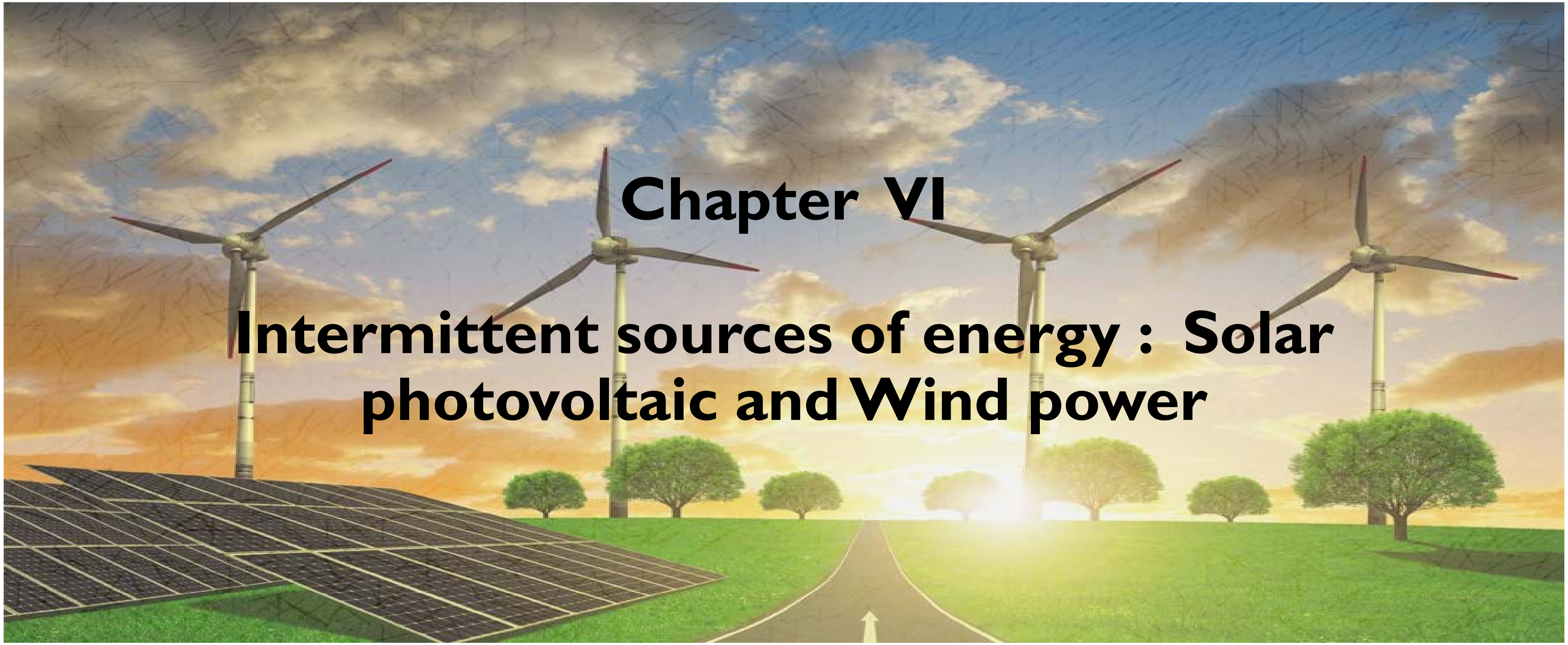
ENERGY PLANNING : MODELLING AND DECISION SUPPORT



Chapter VI

Intermittent sources of energy : Solar photovoltaic and Wind power

LEARNING OUTCOMES OF THE COURSE 9:

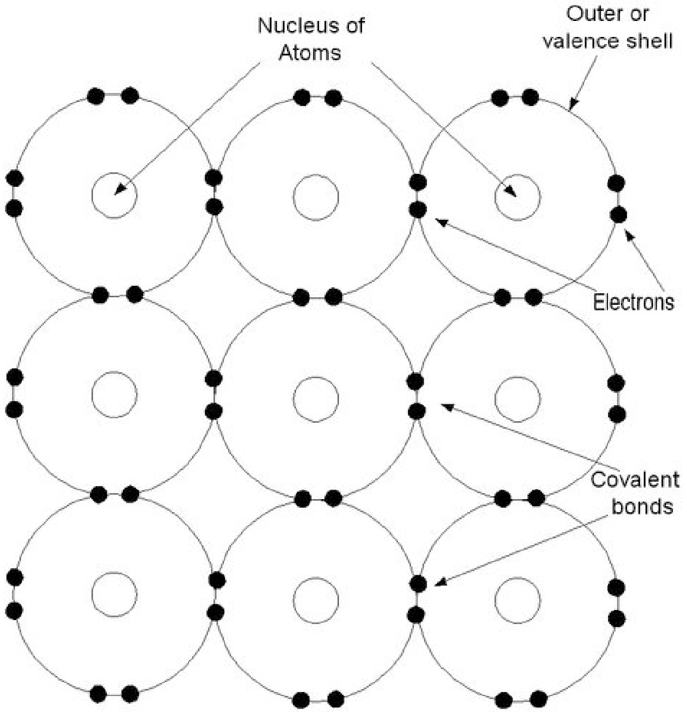
- To get to know the main characteristics of intermittent sources of energy
- To get to know the principles used when estimating the production of intermittent sources of energy

