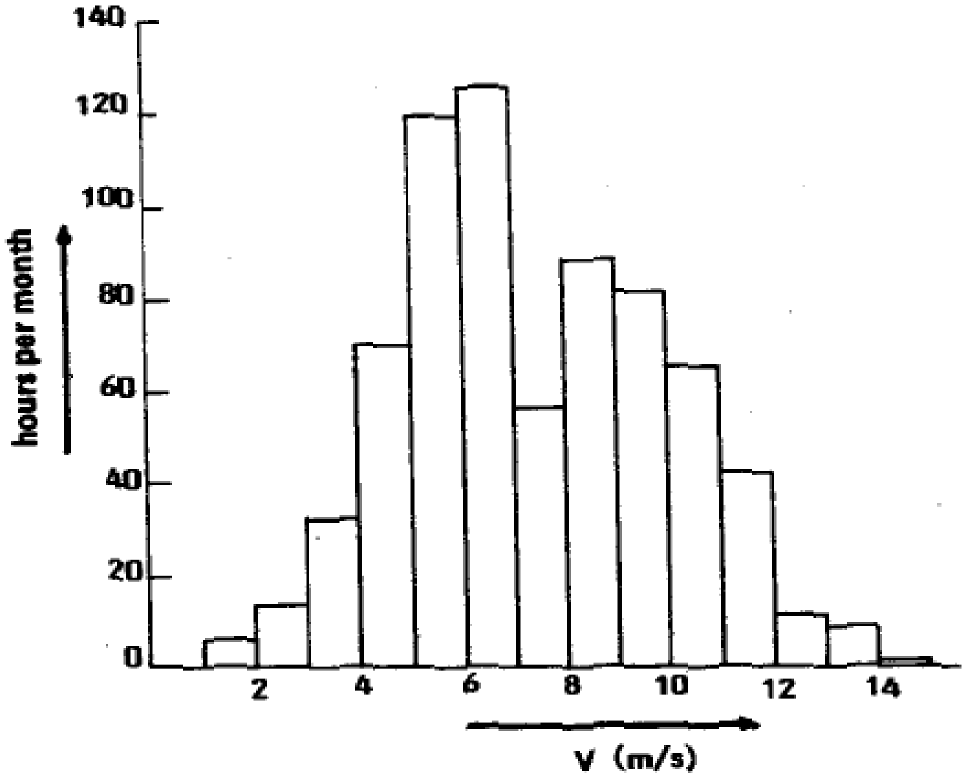
MCP Method: Measurement, Correlation, Prediction

This process makes it possible to have very precise estimation of the distribution and the average of the wind speed on a given site for a long period (20 years for economic study)

interval	frequency	duration V > V'	cumulative V < V'	
m/s	hours	hours	hours	%
0-1	0	720	0	0
1-2	6	714	6	0.8
2-3	13	701	19	2.6
3-4	32	669	51	7.1
4-5	70	599	121	16.8
5-6	120	479	241	33.5
6-7	126	353	367	51.0
7-8	56	297	423	58.8
8-9	89	208	512	71.1
9-10	81	127	593	82.4
10-11	64	63	657	91.2
11-12	42	21	699	97.1
12-13	11	10	710	98.6
13-14	9	1	719	99.9
14-15	1	0	720	100.0
Total	720			

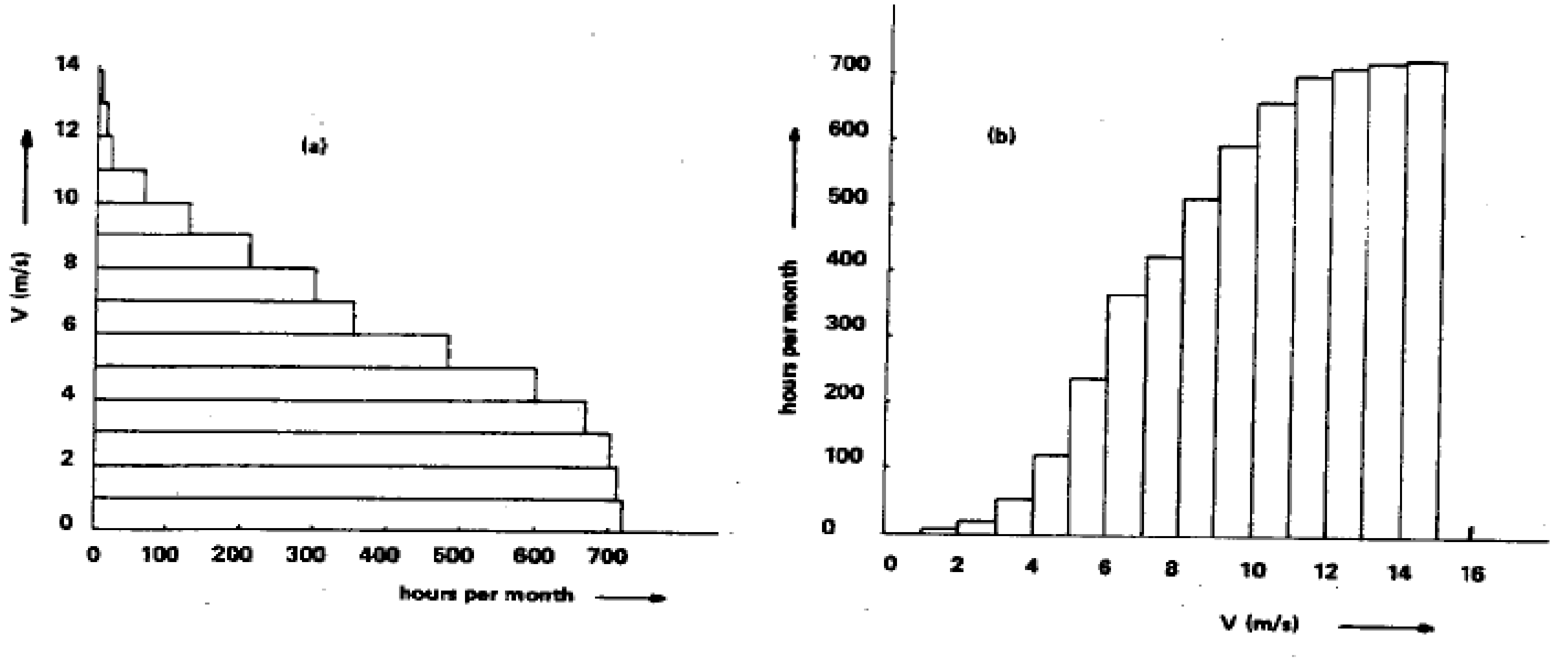
Source: E. Lysen – Introduction to Wind Energy

The velocity frequency data of Praia (june 1975) with duration distribution and cumulative distribution



Histogram of the velocity frequency data for Praia (june 1975)

Source: E. Lysen – Introduction to Wind Energy



Histograms of the duration distibution (a) and the cumulative distribution (b) for Praia (june 1975)

Source: E. Lysen – Introduction to Wind Energy

Calculation of Wind Power Density

For the purpose of mapping the geographical variation of the wind resource, wind power density was chosen in preference to wind speed

$$P = \frac{P_{wind}}{A} = \frac{1}{2}\rho V^3 \quad \left(W/m^2\right)$$

The power density value combines the effect of the distribution of wind speeds and the dependence of the power density on air density and on wind speed.

Quantitative wind data in digitized, summarized, and unsummarized forms

Source :http://rredc.nrel.gov/wind/pubs/

Digitized Data

For stations with l-hour and 3-hour digitized data, the average wind power density (Watts/m²) in a vertical plane perpendicular to the wind direction is calculated from

$$P = \frac{1}{2n}\sum_{i=1}^{n} \rho_i V_i^3$$

where
n = the number of observations in the averaging period
ρ_i = the air density (kg/m³)
$\mathbf{V_i}$ = the wind speed (m/s) at the ith observation time.

Summarized Data

For stations with wind summaries, P is calculated from

$$P = \frac{1}{2}\bar{\rho}\sum_{j=1}^{c} f_j V_j^{3}$$

where

$\bar{\rho}$	=	the mean air density
c	=	the number of wind speed classes
f_j	=	frequency of occurrence of winds in the jth class
V_j	=	the median wind speed of the jth class.

Calculation of Wind Power Density

Unsummarized Data

In the cases for which unsummarized wind data are assessed, the seasonal and annual average speeds. The wind power density is estimated by

$$P = \frac{1}{2} K \rho \overline{V}^{3}$$

where K = a value determined by the shape of the distribution pattern that the wind speeds follow.

For exampe if we assume that the speed frequency distribution follows a Rayleigh distribution with K = 1;91, the wind power density is given by

$$P = 0.955 \rho \overline{V}^{3}$$

Wind Classes

Wind sites can be descibed by their wind classes rather their power density

	10 m (33 ft)	
Wind Power Class	Wind Power Density (W/m^2)	Mean Speed range (b) m/s (mph)
1	<100	<4.4 (9.8)
2	100 - 150	4.4 (9.8)/5.1 (11.5)
3	150 - 200	5.1 (11.5)/5.6 (12.5)
4	200 - 250	5.6 (12.5)/6.0 (13.4)
5	250 - 300	6.0 (13.4)/6.4 (14.3)
6	300 - 400	6.4 (14.3)/7.0 (15.7)
7	>400	>7.0 (15.7)

Characteristics of a wind site

Site selection

The site for a wind turbine must be chosen very carefully to make sure that the location with the highest wind speed in the area is selected.

A number of effects have to be considered :

- *Windshear* : the wind slows down near the ground, to an extent determined by the surface roughness
- *Turbulence* : behind buildings, trees…
- *Acceleration* : on tops of hills, ridges…
- *Tunnel effect* : between tall buildings

Extrapolation of the wind speed with the height

The wind speed is generally collected at a height of 10 m.

For wind projects, it is necessary to estimate the wind speed at the wind turbine hub height.

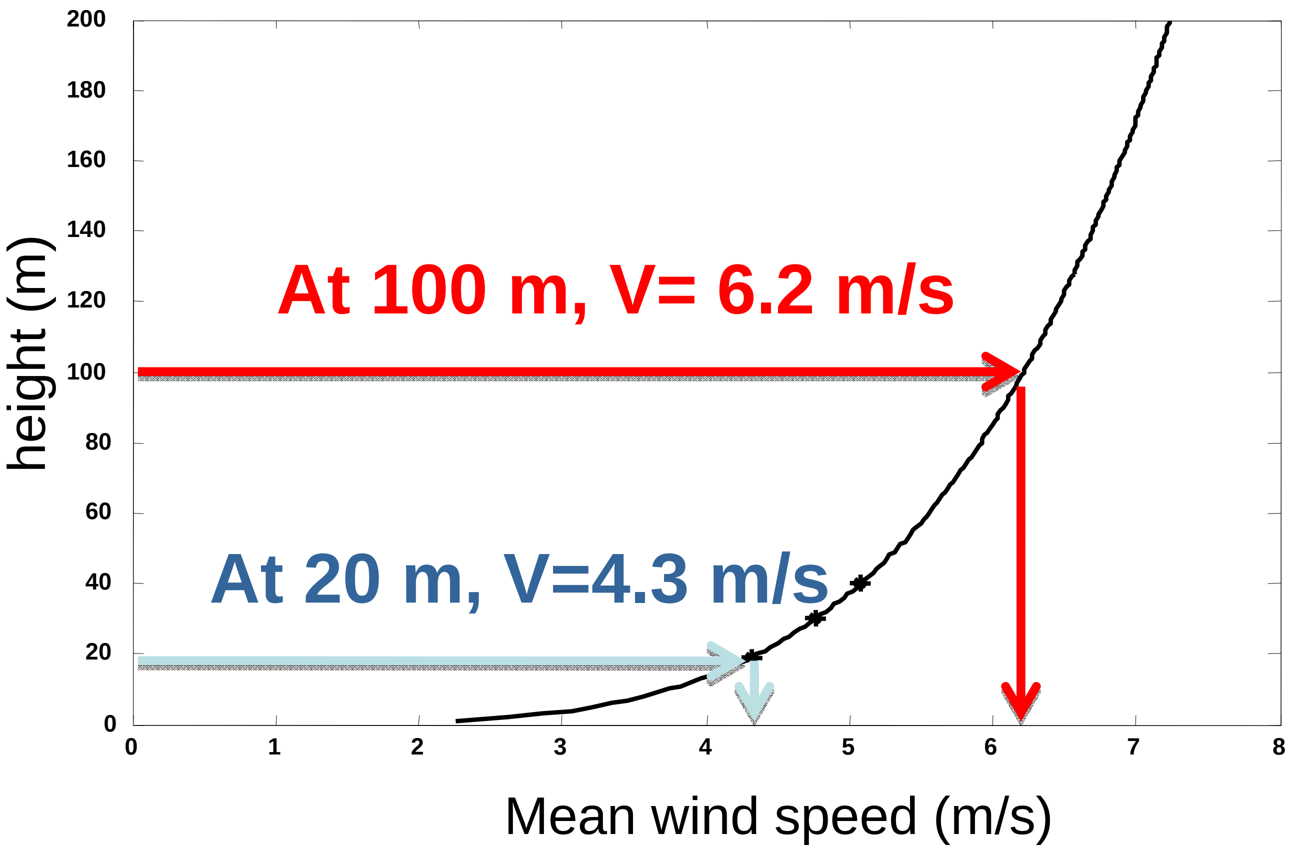
The most commently used method to adjust the wind speed is given by :

$$\frac{V}{V_o} = \left(\frac{H}{H_o} \right)^n$$

- Where Vo is the reference wind speed, Ho is the reference height
- V is the wind speed to be determined at the height H
- **n** is the roughness factor varying from 0.10 to 0.4

