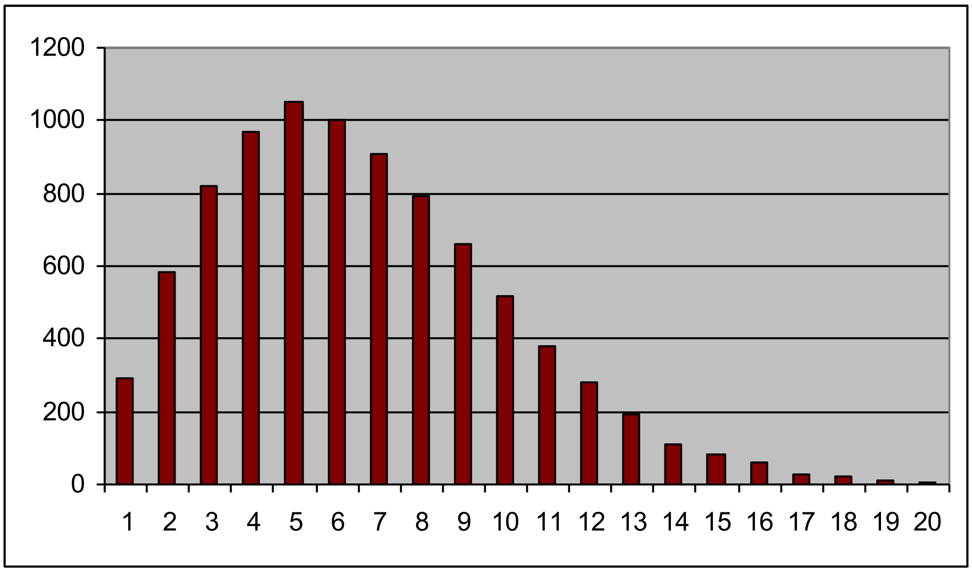
Electricity production and dimensioning of a wind turbine with given wind distribution at the site

- Wind turbine power at a wind of 10 m/s: 150 kWe
  (i.e. above v_{nom} = 10 m/s, the turbine power is constant at 150 kW)

- Wind velocities distribution [*y* hours at *x* m/s]:



x	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
y	290	585	820	970	1050	1000	910	790	660	520	380	280	190	110	80	60	30	20	10	5

- Operating range of the wind turbine: 5 m/s ≤ v ≤ 25 m/s
  (i.e. below 5 m/s wind speed, the turbine does not operate)
- Mechanical efficiency of the wind turbine: 70 %
  (or in other words, C_p = 0.59 * 0.7 = 0.41)
- Air density: 1.22 kg/m^3

1) What is the diameter of the turbine?

Power (Betz formula) : $P_{wt} = (16/27)\cdot\varepsilon_{wt}\cdot\rho_{air}\cdot(\pi\cdot D^2/4)\cdot v^3/2$

Wind turbine diameter: $D_{wt} = \{P_{wt,n}/((16/27)\cdot\varepsilon_{wt}\cdot\rho_{air}\cdot(\pi/4)\cdot v_n^3/2)\}^{1/2}$
$= \{150\ [kW]*1000\ [W/kW]/(\ 0.70\cdot(16/27)\cdot 1.2\ [kg/m^3]\cdot(\pi/4)\cdot 10^3\ [m^3/s^3]/2)\}^{1/2} =$ **27.5 [m]**

2) Evaluate the electricity produced during a year (cf. excel solution sheet)

Produced electricity (such as 5 [m/s] $\leq v_i \leq$ 20 [m/s]) :
$\Sigma\ P_{wti}\cdot t_i$ = **484’500 [kWhe]**

3) Evaluate the *mean* equivalent power of this turbine

Operating time of the wind turbine over one year:
$t_{an} = \Sigma\ t_i$ (such as 5 [m/s] $\leq v_i \leq$ 20 [m/s])
= 6'095 [h]

Produced annual electricity / actual operating hours (5 [m/s] $\leq v_i \leq$ 20 [m/s])
= 484’500 kWhe / 6095 h = 79.5 kWe

4) What is the equivalent annual load factor at nominal power?

Produced annual electricity / nominal power = 484500 kWhe / 150 kWe = 3230 h= 36.9% of the year (8760 h).
This value is here rather high (normal is 20-25%), since it was assumed that the turbine operates at <u>all times</u> when the wind blows between 5 and 25 m/s. Also, the distribution disconsiders hours at v=0 m/s (periods of total absence of wind). These 2 factors overestimate the annual load factor in this case.

5) Calculate the wind mean velocity and mean cubic velocity (operating range). Compare the results.

Operating time of the wind turbine over one year: t_{an} = 6'095 [h]

Mean velocity: $v_m = \{\Sigma\ v_i\cdot t_i$ (5 [m/s] $\leq v_i \leq$ 20 [m/s])$\}/t_{an}$ = **8.20 [m/s]**
$\rightarrow\ v_m^3 = 550\ m^3/s^3$

Mean cubic velocity: $v^3_m = \{\Sigma\ v_i^3\cdot t_i$ (5 [m/s] $\leq v_i \leq$ 20 [m/s])$\}/t_{an}$ = **765 [m³/s³]**

Conclusion: $v^3{}_m \neq v_m{}^3$

6) Estimate the Weibull c- and k-parameters from the above wind velocities distribution

Weibull c-parameter estimate

$$c \approx \frac{2\overline{v}}{\sqrt{\pi}}$$

with v the mean wind speed over the whole distribution (1-20 m/s):
v_avg (1 – 20 m/s) = 6.6 m/s

c = 2*6.6 / sqrt(Pi) = 7.44

In a pure Weibull distribution the value of c indicates that 63% of wind speed values in the distribution should be below c. We can verify that the number of hours that the wind speed is below 7.44 m/s amounts to 5625 h (hours at 1 to 7 m/s in the distribution table). This corresponds to 5625 / 8760 = 64%, so this fits quite well.

Weibull k-parameter estimate

$$k \approx \frac{3}{2} \frac{c^3}{\left\langle v^3 \right\rangle} \sqrt{\pi}$$

For the mean cubic velocity, it has here again to be taken over the whole range 1-20 m/s, since this is the relevant range that covers the whole distribution and therefore also the shape (k = shape factor) of this distribution.
The mean cubic velocity over 1-20 m/s is calculated to 542 m^3/s^3, and thus

k = 1.5 * sqrt (Pi) * (7.44)^3 / 542 = 2.0