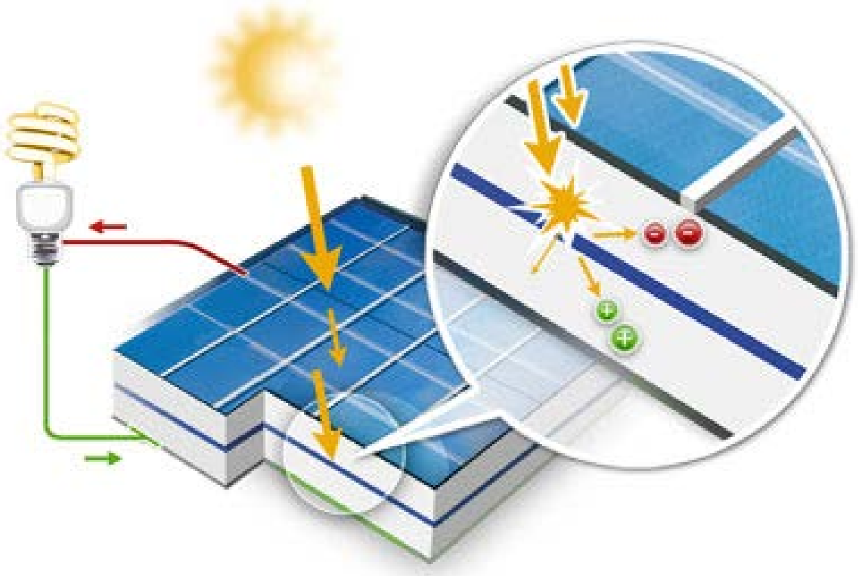
-CONTENT-

6.1. Solar photovoltaic

6.2. Wind power

6.1. SOLAR PHOTOVOLTAIC

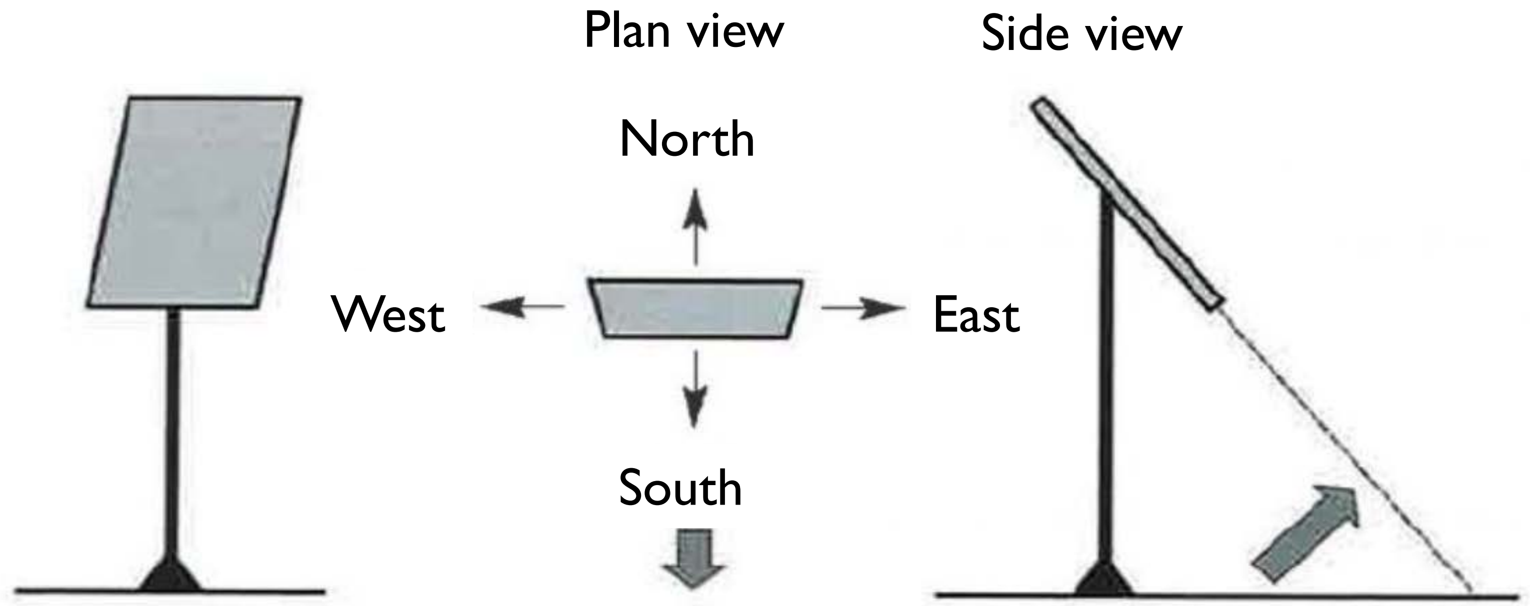




https://www.youtube.com/watch?time_continue=18&v=gl5tY5Noacc&feature=emb_logo

Material	**Efficiency [%]**
Monocrystalline Silicon	16 – 24
Polysilicon	14 – 18
Amorphous Silicon	6 – 8
Microcrystal Silicon	8 – 12
Copper Indium Selenide (CIS)	10 – 12
Copper Indium Gallium Selenide (CIGS)	11 – 14

Table of the materials used and their efficiency



Module exposed
towards the exterior

Orientation
=
Cardinal point faced
to the module

Tilt
=
Angle with respect
to the horizontal
axis

Tilt	0°	30°	60°	90°
Orientation				
East	0.93	0.90	0.78	0.55
South-East	0.93	0.96	0.88	0.66
South	0.93	1.00	0.91	0.68
South-West	0.93	0.96	0.88	0.66
West	0.93	0.90	0.78	0.55

Table of tilts according to the cardinal directions

Peak Power of a solar photovoltaic pannel

$$\boxed{P_p = I_{STC} * S * \eta_{STC}}$$

P_p :Peak power (Wp)

I_{STC} : Irradiation in the test's standard conditions (W/m2);

I_{STC} = 1000 W/m2

S: Surface area of panel

η_{STC} : Panel's efficiency under STC

Example:

$I_{STC} = 1 \text{ kW/m}^2$

$S = 10 \text{ m}^2$

$\eta_{STC} = 10\%$

$P_p = 1 \text{ kW}_p$

- **Shading losses:** a solar module’s environement can include trees, mountains, walls and buildiings. All of which can cause shading on the module thus affecting directly the harvested energy.