An example of extrapolation of the wind speed with the height

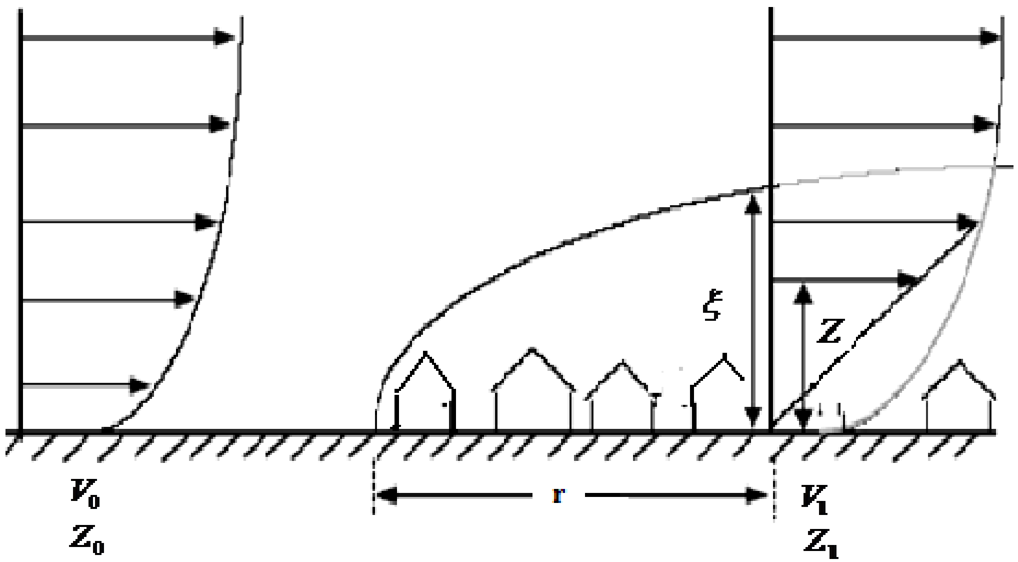
n=0.22 for Kayar



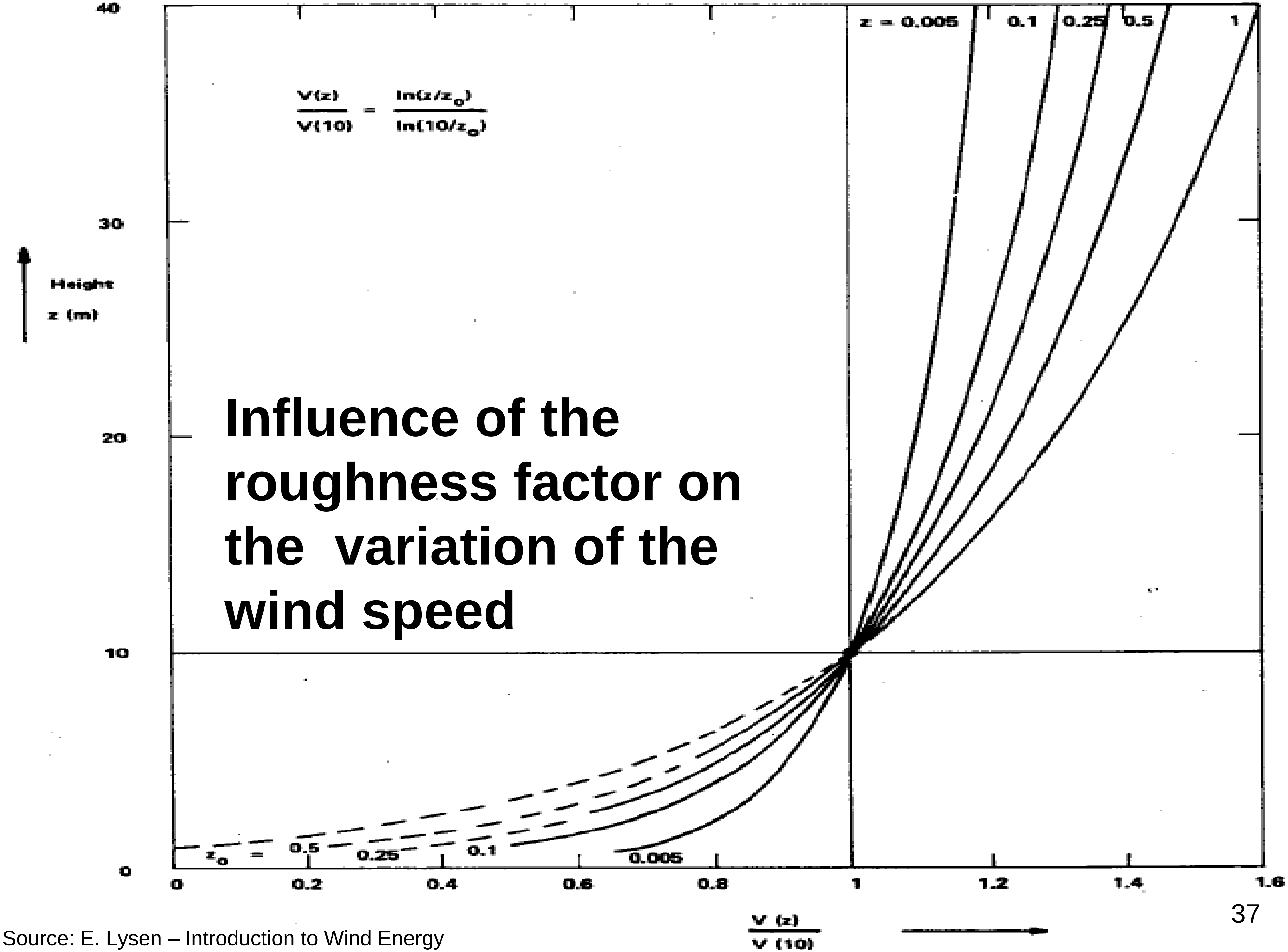
Influence of the roughness height (Windshear)

Roughness height Zo: Height above the ground at which the wind speed is different from 0 m/s

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



Type of surface	z_0 (mm)	n
sand	0.2 to 0.3	0.10
mown grass	1 to 10	0.13
high grass	40 to 100	0.19
suburb	1000 to 2000	0.32