- **Losses by "dust or dirt“:** Deposition causes a reduction in the voltage and power produced by the photovoltaic generator (~3-6%).

- **Losses by dispersion of the nominal power:** industrially produced solar panels are not identical. The manufacturers guarantee deviations between 3% and 10% around the nominal power.

- **Connection losses:** the connection between power modules that could be slightly different causes the device to function with reduced power. These losses are increased by the number of modules in series or in parallel.

- **Angular or spectral losses:** photovoltaic panels are spectrally selective which means a solar spectrum variation affects the power they can generate.

- **Losses from ohmic drops:** ohmic drops are caracterized by voltage drops during current flow in a material conductor with a given section area. These losses can be minimized with an adequate sizing of the parameters.

- **Losses due to temperature:** modules generally lose 0.4 % per degree above the standard temperature (25ºC standard test conditions STC). The module's operating temperature depends on the incident irradiation, the ambient temperature and wind velocity (5% to 14%).
- The application of the different **loss factors** leads to a global factor FG characterizing energy availability that can be established between 35% and 80% according case-based.

$$\boxed{E = Peff * H = Pp * FG * H = I_{STC} * S * \eta_{STC} * FG * H}$$

E: Energy produced (Wh)

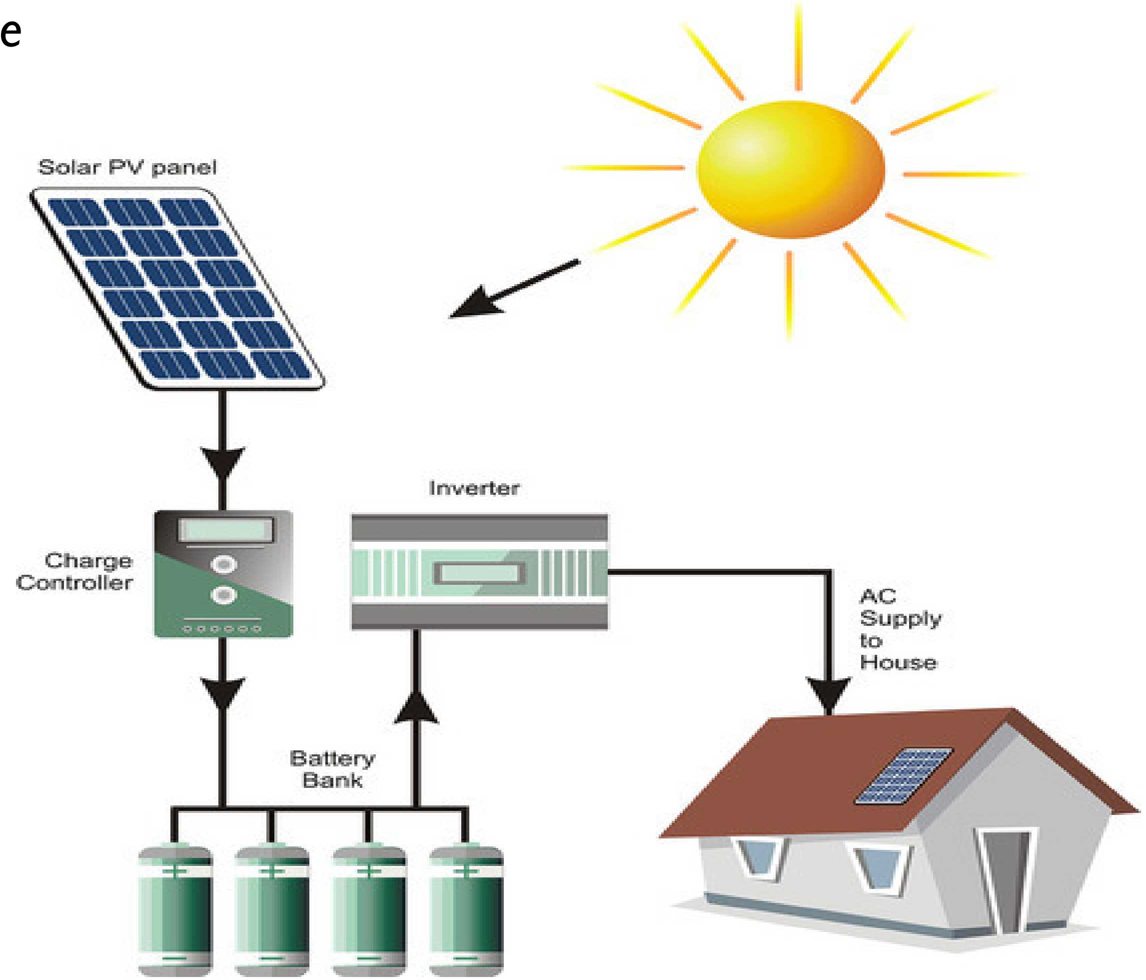
Peff: Effective power(W)

H: Equivalent number of hours of sunshine during the considered period (h)

FG: Global factor of availability due to the different losses

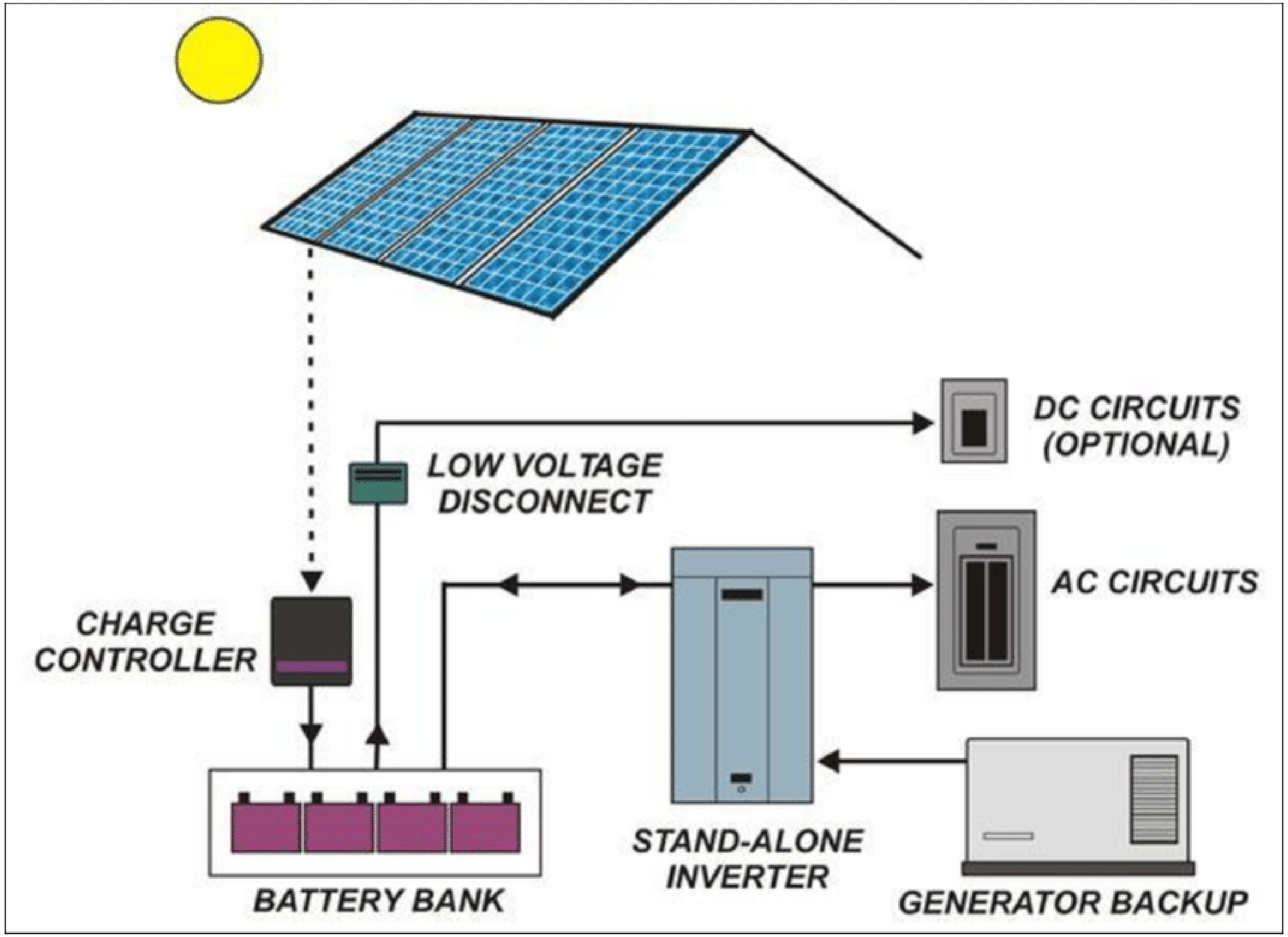
Off-grid solar photovoltaic

Bloc diagram of the principle

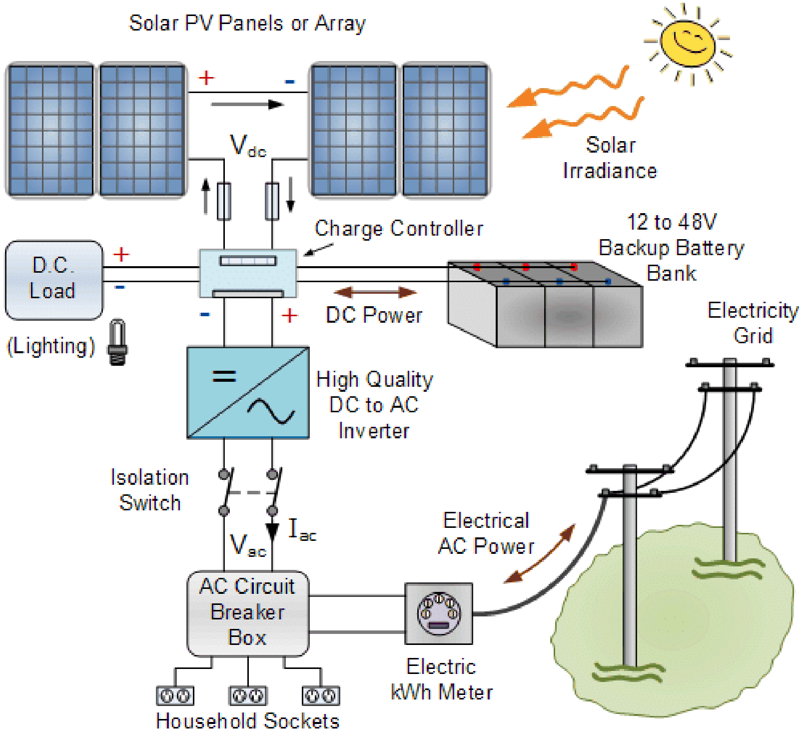


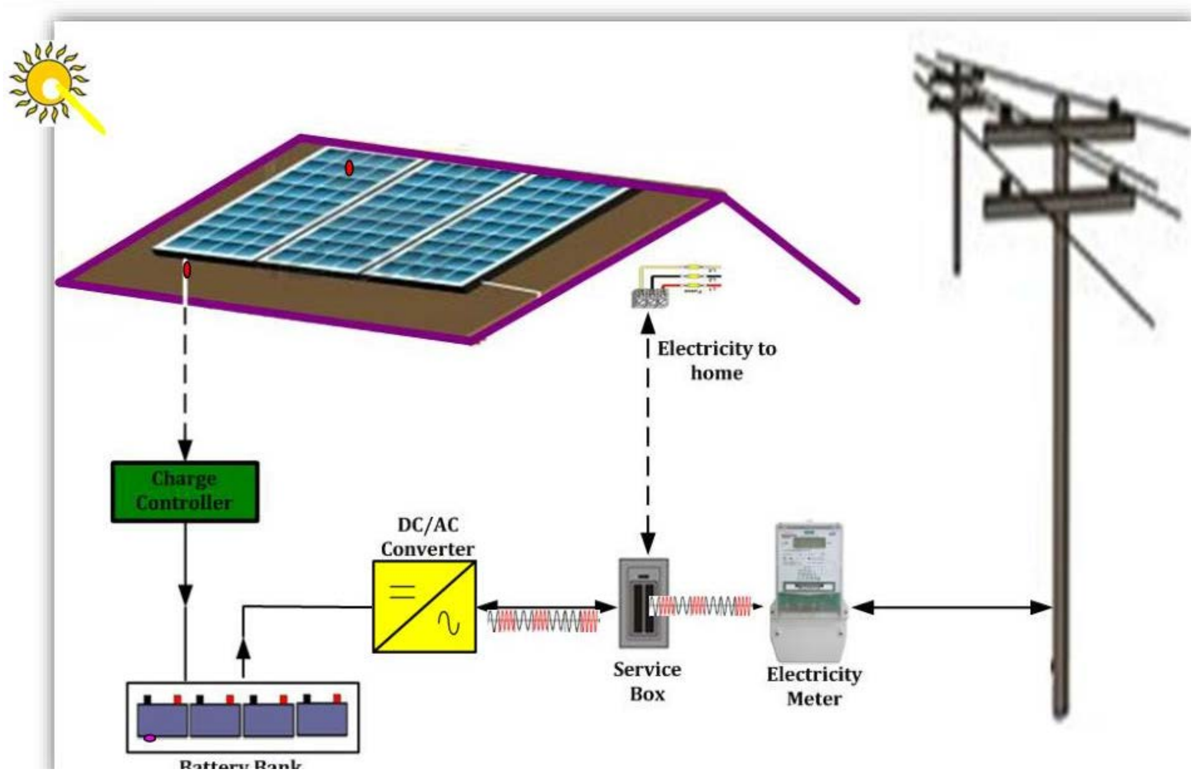
Off-grid solar photovoltaic with generator

Bloc diagram of the principle



Grid connected solar photovoltaic panels





Life cycle analysis of a solar photovoltaic panel

Technology	Energy/ m^2	Energy/Wc	EPBT	ERF
Mono – Si	600 kWh/m^2	4 kWh/Wc	4 years	5
Poly – Si	420 kWh/m^2	3.5 kWh/Wc	3.5 years	6
A- Si	120 kWh/m^2	2 kWh/Wc	2 years	10
CIS	300 kWh/m^2	3 kWh/Wc	3 years	7
CdTE	130 kWh/m^2	1.3 kWh/Wc	1.3 years	15