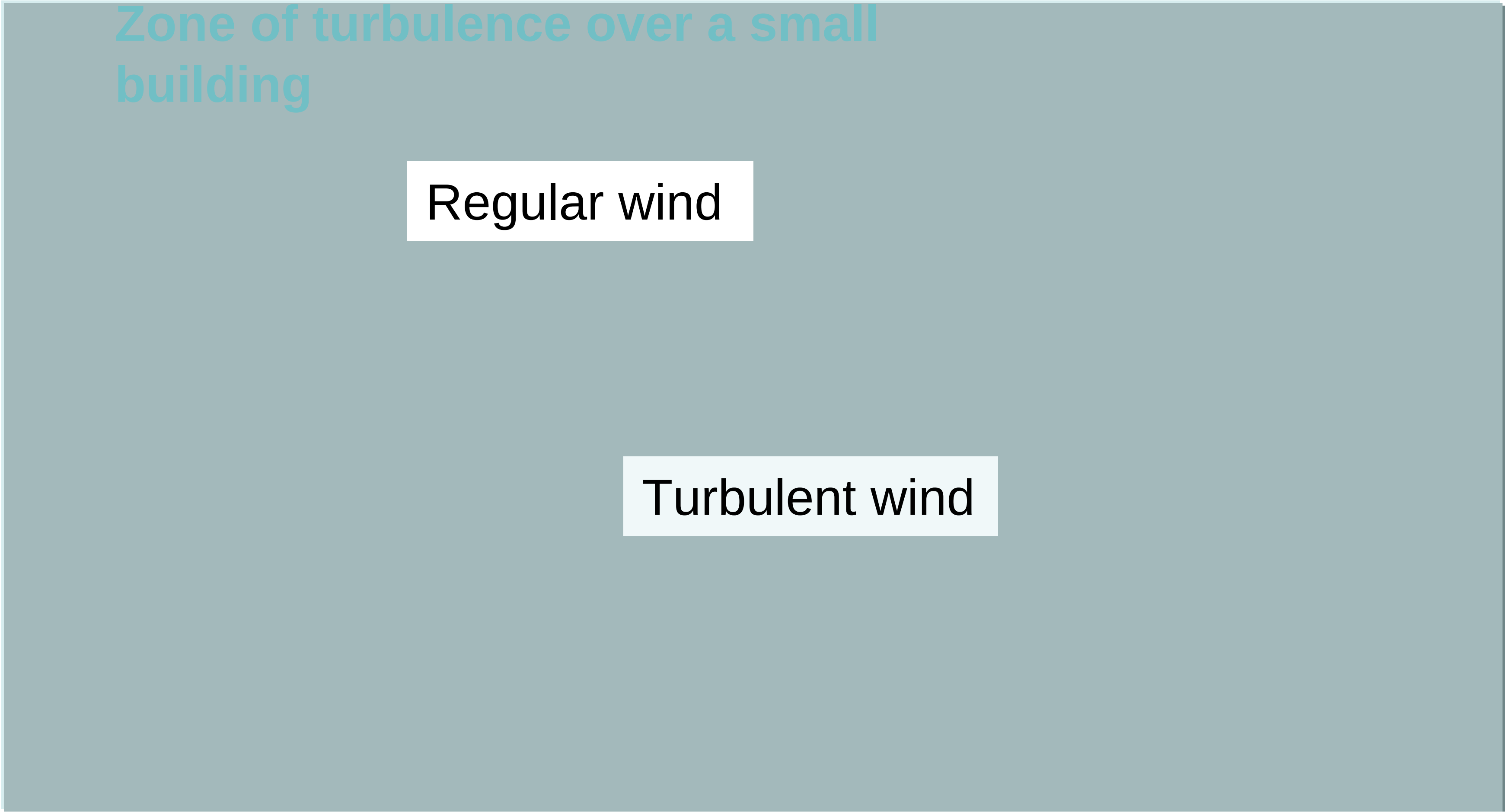


Influence of the roughness factor on the variation of the wind speed

Source: E. Lysen – Introduction to Wind Energy

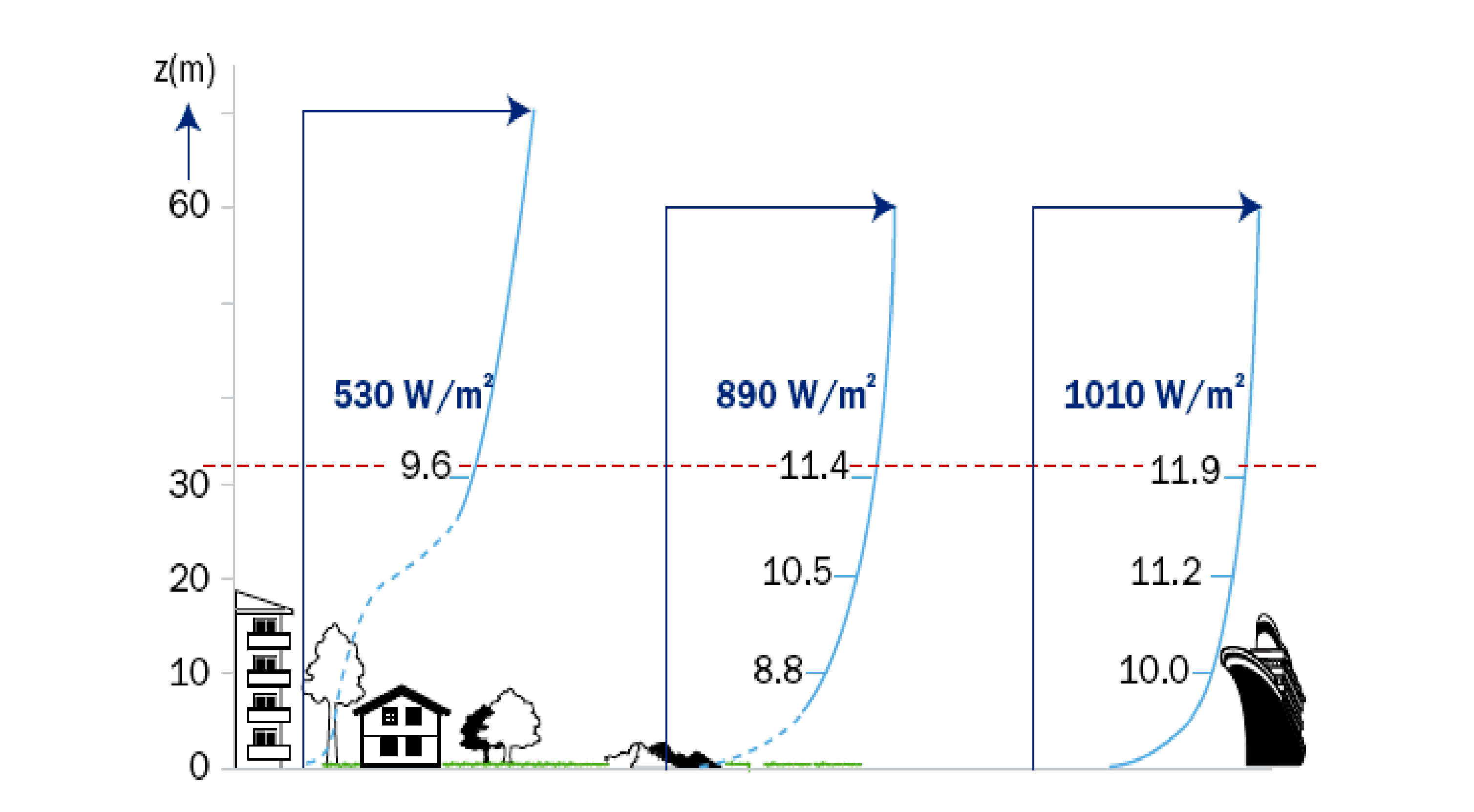
Effect of isolated obstacles (turbulence)

Wind flowing around buildings or over very rough surfaces exhibits rapid changes in speed and/or direction, called turbulence.



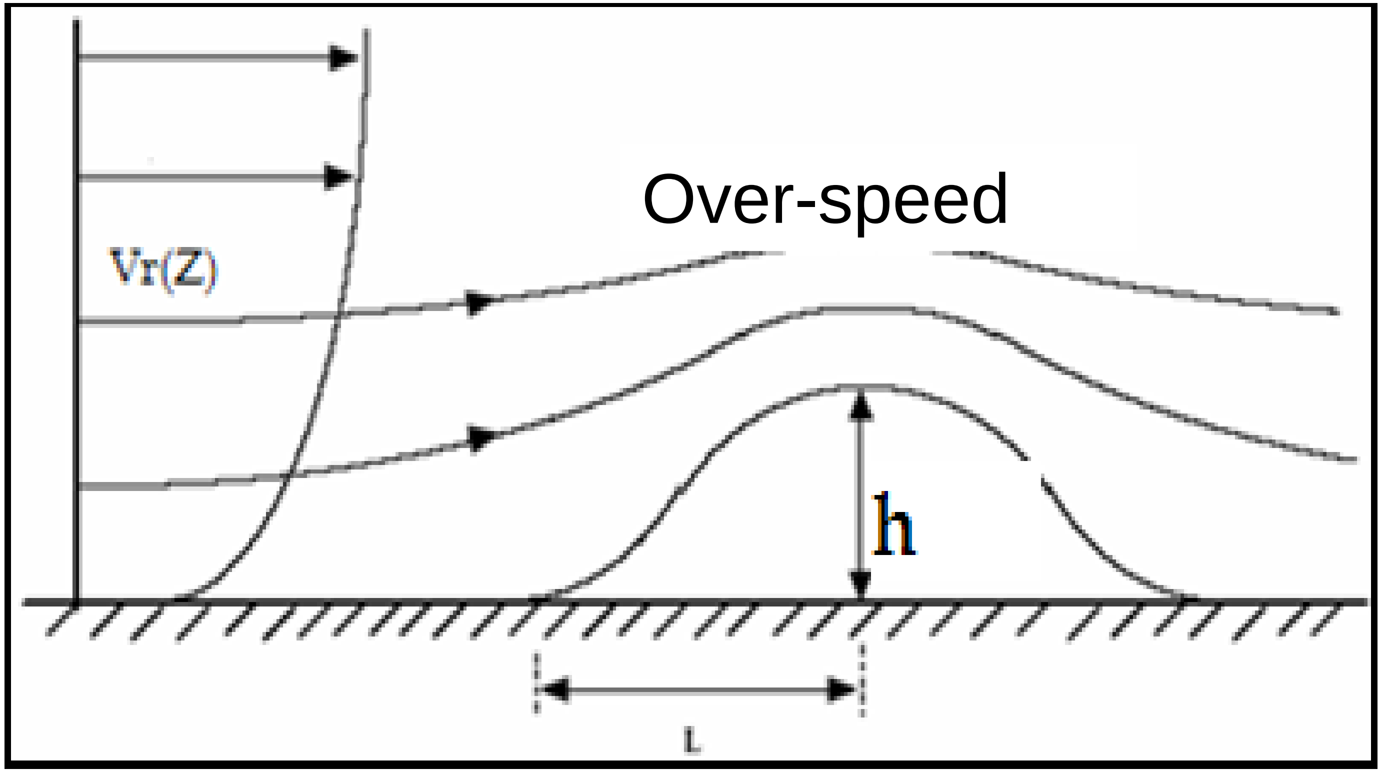
Effect of isolated obstacles

As one moves away from the obstacle, the effect decreases and the power density increases accordingly.



Acceleration on ridges

The ridge causes the air to accelerate near the top.



Tunnel Effect

- Between tall buildings or in a narrow corridor, the wind is compressed on the windward side of the building or the mountain, making its speed significantly accelerate. This is called a "tunnel effect“

The presence of a tunnel effect allows mean speed favorable for the harnessing of wind potential

A simple observation of the landscape can give an idea of the prevailing wind direction

Modelling wind regimes

Weibull function is generally used to approach the frequency distribution and duration curves of the wind speed.
For example, this tool can be used to predict the output of a wind turbine in a given location.
The probability density function is given by :

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

The weibull distribution is characterized by two parameters :
The shape parameter k (dimensionless) and the scale parameter c or A (m/s)

The Weibull function

Two functions are used :

- The probability density function f(V) representing the velocity frequency curve

- The cumulative distribution function F(V) (duration curve) indicating the time fraction or probabilty that the wind speed V is smaller than or equal to a given wind speed V'

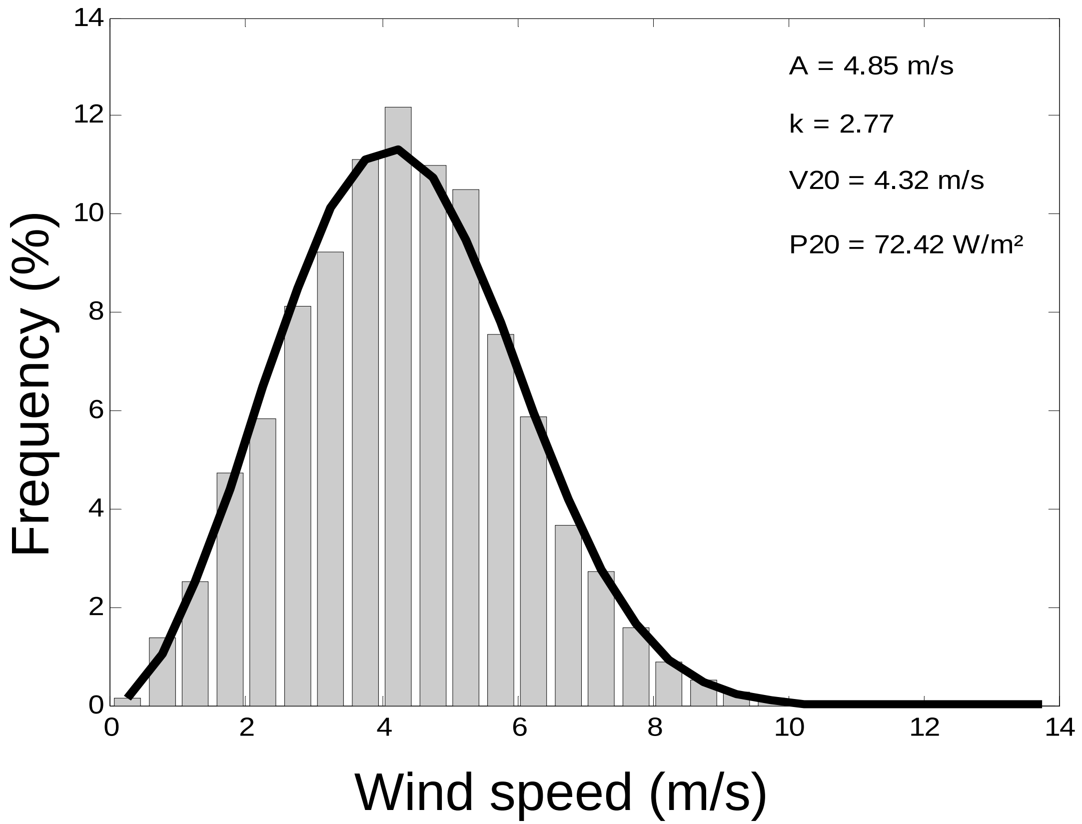
$$F(V) = P[V < V'] = \int_0^V f(V')dV'$$

Estimation of the Weibull parameters from given data

The Weibull distribution shows its usefulness when the wind data of one reference site are being used to predict the wind regime in the surroundings of that station.

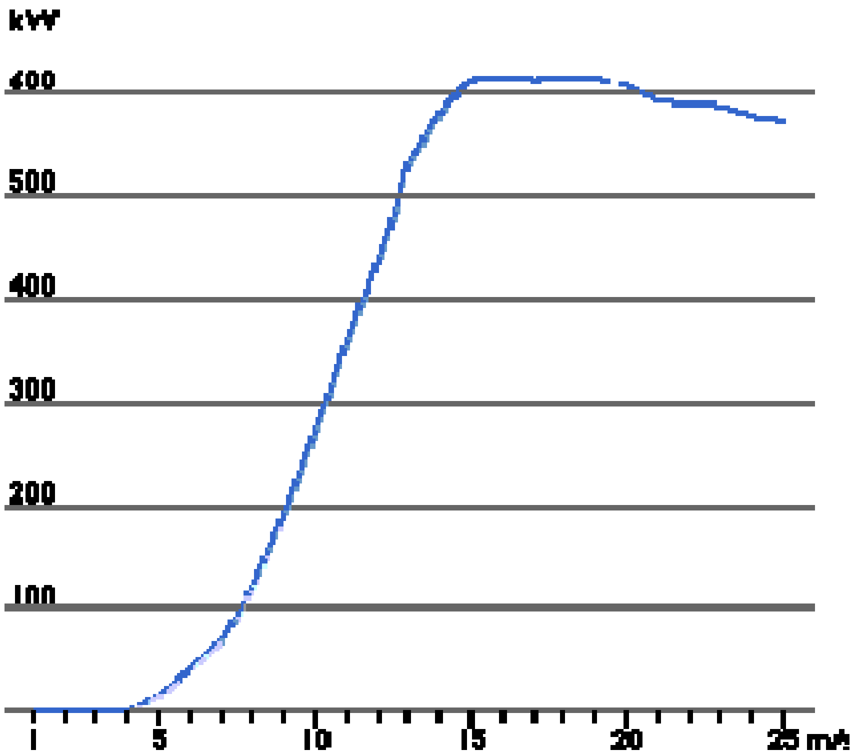
There are several methods for extracting the Weibull parameters k and c from a given set of data.

Example : **Weibull Distribution** in the site of Kayar (Senegal)



The most likely wind speed is 4 m / s
The available energy is higher for wind speeds between 6 m/s and 10 m / s, however, these speeds are less frequent
The available energy is low for the range of speed of 4 m/s to 5 m / s, compared to the previous track, but they are more frequent

Application : Method for determining the power produced by a wind turbine



- For each elementary interval of 0.1 m/s of the wind speed,
- We multiply the probability of occurrence of this interval (determined by the Weibull curve) by the corresponding value on the power curve.
- Then we take the total of all these multiplications to compute the average output power

The Capacity Factor (CP)

Another way to know the annual energy output of a wind turbine is to consider the capacity factor at the site where it is located.

The capacity factor is the annual energy output divided by the maximum theoretical production calculated as if the turbine was operating at its rated power (maximum) for all the 8766 hours of the year

.

Example:

If a 600 kW wind turbine produces 1.5 million kWh in a year its capacity factor is equal to 1,500,000 divided by (365.25 * 24 * 600) = 1,500,000: 5,259,600 = 0.285 = 28.5%.

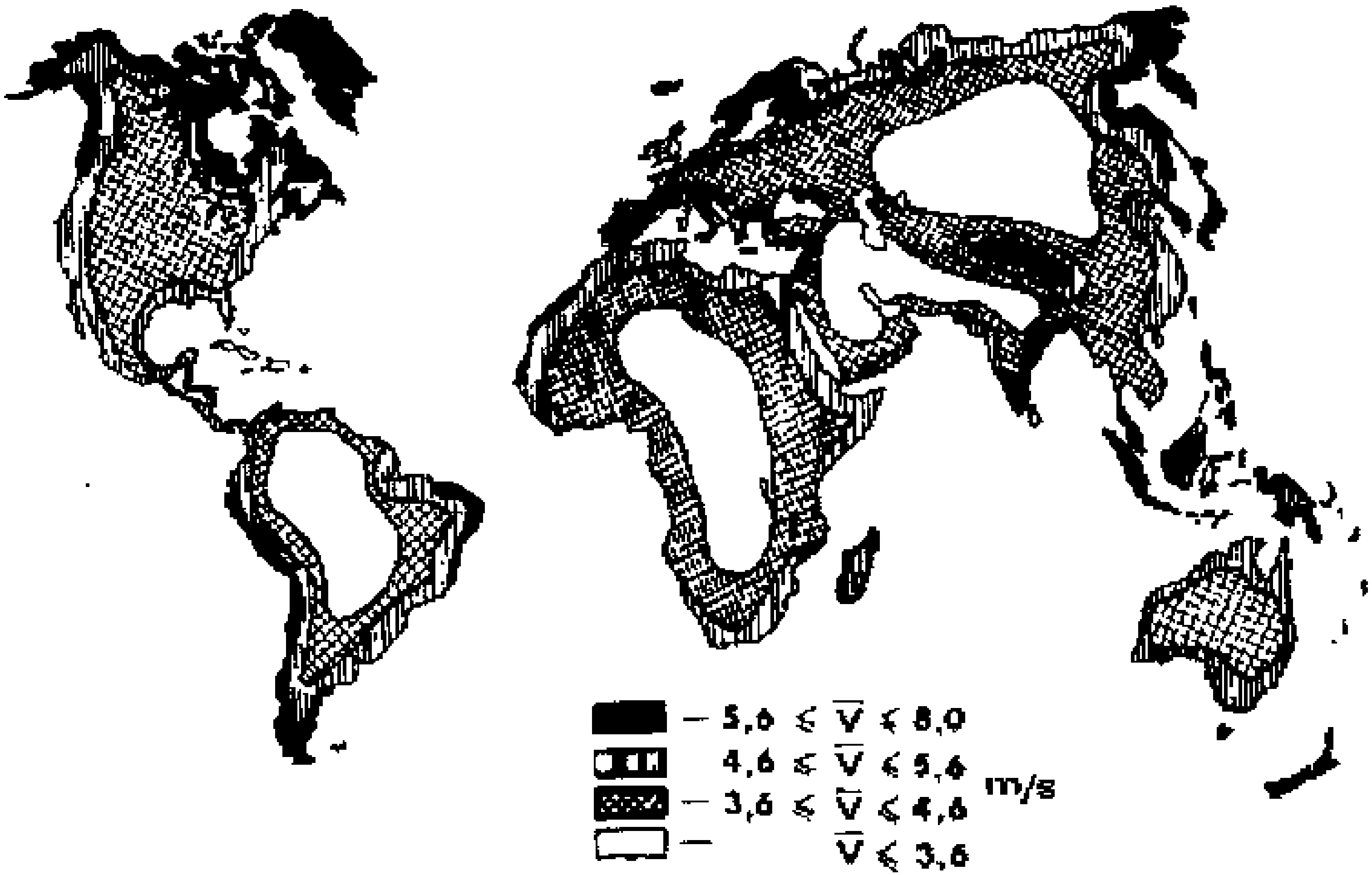
In theory, capacity factors can vary from 0 to 100%, but in practice they are between 20 to 70%, and most often between 25% and 30%.

The Capacity Factor (CP)

In simplified terms, one must choose between
- a relatively stable output power (near the design limit of the turbine) with a large capacity factor,

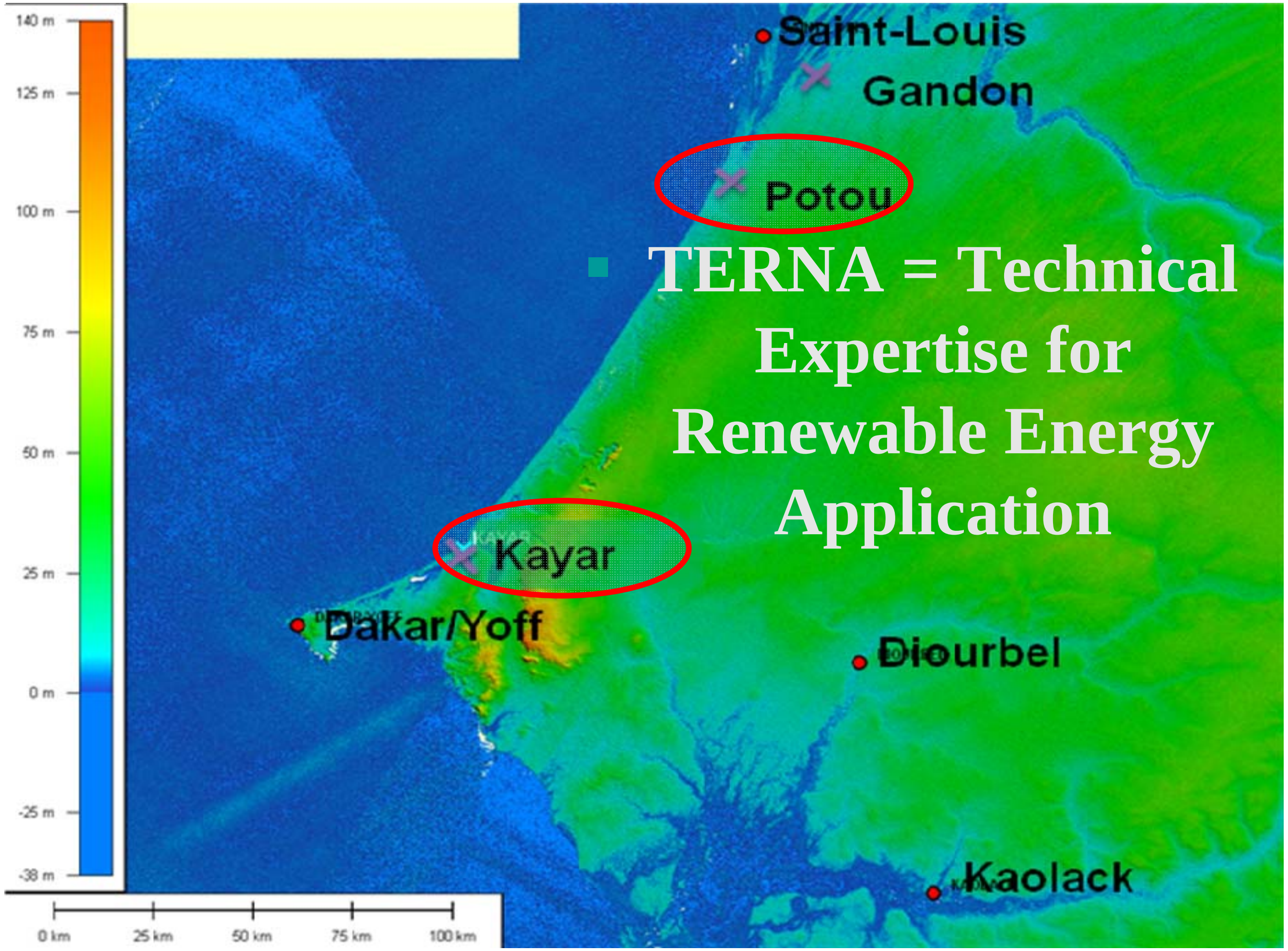
and
- a high output power and variable with a low capacity factor.