Grey energy for manufacturing

EPBT: Energy Pay Back Time, for 1000 hours of operation per year

ERF: Energy Return Factor, for 20 years of electrical production

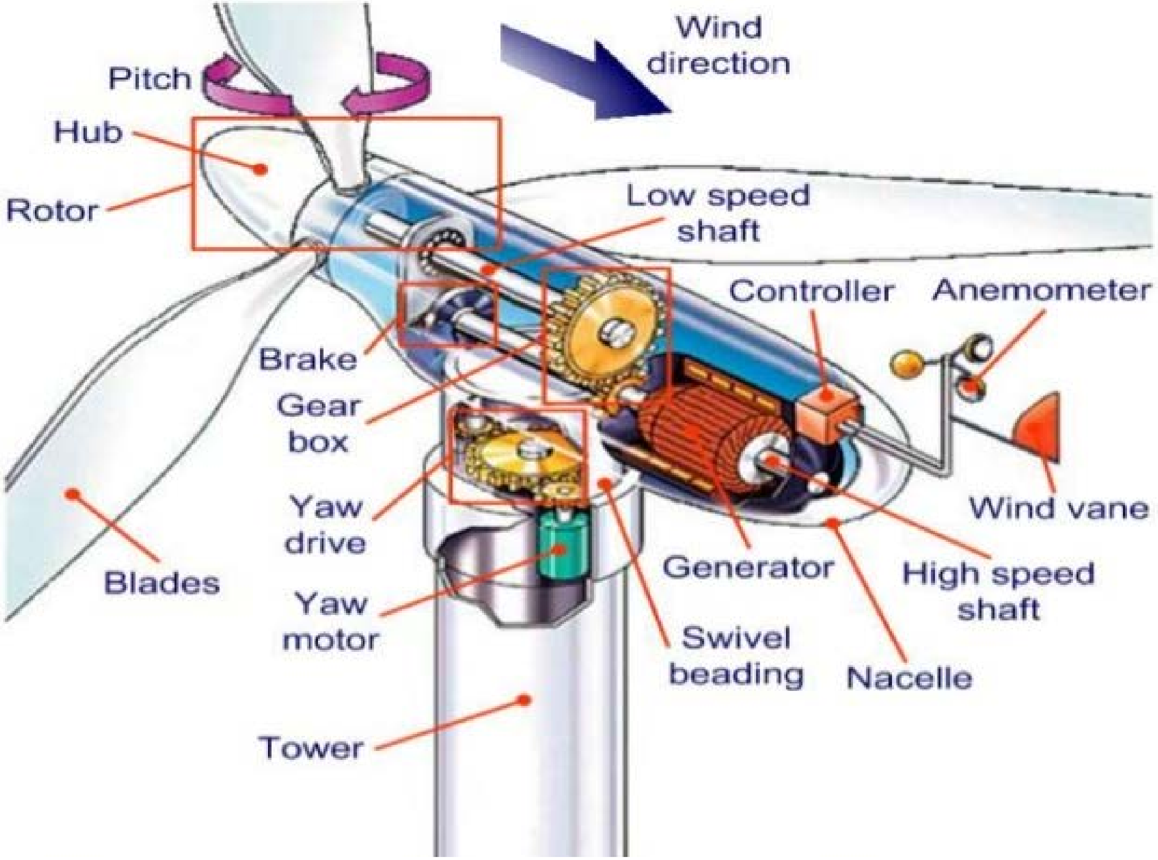
6.2. WIND POWER

- The energy related to the movement of air masses has been used for centuries in various ways: sailing boats, pumping water, or even cereal grinding.
- The most visible energy use is the conversion of the kinetic energy of the wind into electrical energy by wind generators.
- This kinetic energy is due to the movement of air masses caused by the atmosphere's heating differences from solar radiation.

https://www.youtube.com/watch?v=Z5c50-_hcD0

Aerogenerator

6 wind turbines installed on Thornton Bank, off the coast of Belgium, operating since 2009. Two and a half year review of the work for the Belgian corportion C-Power that conducted this project.



Caracteristics of big wind turbines

Nominal power : 600 – 2 500 kW

Height of the hub : 50 – 100 m

Rotor diameter : 44 - 90 m

Total height: 72 – 145 m

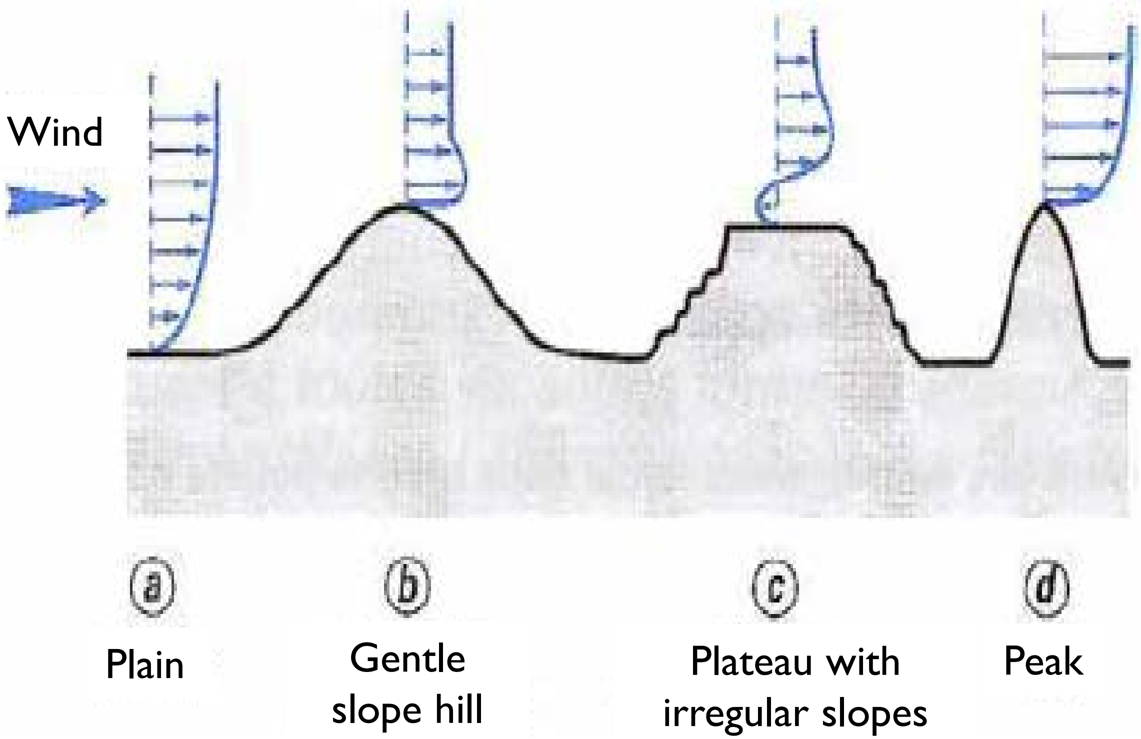
Choices in the framework of the Wind power Concept in Switzerland (OFEN, 2004)

- Nominal power : approx 1 250 kW
- Height of the hub : approx 70 m
- Rotor diameter : approx 60 m
- Total height: approx 100 m

- Total Investment cost: approximately 2.1 million of Francs (CHF) which is approximately 1 700 per kW of power installed (75 % corresponding to the cost of the wind turbine)
- Electrical production cost 9 – 25 ct./kWh according to the site (wind patterns and infrastructure)
- Energy production: 1 000 – 2 500 MWh per year
- 60 % of the energy produced during the winter semester
- Gain factor: 40 to 80%

Wind velocity

- Wind speed at a point depends on various factors: relief, roughness, latitude, altitude, situation, season etc
- Depending on the relief, there can be an inversion in the speed gradient as seen in the case of the rounded peak of a hill



Wind speed distribution according to the altitude for various reliefs

Wind velocity

On a plain field, the speed variation according to height can be represented by the following:

$$\boxed{v/v_0 = (h/h_0)^{\alpha}}$$

v_0: speed at height h_0

α: site characteristic coeffient

At sea:	$\alpha = 0{,}13$
On a shore:	$\alpha = 0{,}16$
On a plain:	$\alpha = 0{,}2$
In wooded plain:	$\alpha = 0{,}24$
In the city:	$\alpha = 0{,}3$