World wind energy resources



Some examples of wind potential studies

Location of the sites

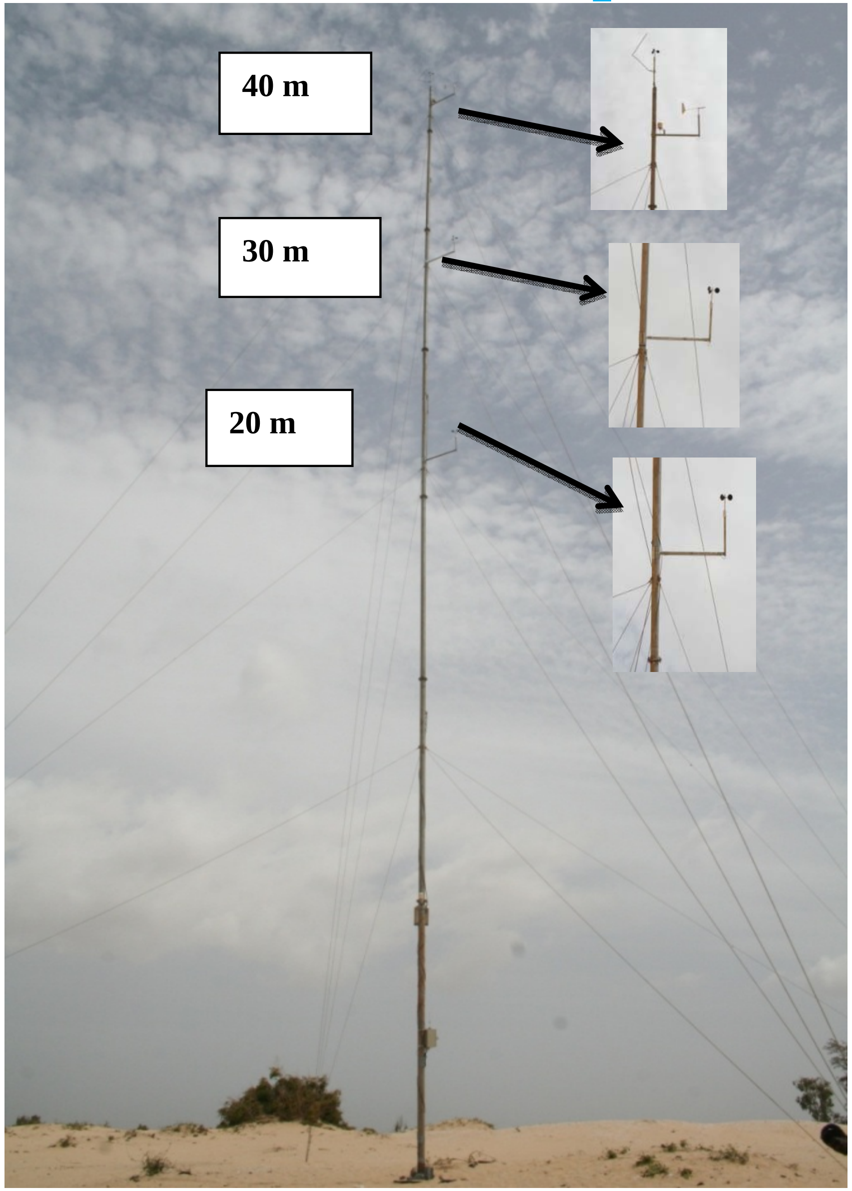


- TERNA = Technical Expertise for Renewable Energy Application

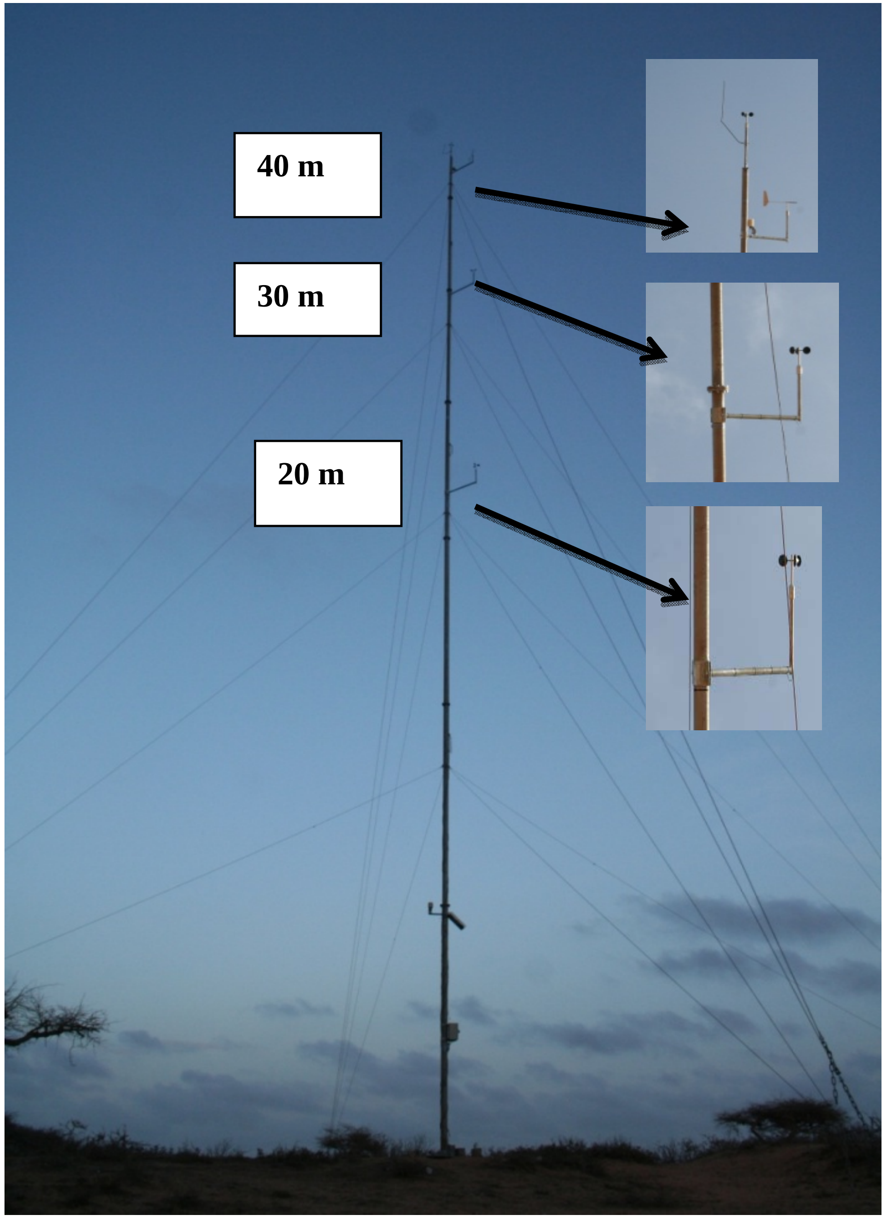
Location of the sites

Site	Longitude (°) West	Latitude (°) North	Altitude (m)
Kayar	17,07	14,55	3
Potou	16,27	15,43	27

Data acquisition



Kayar



Potou

Energy Research Centre

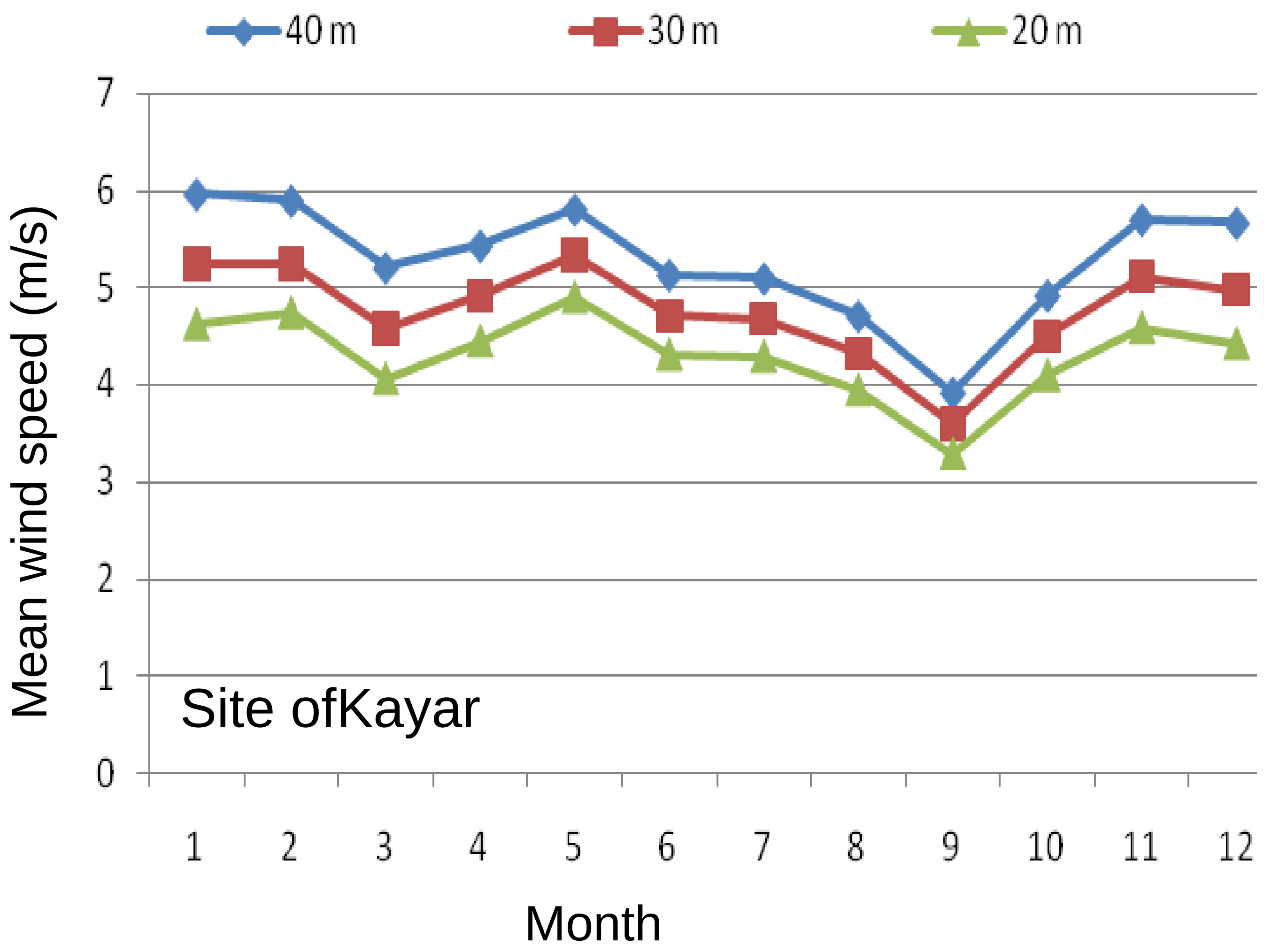
Collected data period

The collected data period covers *August 2007– July 2008*

Evaluation of the data

site	Number of data collected	Coverage rate(%)
Kayar	52704	100
Potou	52704	100

Monthly mean wind speed



The most favorable month
January, V = 5.3 m / s to 30 m

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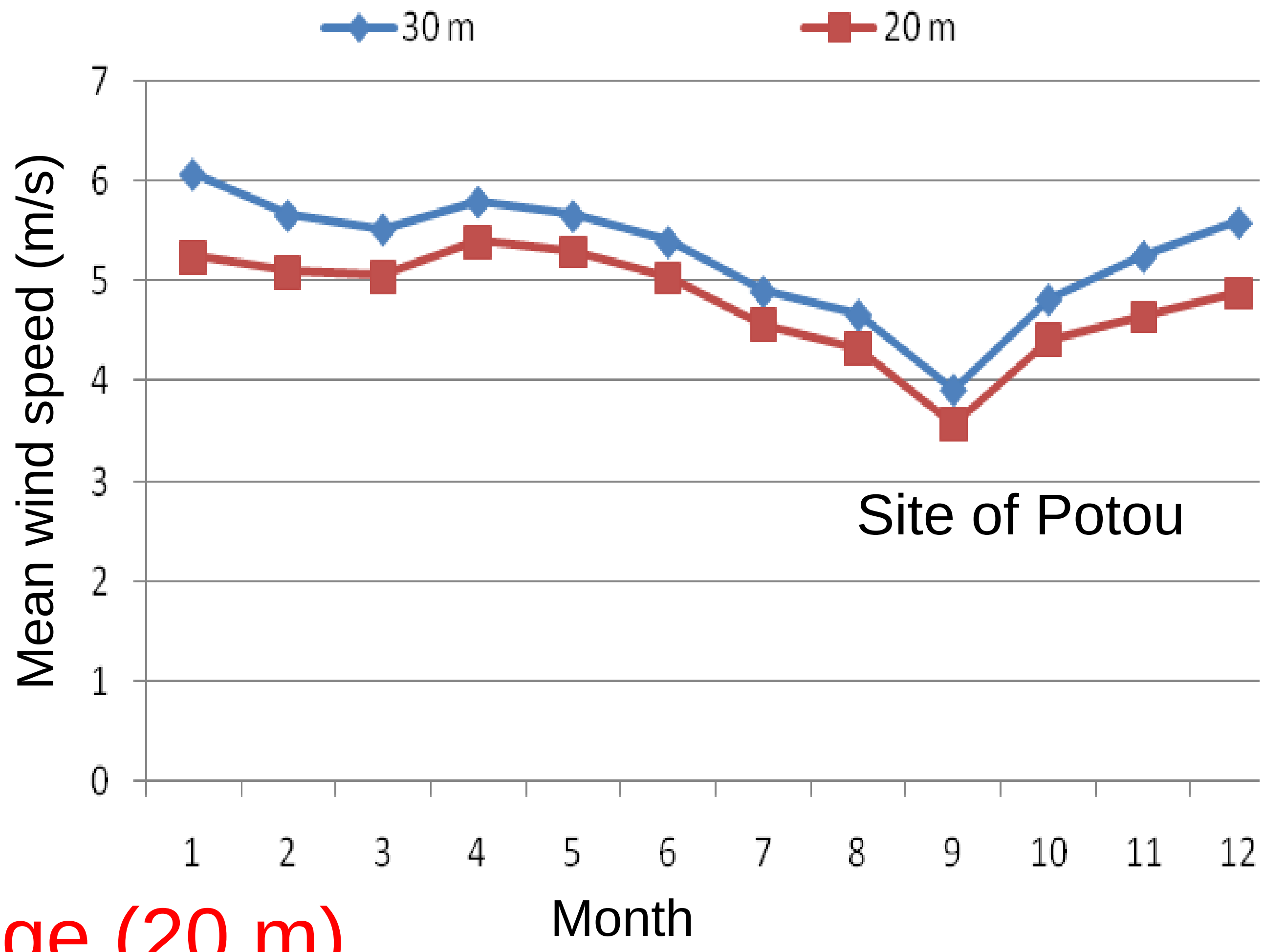
Monthly mean wind speed



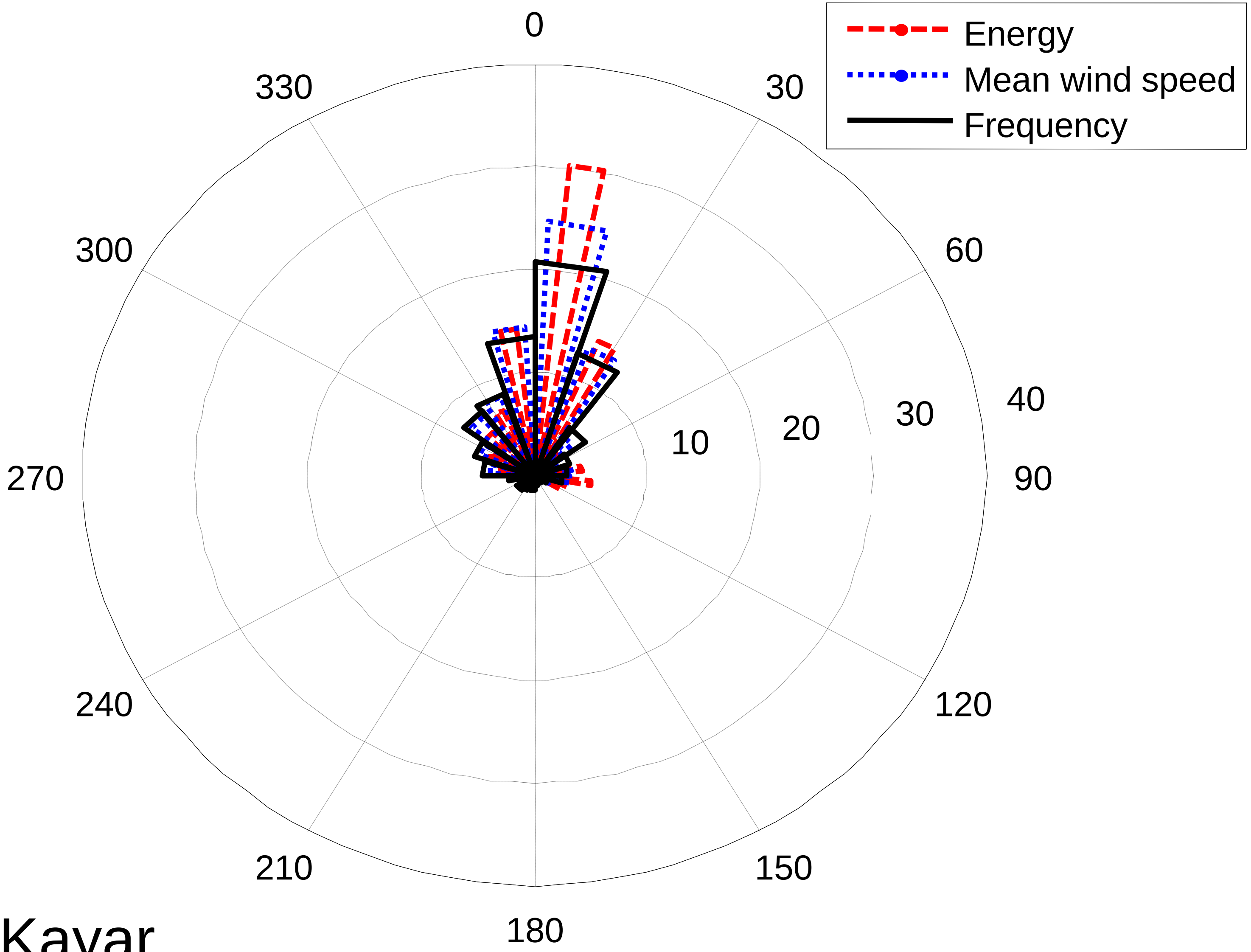
wind speed average (20 m)

V = 4,77 m/s in Kayar

V= 5,27 m/s in Potou

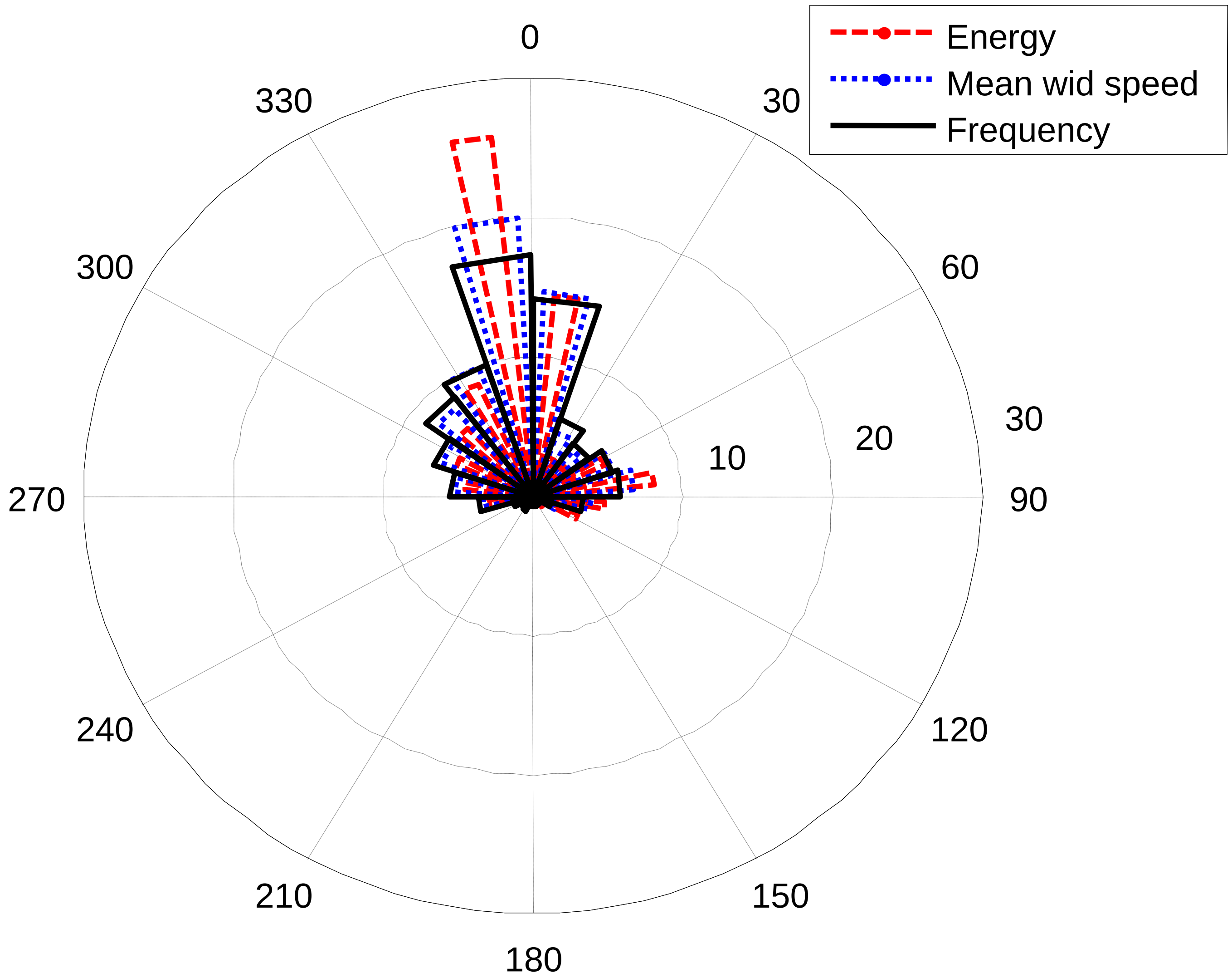
The most favorable month January, V = 6 m / s to 30 m