Theoretical potential

- The kinetic energy of the air passing through a surface S at speed v during a given duration t is:

$$Ec = \frac{1}{2} \gamma v^2 S v t$$

- With γ the volumetric mass of air γ = 1.25 kg/m3 under normal temperature and pressure conditions
- The power is thus:

$$P = \frac{1}{2} \gamma v^3 S$$

- The power is proportional to the cubic power of the speed

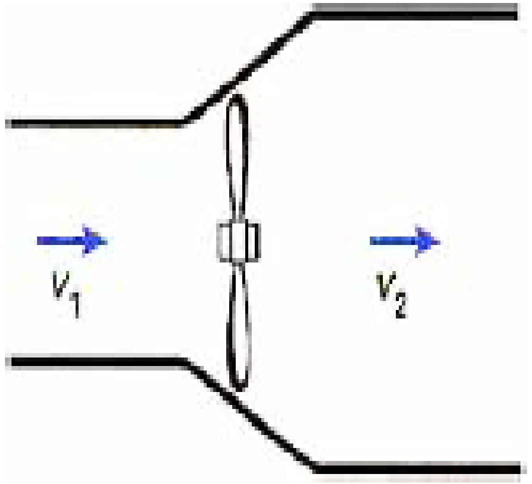
Choosing the site

- **On the ground**, the most interresting sites are situated on the sea side area or on top of mountains, provided they are well cleared to assure a stable wind velocity.
- **Site prospecting** is carried out on the basis of meteorological records taken over one or several years.
- **Totalizer anemometers** not only allow an estimation of the average speed but also the energy during a given period, a year for example.
- On the selected sites, the wind has to be sufficiently regular, with an average speed of 5 to 20 m/s

Technical power: case of an horizontal axis sensor

According to Betz theory, the power produced by wind turbines can be estimated from the variation of kinetic energy between upstream and downstream of the sensor.

$$\boxed{P = \Delta \dot{E}c = \frac{1}{2}\dot{m}(v_1^2 - v_2^2)}$$



The theorem of variation of quantity of movement allows an estimation of the force being applied on the wind turbine

$$\vec{F} = \gamma\, S\, v\, (\vec{v_1} - \vec{v_2})$$

The technical potential is deduced:

$$\boxed{P = \vec{F} \cdot \vec{v} = \gamma\, S\, v^2 (v1 - v2)}$$

Technical power: case of an horizontal axis sensor

If we set: $\mathbf{v} = \frac{\mathbf{v1 + v2}}{\mathbf{2}}$ $\mathbf{k} = \frac{\mathbf{v2}}{\mathbf{v1}}$

We have: $\mathbf{W = \frac{1}{4}\,\rho\, S\, v1^3(1+k)^2(1-k)}$

We can deduce: $\mathbf{\frac{dW}{dk} = 0 \rightarrow 2(1+k)(1-k) - (1+k)^2 = 0}$ $\mathbf{be\ k = \frac{1}{3}}$

$$\mathbf{W_{max} = \frac{16}{27}\,\frac{1}{2}\,\rho\, S\, v1^3 \approx 0.6\,\frac{1}{2}\,\rho\, S\, v1^3}$$

Betz’s efficiency : 60 %

Variability of wind velocity

Weibull's probability of density

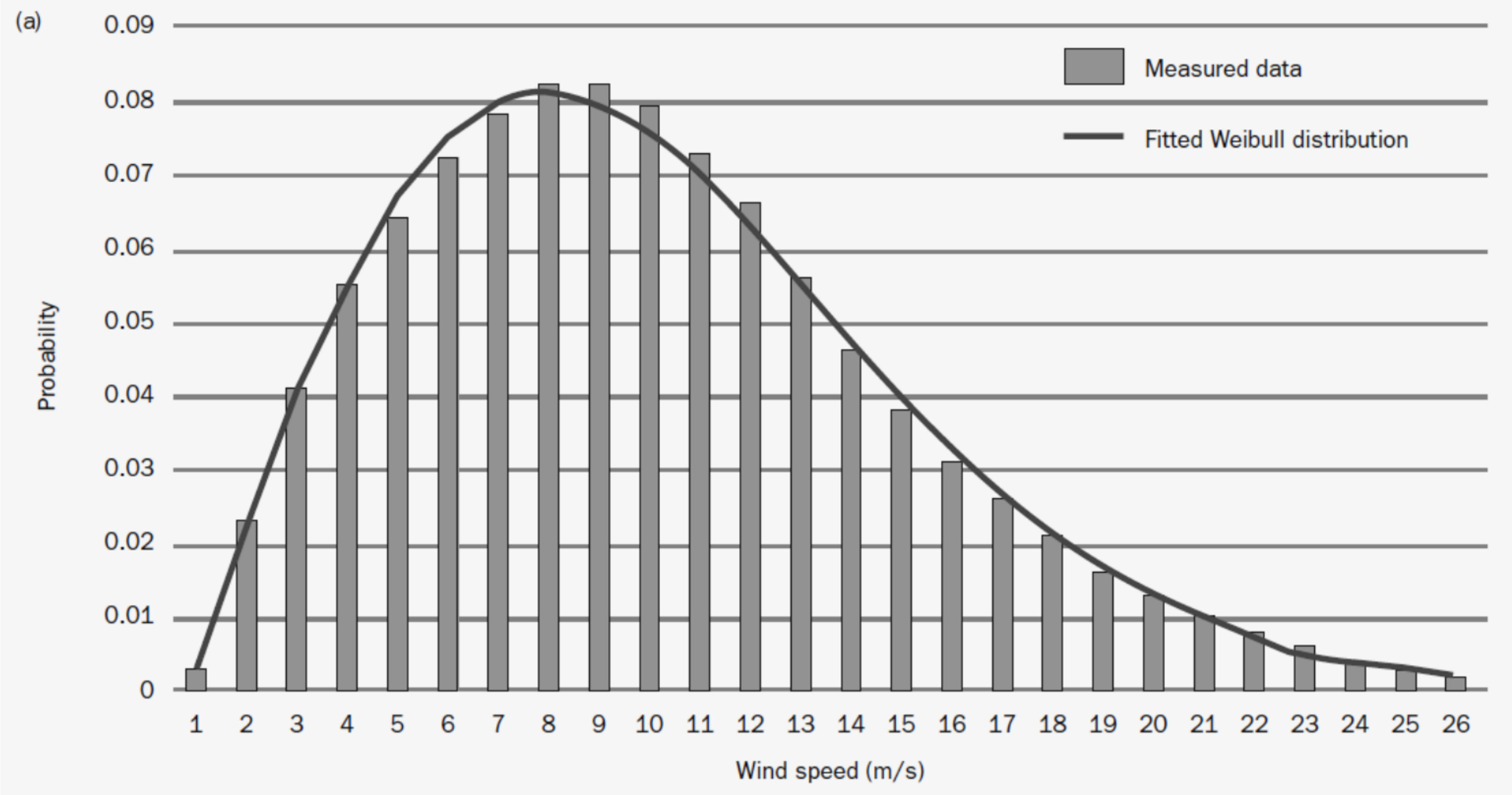
$$f(V) = \left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1} exp\left(-\left(\frac{V}{C}\right)^{K}\right)$$