Wind Rose



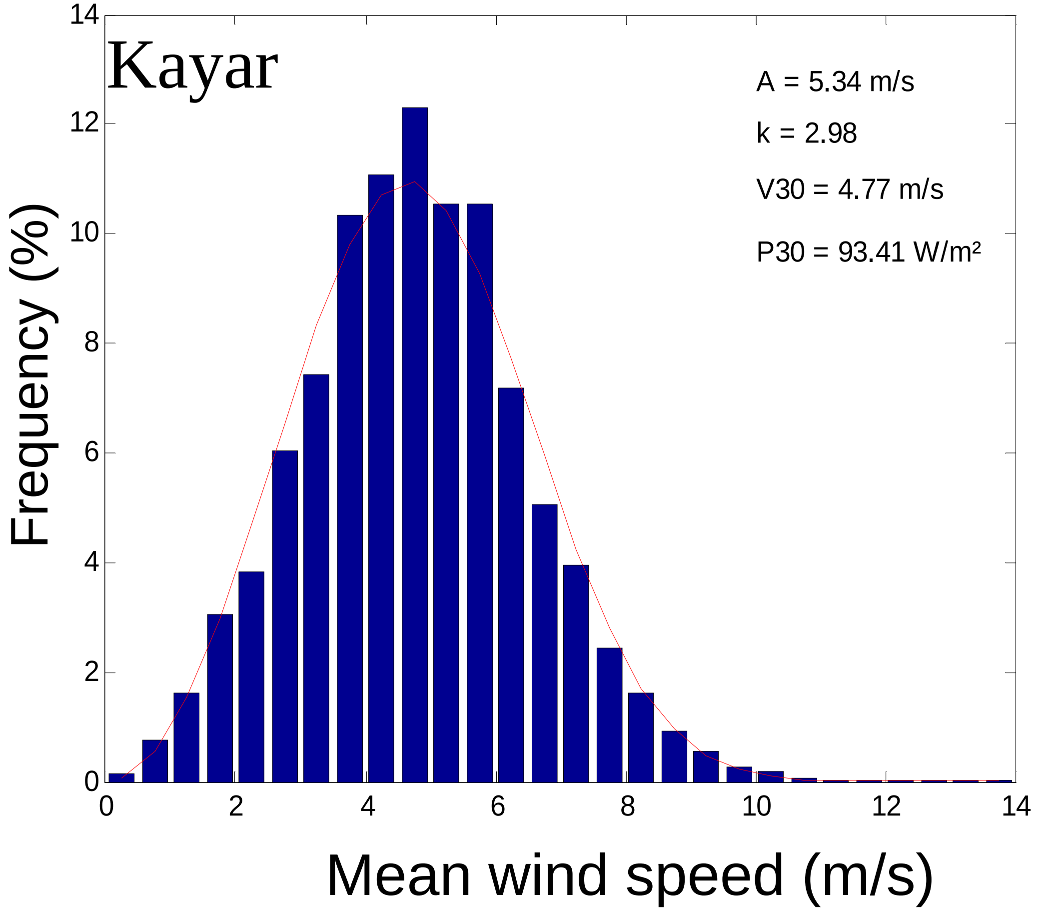
Kayar

Wind Rose

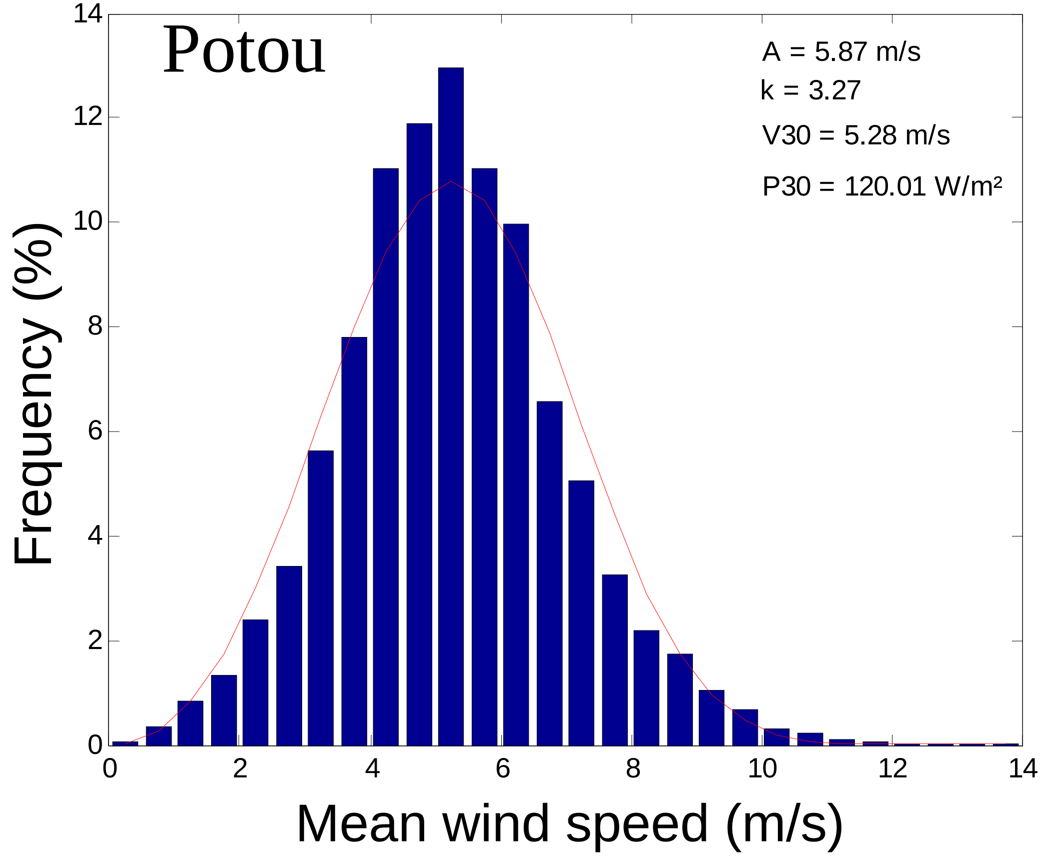


Potou

Weibull distribution

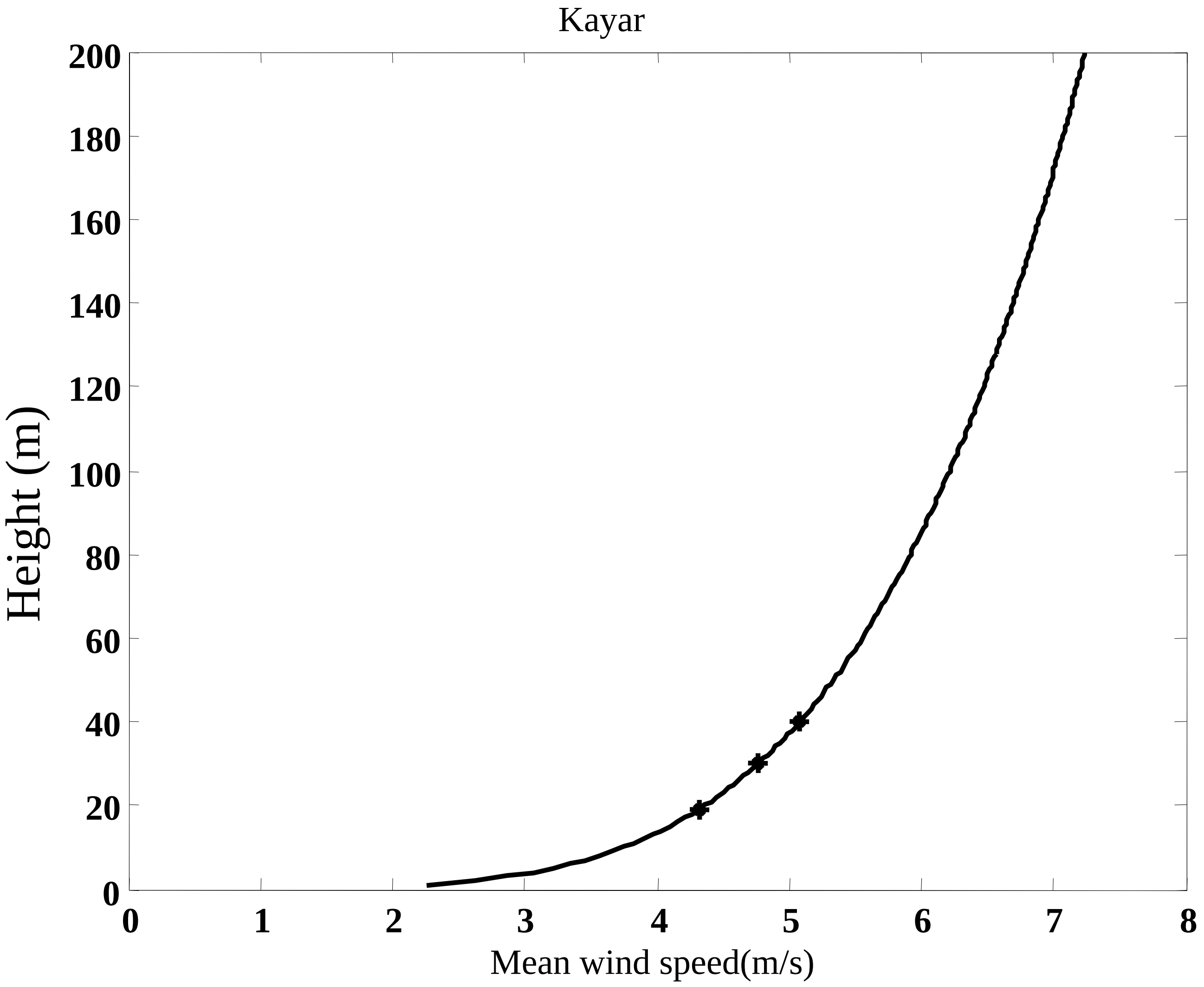


Weibull distribution

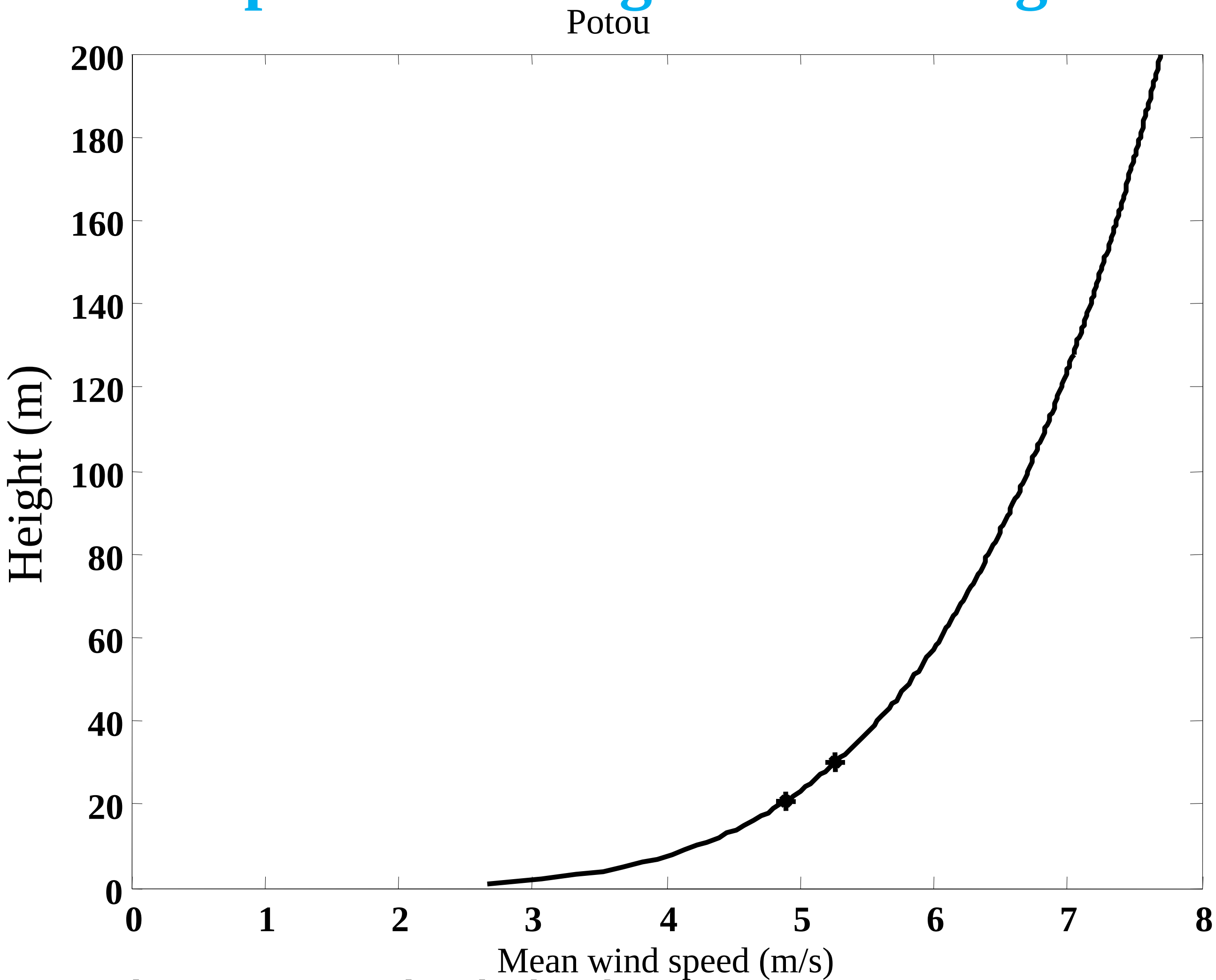


Site	Kayar			Potou	
Height (m)	40	30	20	30	20
P (W/m²)	122,95	93,41	72,42	120,01	94,54

Variation of the wind speed with height above the ground



Variation of the wind speed with height above the ground



The average speed at 77 m height is
5.8 m / s at the site of Kayar
6.3 m / s at the site of Potou

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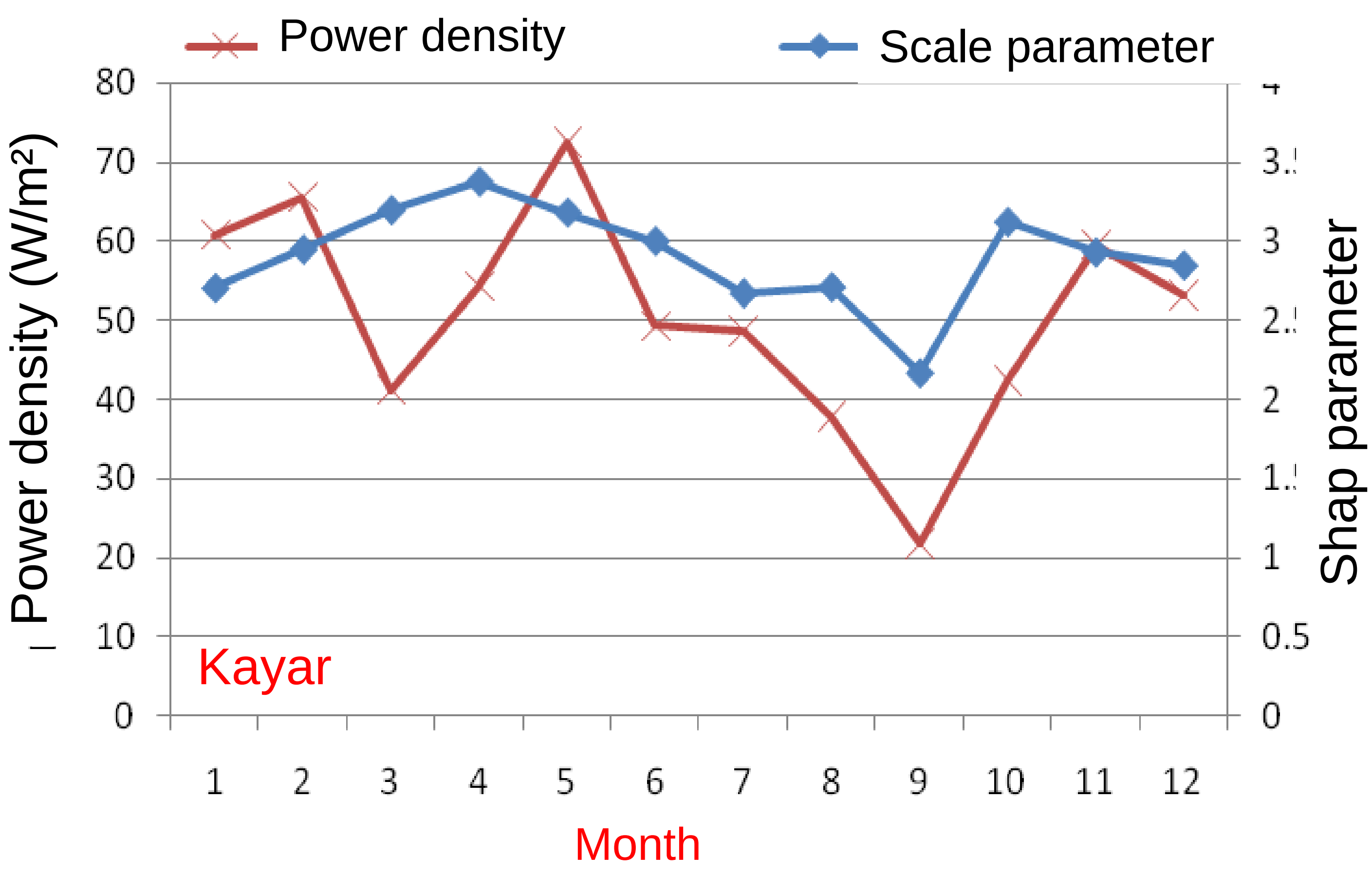
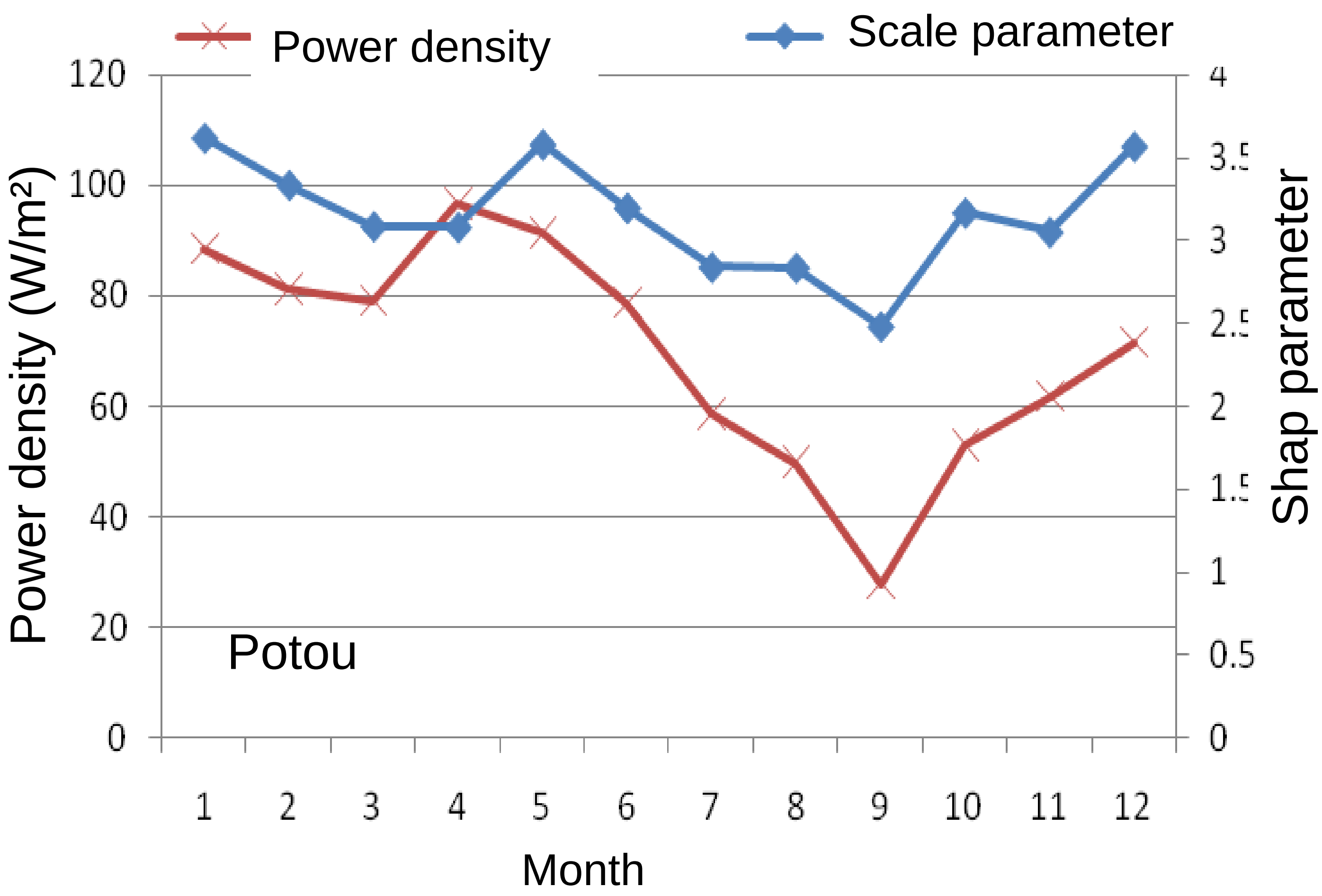


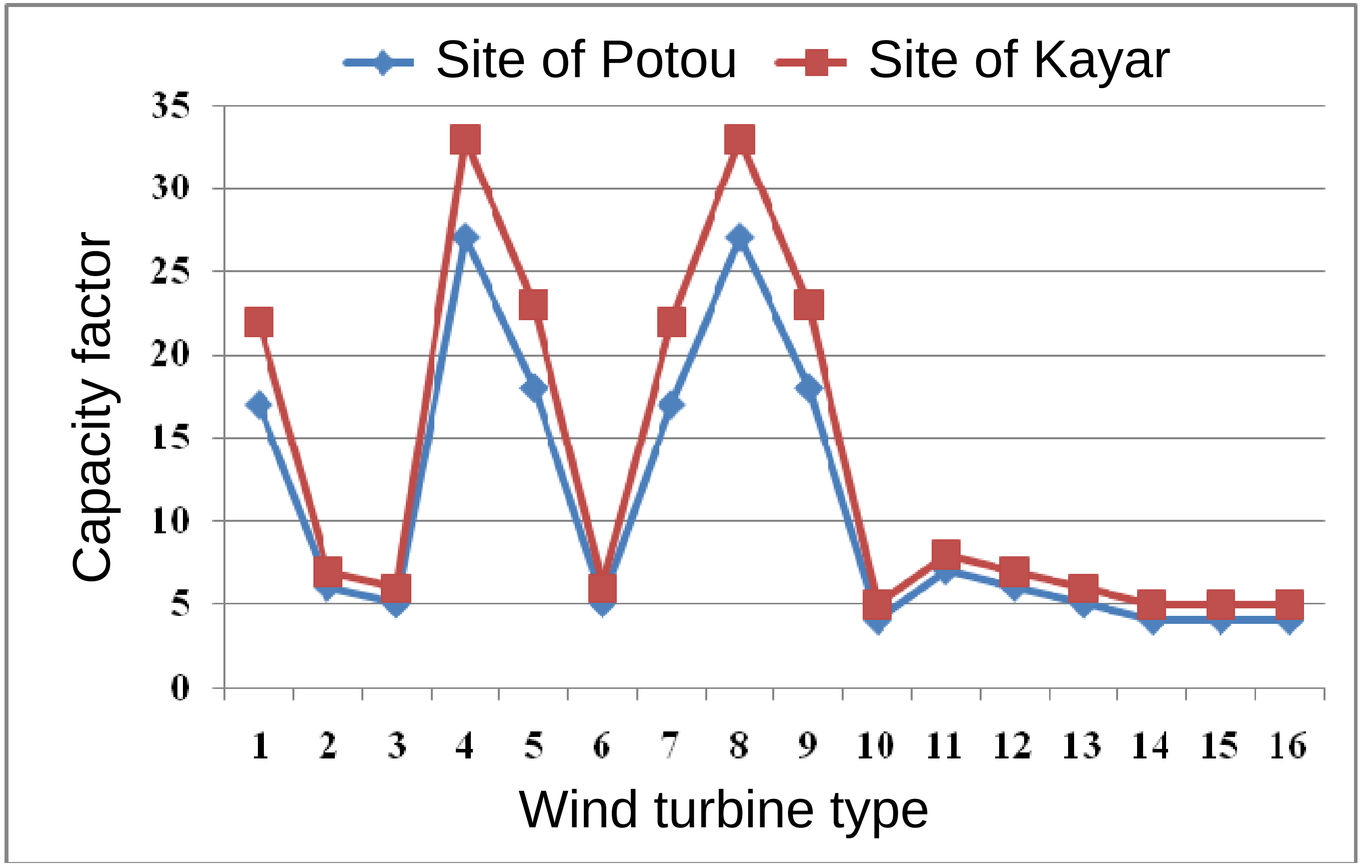

Power density
Scale parameter
Power density (W/m²)
Shap parameter
Potou
Month
120
100
80
60
40
20
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12

Application : determination of a wind turbine for a site

Characteristics of some wind turbines on the market

N°	Model	Vd (m/s)	Vn (m/s)	Vc (m/s)	Pn(W)
1	Eol/300W/12V	3,3	8	25	300
2	Eol/300W/12V	3,5	11	15	300
3	WS 400W/12V	3	12	17	400
4	Navitron/200W/24V	3	7	25	200
5	Navitron/300W/24V	3	8	25	300
6	WS 400W/ 24V	3	12	17	400
7	Eol 500W /24V	3,3	8	25	500
8	Elosénégal/500W/24	3	7	10	500
9	Navitron/500W/24V	3	8	25	500
10	HWG600/ 24V	3,5	12,5	17	600
11	Barney Inclin/250W/48V	3	11	13	250
12	Barney Inclin/600W/48V	3,5	11	13	600
13	Navitron/1000W/48V	3	12	25	1000
14	Barney Inclin/1500W/48V	3,5	12	14	1500
15	Barney Inclin/3000W/48V	3,5	12,5	14	3000
16	Barney Inclin/6000W/48V	3,5	12	14	6000

Capacity factor



Navitron/**200W**/24V

Elosénégal/**500W**/24

CP=27 % Kayar

CP=33% Potou

WASP : Wind Atlas Analysis and Application Program (Technical University of Denmark (DTU)

Input

- Wind speed
- Direction,

Output

Number of classes of Wind speed

Average wind speed

frequency

Distribution of wind speed

Wind rose

Wind map,

Conclusion

Features indicative of high mean wind speeds are:

- Gaps and passes, in areas of frequent strong pressure gradients
- long valleys extending down from mountain ranges
- high elevation plains and plateaus
- exposed ridges and mountain summits in areas of strong upper-air winds
- exposed coastal sites in areas of strong upper-air winds or strong thermal/pressure gradients.

Conclusion

Features that signal rather low mean wind speeds are:

- sheltered basins valleys perpendicular to the prevailing winds aloft
- short and/or narrow valleys and canyons
- areas of high surface roughness, e.g., forested hilly terrain.

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Links

www.afriwea.org : African Wind Association
www.windpower.org : Danish Wind Association
www.wind-works.org : Paul Gipe site
www.awea.org : American Wind Association
www.ewea.org : European Wind Association
www.cwea.org : Canadian Wind Association

Thank you