K and C are the parameters of the probability of density:

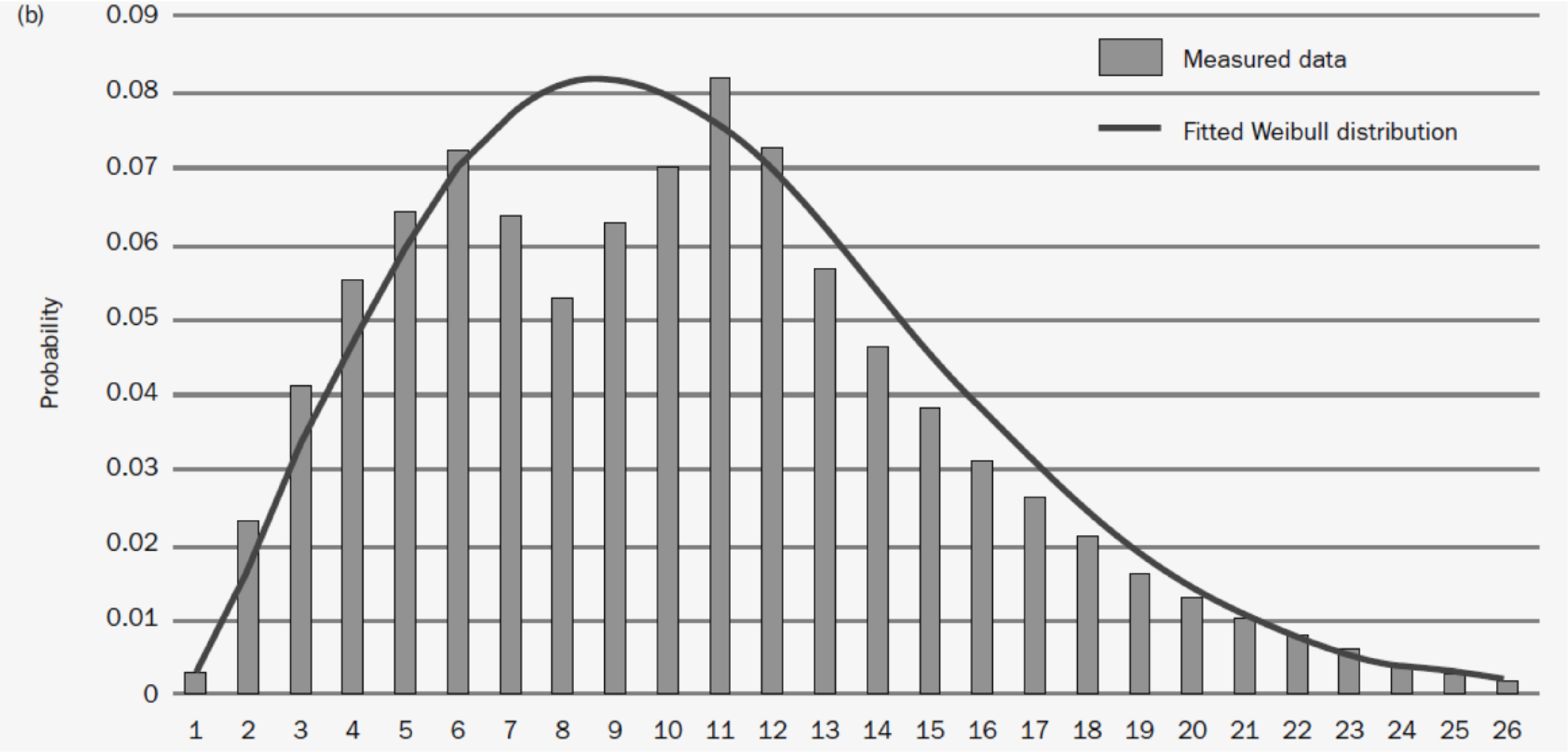
K: form factor

C: scale factor

Variability of wind velocity



Variability of wind velocity



CO_2 Emissions (principal greenhouse gases)

CO2 emissions in various electricity production lines								
Production mode	**1 kwh Hydro-electricity**	**1 kwh Nuclear**	**1 kWh Wind**	**1 kWh Solar PV**	**1 kWh combined Cycle**	**1 kWh Natural Gaz (GT)**	**1 kWh Fuel oil**	**1 kWh Coal**
CO2 emissions per kWh (grams)	4	5	3 to 22	60 to 150	427	883	891	978

On average: 90 g CO2/ kWh in France, 610 in Germany